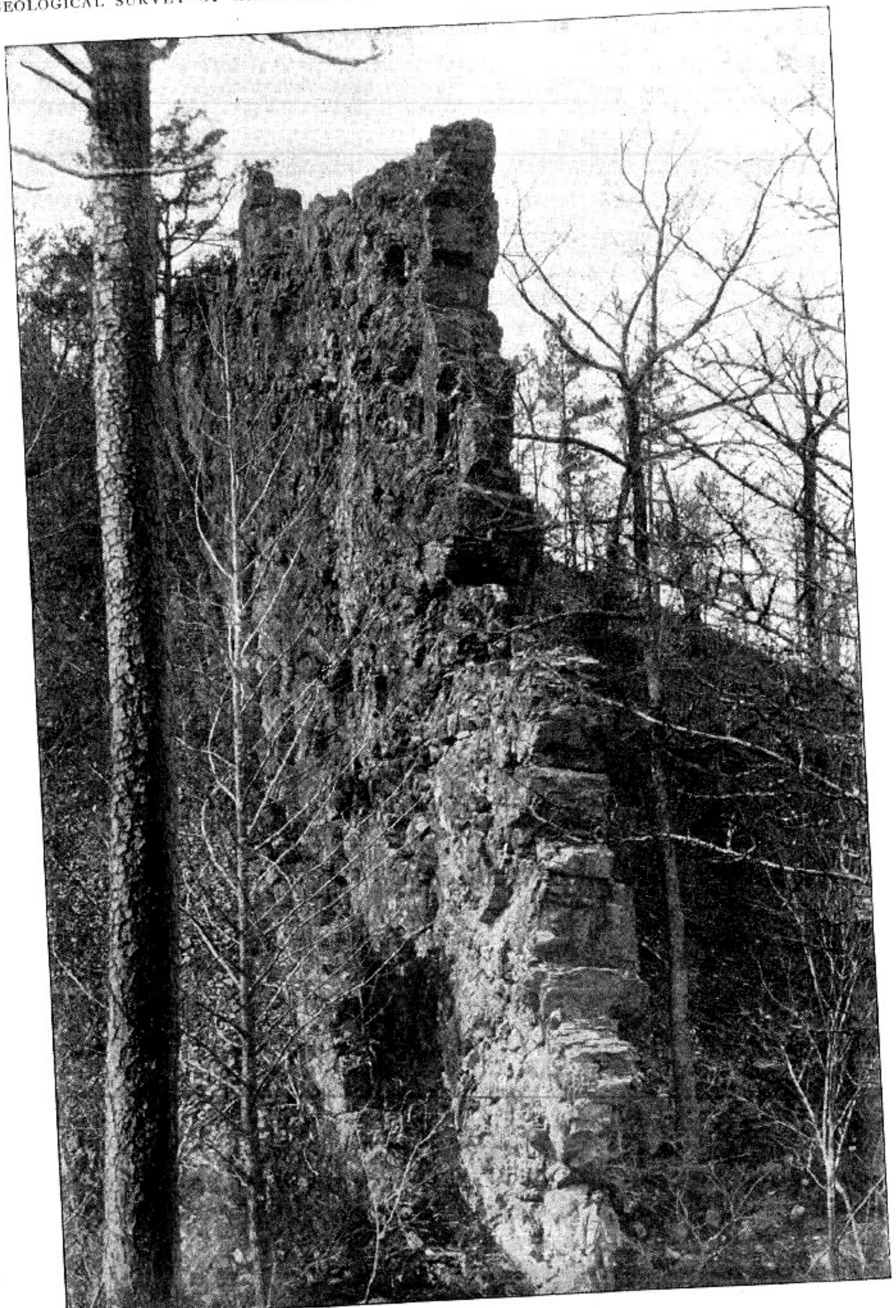

"STANDING ROCK," A NOVACULITE LEDGE ON BOARD CAMP CREEK, POLK COUNTY, ARK. (SEE PAGE 276.)

ANNUAL REPORT

OF THE

GEOLOGICAL SURVEY

OF

ARKANSAS

FOR 1890

VOLUME III

WHETSTONES AND THE NOVACULITES OF ARKANSAS

By L. S. Griswold

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State Geologist

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OFFICE OF THE GEOLOGICAL SURVEY OF ARKANSAS,
LITTLE ROCK, Sept. 1, 1891.

To His Excellency,

Hon. James P. Eagle,

Governor of Arkansas.

Sir:

I have the honor to submit herewith Volume III. of my annual report for 1890, and to remain,

Your obedient servant,

JOHN C. BRANNER,

State Geologist.

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PREFACE.

The direct economic object of the Survey's work upon the novaculites was the determination of the geologic and geographic distribution of the whetstone rocks and of the conditions under which they occur. This investigation was entrusted to Mr. Leon S. Griswold, the author of the present volume, who began the field work in August, 1890, and did it almost entirely alone and on foot, and that, too, under difficulties arising from the wooded condition of the country and a sparseness of the population and lack of maps that were well-nigh appalling. He also had this additional disadvantage, that nearly all that had been written of the structure of the novaculite area up to the time he began his work was more likely to mislead than to aid him. Of Mr. Griswold's investigation the State may justly feel proud, for aside from its economic importance and value, this study has made known one of the most beautiful and interesting pieces of structural geology in this country—that of the Ouachita uplift.

A theory is said to have been held by Dr. Owen, former State Geologist, to the effect that there was a mineralized zone or belt running from somewhere in Missouri southwest across Arkansas by way of the Kellogg mines, and various other mines and prospects, and intimately related to a supposed granitic axis of the State, or to its axes of plication.

How vague and unwarranted such a theory is has long been evident, but prior to the working out of the structure of the Ouachita uplift as here presented by Mr. Griswold, facts were lacking for pointedly proving such futility, and nothing effective could be said in opposition to it. The granitic axis theory advanced by Owen was accepted as a fact by those who followed him,* while prospectors have clung to and worked upon the theory of a mineralized zone with a faith born of despair. The present Survey has already shown that there is no granitic axis in the State,† and that the eruptive rocks formerly supposed to be Archæan granites are of post-Cretaceous age. With the present volume it is shown beyond the shadow of a doubt that the structural axis—the great Hot Springs anticline or Ouachita uplift—has no such trend as that assigned the theoretic granitic axis and mineralized zone, but that it has a slightly undulating, nearly east-west trend, while all the rocks of the region follow more or less closely this trend of the main axis.

The graptolites found by Mr. Griswold, at Hot Springs, are the first fossils known to have been found in the area of the Ouachita uplift. The discovery is one of great interest and geologic importance, for it settles in a satisfactory manner the age of the novaculites, and in a general way of the rocks underlying them. It is true that Rogers speaks of Trenton rocks in the "Washita" regions of Arkansas, but I am much inclined to think that this was simply an inference on his part and not a determination based upon paleontologic evidence.

It is proper that some reference be made in connection with this report to the schemes occasionally put on foot for boring for oil and gas in the vicinity of Hot Springs, and at other points within the area here discussed. For the benefit of those who may be tempted into such speculation, it may be said without going into details that there is not the slightest evidence that there is either gas or oil in the region in question, and lest some one may be led to hope for such things because there are "Trenton" rocks in the novaculite area, it may be said once for all that Trenton rocks do not necessarily have anything whatever to do with the presence or absence of oil or gas.

*See Second Report of a Geological Reconnoissance of Arkansas, by David Dale Owen, Philadelphia, 1860, pages 16, 17 and 111; a pamphlet entitled "Silver in Arkansas," by C. P. Conrad, Little Rock, 1880, p. 3; also Geological Reconnoisance of the State of Arkansas, by George Haddock, Little Rock, 1873, p. 37.

†Annual Report of the Geological Survey of Arkansas for 1890, Volume II.

In examining the maps accompanying this volume, the reader must not imagine that all the area represented as novaculites is covered by commercially valuable Ouachita or Arkansas stone. Indeed it is not possible to say just where, in this area, the good whetstone rocks do occur, for valuable whetstone rock is only locally developed, and its exact distribution can only be determined by prospecting, and prospecting is outside the duties of the Geological Survey. It will always be found, however, when found at all, within the area colored for novaculites. The prospector will therefore be able by the aid of this report and its maps, to direct his efforts to good purpose, and to avoid the mistakes and the loss of time that always come from aimless and random work. He must, however, lay aside the theory hitherto followed, that good whetstone rock can only be found in northeast-southwest lines, except in localities where the structural lines have a northeast-southwest trend. The whetstone rocks follow the structure of the region in which they occur, and when the structure changes the trend of the whetstone beds must change also. In the Trap Mountains these outcrops have an east-west trend; in the Cossatot region they run northeast-southwest, and so on, the trend of each bend depending upon the geologic structure in its own locality.

The discovery by Mr. Griswold that the porosity of the Arkansas whetstones is due to the solution and removal of rhombs of calcite is one of scientific interest and of much economic importance, and the prospector should keep in mind the conditions under which such leaching is most likely to take place. It is my own opinion that when whetstone rocks occur in ridges with beds of clay underlying them, these clay beds are mechanical factors of the first importance in the removal of the calcite by directing penetrating waters along the novaculite beds and consequently in changing the compact rock into material porous and soft enough for whetstones. If this is correct the presence or absence of the confining clay bed should be accepted as valuable information.

The discussion of the advisability of establishing whetstone factories in this State cannot safely be based upon geologic fact alone. For the establishment of such industries it is indispensable of course that we have an abundance of the rough stone; that we have this abundance there is no question, but other considerations, such as the demand for good whetstones, the competition of cheaper stones, the distance of the markets, the cost of skilled labor, the comparative freight rates upon rough and finished products, and the convenience of quarries to transportation are of quite as much importance in the establishment of factories as the abundance of the unmanufactured stone.

In connection with the present work upon the novaculites, the Survey has received the kind co-operation of many persons. Especial mention should be made of Mr. J. J. Sutton, of Hot Springs, whose intimate acquaintance with the quarrying and whetstone industries has been of much value. Acknowledgments are also due Dr. R. R. Gurley, of the United States Fish Commission, for his careful study of the graptolites found in the novaculite area; to Dr. J. E. Wolff, of the Harvard University, and Prof. C. R. Van Hise, of the University of Wisconsin, for assistance in making the microscopic examinations The photograph from which the frontispiece was made was kindly furnished by Mr. W. P. Jenny. Others to whom the Survey is indebted are mentioned in the text.

JOHN C. BRANNER,

State Geologist.

ERRATA AND ADDENDA.

PAGE.

2. Second foot-note, Alfenue should be Alfenus.
14. Thirteenth line, zoir should be razoir.
14. Twentieth line, words should be works.
15. Second foot-note, Fichtelgebage should be Fichtelgeberge.
45. Under North Carolina, How River should be Haw River.
101. Eleventh line, and should be end.
121. Fifth line, XIII. should be XVIII.
124. Bottom of page should be inserted, (Magnified 200 diameters.)
209. Second line, V. should be III.
257. Seventh line, 37 should be 27.
268. Fourth line, 37 should be 27.
381. Sixth line, Bear Den Mountain is the same as Bare Mountain of page 241.
421. Twentieth line, 1858 should be 1878.

THE NOVACULITES OF ARKANSAS.

By LEON S. GRISWOLD.

PART I.—ON WHETSTONES.

CHAPTER I.

THE EARLY HISTORY OF WHETSTONES.

Earliest use.—In very early times, while man was still defending himself against wild beasts with weapons of stone, he must have made use of other stones on which he could grind edges for his weapons or smooth them into shape. The first grinding was probably done by rubbing upon a large stationary stone the fragment to be shaped. Furrows in the bed rock made by this sort of grinding have been noticed in Brazil: "The grooves are from eighty to one hundred and twenty centimeters in length, about the length of the natural movement of a man's arms when in a kneeling position." * These grooves were made chiefly in the grinding of axe heads; and the scratches made during this process are almost always visible on the finished tools.

All the world over ground implements occur together with chipped ones. In the Report of the Smithsonian Institution for 1879, Mr. Knight mentions a stone sword with a ground edge from New Zealand,† as well as axes and arrow heads from all parts of the world. In the same report whetstones‡

* Archivos do Museu Nacional, Rio de Janeiro, Vol. VI., 1885, p. 484.

†A Study of the Savage Weapons at the Centennial Exhibition, by Edward H. Knight, Philadelphia, 1876.

‡Indian Relics from Scoharie, N. Y., by F. D. Andrews, p. 391.

are noted amongst Indian relics found at Scoharie, New York. The use of detached fragments of stone for abrading purposes must have come later than the grinding on stationary rocks, however, and must be taken as an evidence of progress in civilization.

As the use of metals for spear points and arrow heads, and finally for knives, swords and tools became known, the need of a substance for producing an edge was felt more strongly, and must have led to search for and discrimination in the various kinds of stones. In all probability sandstone was first used, as it is generally distributed; its coarse grit would first attract attention, and the rough edge that it gives was all that was at first required. With the progress of the arts probably came the discovery and use of the gritty shales for sharpening purposes.

Derivation of early words for whetstone.—The importance and antiquity of this process of sharpening is shown by the existence in the Sanskrit of a word ça, meaning to whet, to sharpen. From this is derived the Latin *cos*, which means in particular a whetstone or hone, but may be used in general to denote a flintstone or any hard stone. From *cos** are derived *cotaria*† which means a whetstone quarry, the existence of the word showing the importance whetstones had reached before the Christian Era, and *coticula*‡ meaning small touchstone, from which comes the French *coticule* meaning whetstone of a fine quality.

Another Latin word, *novacula*, in use by Cicero, Petronius, Celius, Valerius Maximus, Livy and others, and denoting first a sharp knife and then a razor, is used by Linnæus§ with and without the word *cos* to denote a fine quality of whetstone, the razor-hone. To Richard Kirwan, in his mineralogy of 1784, is attributed the anglicizing of this word to *novaculite*, which form of the word has since been retained.

*See Harper's Latin Lexicon under *cos*.

†See P. Alfenue Varus, Digesta 39, 4, 15, B. C. 2.

‡Pliny, Hist. Nat., 33, 8, 43.

§Linnæus, Systema Naturæ, 1768 and 1796.

FOREIGN WHETSTONES.

Pliny.—Pliny, A. D. 23-79, in his Natural History,* says that there are many kinds of stones used for sharpening iron implements. A translation reads: "Crete for a long time had the best reputation; Laconia was second with stones from Mount Taygetus, both needing oil; among water stones the reputation of the Naxian was at first the best, afterwards of the Armenian, * * * the Sicilian stones can be used without oil or water; with water those of Arsinœ.† They are found both in Italy, producing, with water, an edge of the keenest sort, and also across the Alps, and these they call *passernices*.‡ A fourth kind is of service in barber shops, used with the spittle of men; these are of no use when brittle or soft. Small layers of this kind of stone particularly come from the nearer part of Spain."

From this sketch of Pliny's we learn that all the methods of using whetstones which are now known, with oil, with water, and dry, were known at least shortly after, and probably before, the beginning of the Christian Era. Of the localities which he mentions, Crete and Laconia are not noted as producing whetstones of late years. Naxos is known for its production of emery, but not for whetstones; a fact which suggests that emery stones were used in this early time and called whetstones. The Armenian stone which came to rival the Naxian was very likely the Turkey oil-stone which comes from the interior of Asia Minor, and is perhaps the best known whetstone in the world at the present time. Sicily and Egypt are no longer important whetstone producing countries, but whetstones are still obtained in Switzerland, Italy and Spain. The existence of the razor-hone at the time of Pliny is interesting to note, and his account is rendered much more valuable from hones and whetstones having been found among the ruins of Pompeii.§

*Historia Naturalis, 36, 22, 47, par. 164.

†Arsinœ, a town of Lower Egypt or Cyrenaica.

‡*Passernix* is the Celtic word for whetstone.

§Museum of Antiquity by L. W. Yaggy and T. L. Haines, Chicago, 1882.

De Bomare.—M. Valmont de Bomare, in his Dictionaire Raisonné Universal D'Histoire Naturelle,* to indicate the general class of stones, uses the name "pierre à rasoir" (razor-stone) and gives as synonyms, *cos*, *queux*, *pierre naxienne* and *lapis coticularis*. "As it comes from the quarry this stone is soft, but it hardens with use: it is composed of fine particles compactly arranged: it is divided into layers, the colors of which are sufficiently different and easy to distinguish for one to notice them in all the whetstones (*pierre à aiguiser*), oil-stone, or razor-hone stone (*pierre à rasoir*), which are sometimes composed of two layers, one brownish and the other gray or yellowish-white; the two are as though glued together; neither is dissolved by acids."†

"They chip the stone into shape in making whetstones out of *pierre à aiguiser*. The true *pierre à rasoir* are the gritty shales."

The names *cos* and *queux* are given by some authors to sandstones.

Bomare says that "Turkey grit or scythestone (*pierre à faux*), *cos Turcica*," resembles a certain species of hornstone. With oil it hardens considerably.

"The grit of the knife-grinders, *lapis cotarius*, is a stone the particles of which are of unequal coarseness, bound together so closely that water can scarcely penetrate it. By chipping it they make grindstones or whetstones used with or without water."

In these descriptions Bomare confuses terms, making the true razor-stone (*pierre à rasoir*), which is a gritty shale, synonymous with the *pierre à aiguiser* and with *cos*, which are merely coarse sandstone whetstones. It is interesting to note the preservation of the name of the Naxian stone of Pliny, though the Island of Naxos is not given by Bomare as a whetstone locality. So, too, the name of Turkey stone is applied to stones from various parts of Europe, omitting the single locality where this stone is found.

*Published previous to 1749, but not long before.

†The stone here described is the celebrated Belgian stone from the vicinity of Liège.

Buffon.—Buffon's Histoire Naturelle was published in 1749. Its author makes two divisions of whetstones, the sandstones and the Turkey grit, and tells the use of each, the sandstone being used to give simply a sharp edge, the Turkey grit for a very fine edge. He, too, is of the opinion that the Turkey grit is found elsewhere than in Turkey.

Da Costa—Da Costa mentions* various kinds of sandstone which are used for whetstones, and he gives as synonyms for whetstone, "*cos portabilis*," and "*cos aquaria*," meaning portable stone and water stone. Da Costa very justly questions the use in a general sense of the word Turkey stone, as such a term should only be used commercially and not to denote a class of stones which may be very different in texture, though used for the same mechanical purposes. Whether it was brought about by the influence of Da Costa's writing or not, it is impossible to say, but the principle which he advocated is the one prevalent today, the names of places being very generally used in speaking of whetstones, but only used to designate the locality whence they come; thus we have "Scotch water-of-Ayr stones," "Belgian hones," "Norway rag-stones," Hindostan and Arkansas stones, etc. Some mode of distinguishing the various whetstones is necessary, for there are decided differences in stones from different localities; the idea of using the geographic location is commendable for its simplicity and for the information it conveys concerning the origin of the stone.

Wallerius.—In the Mineralogy† of Wallerius the following classification of whetstone is given:

"VITRIFIABLE STONES."

"*Slate* whetstone.

The varieties of whetstone are:

1. Black whetstone (*coticula nigra*, *cos salivalis*).
2. Gray whetstone (*coticula cineræ*, *cos salivalis*).
3. Yellow whetstone (*coticula flavescens*, *cos salivalis*).

Sandstone. Turkey whetstone (*cos turcica*)."

Of the different species of grindstone grit, Wallerius says

*History of Fossils, by Emanuel Mendes de Costa, 1757, p. 133.

†Mineralogie, Jean Gottschalk Wallerius, Paris, 1759, vol. I.

small whetstones are made, which must not be confused with those made from shales.

Linnæus.—Linnæus* in his Systema Naturæ, 1768, mentions several varieties of whetstone, including "sandy stones (*cos novacula*)," stones with gritty, or impalpable particles found in the Orient, etc., and used by barbers to sharpen razors." Earthy stones, comprising a schist described as white, or black, having a firm texture and taking a polish; and Lydian stone.

In the Systema Naturæ, edition of 1796, the clayey rocks, including shale, have as a sub-heading "Novacula." This is described as "a stone shining and glistening within, not entirely opaque, somewhat hard, greenish, ash-colored or white."

He mentions as localities from which novaculite comes, Oelandia, and Franconia near Lauenstein, and names as localities for sandstone whetrock, Sweden, Westrogoth, Scania, Saxony, Thuringia, Hesse, Lorraine, Switzerland, Transylvania, and Spain.

Descriptions by Wallerius and Linnæus compared.—These descriptions by Wallerius and Linnæus are very similar; they both call the Turkey stone a fine sandstone, as undoubtedly Linnæus has the Turkey stone in mind when he mentions the Orient among his localities of sandy stones; Wallerius makes a decided distinction between the sandstones and shales or slates, the shales clearly corresponding with the "*novacula*" of Linnæus. Linnæus uses *novacula* also as a descriptive term in mentioning sandstone and schists used as whetstones.

Linnæus is the first to mention the Lydian stone, though it must have been in use long before his time. This is a black stone of very fine grain, used to test the quality of gold and silver. The article to be tested is rubbed on the stone; the quality of the metal is judged by the color of the streak, and also by noting the effect of acid on the streak. The essential qualities of the stone are the same as those of a whetstone, except that the grit should be much finer; thus it is very properly put in this group of stones. The name indicates the original

*The Systema Naturæ is dated 1768, but as Wallerius in his work, (1759), refers to Linnæus, some publications must have been made by him before that date.

source of supply to have been Lydia in Asia Minor; as stones from other localities came into use, the general term for stones used for this purpose became "touchstone," though "Lydian stone" is still sometimes used. Another synonym for touchstone is basanite.*

Kirwan.—The first English mineralogy of repute was published in 1784 by Richard Kirwan. He follows Wallerius and Linnæus in his description of whetstones, but adds some new facts. The Turkey stone is correctly described by him for the first time: "This is of a dull colour and uneven texture, some parts appearing more compact than others, so that it is in some measure shattery; it hardens with oil; its specific gravity is 2.598; it gives fire with steel, yet effervesces with acids. I found 100 parts of it to contain 25 of mild calcareous earth and no iron.† Ragg-stone.—Its colour is gray; its texture obscurely laminar, but the laminæ consist of a congeries of grains of a quartzy appearance, coarse and rough; its specific gravity is 2.729; it effervesces with acids, and gives fire with steel. I found it to contain a portion of calcareous earth, and a small proportion of iron. It is used as a whetstone." Kirwan also speaks of sandstones with argillaceous cement as being used for whetstones, and gives as localities, Keredge, and Brownedge in Staffordshire.

D'Hauy.—René d'Hauy,‡ calls whetstone "*argile schisteuse novaculaire*," synonymous with *coticula*, and says that it is commonly called *pierre à rasoir*. His description is that of the Belgian hone, "found near Liège."

Brongniart.—The subject is much more fully and clearly treated in Brongniart's Mineralogy.§ In this account the point is made that many of the stones which serve to abrade steel can be scratched by iron, or even by points of softer metal. His description of the whetstone schist (*schiste coti-*

*See Egleston's Catalogue of Minerals and Synonyms under *Basanite*.

†Op. cit., p. 140.

‡Minéralogie, par D'Hauy, Paris, 1801, Vol. IV., p. 448.

§Traité Élémentaire de Minéralogie par Alexander Brongniart, Paris, 1807, Vol. I., p. 558.

cule) corresponds to that of novaculite given by Linnæus. According to Brongniart, the following varieties were sold in Paris: "Razor hone.—This schist comes from the vicinity of Namur. The lancet stone (*pierre à lancette*) is of a greenish gray; its texture is hardly schistose, and its fracture conchoidal and flinty; it comes from Germany. The hard water stone is compact, with a flinty fracture, greenish, but paler than the preceding."

It is evident from these last authors that the mica schist was in use as a whetstone at the time of Linnæus, but it was probably not well known, as he merely mentions it. De Bomare's description indicates that the Belgian hone was one of the first, if not the first, schists to be used. These writers make apparent also the new use of the talcose rocks for whetstones, for these stones are not described by the earlier writers.

Steffens.—Heinrich Steffens in his Mineralogy* introduces the name "Wetzschiefer" as a synonym for novaculite. This word is credited, however, by Brongniart to Brochant. The occurence of the new word is additional evidence of the use of a new whetrock, though "Wetzschiefer" now means whetslate rather than whetstone schist.

Delametherie.—Delametherie goes back to the old word *cos*, and gives a general description of both fine and coarse whetstones. He mentions† the German word "Wettstein," and credits Werner with originating the word "Wetzschiefer," which he spells "Westschieffer."

Jameson.—Jameson's Mineralogy mentions‡ a new abrading stone, "polier or polishing slate." This is a soft, friable stone used only for polishing purposes.

Jameson uses "whetslate" as the term for a fine-grained whetrock. He places the Turkey stone in this group, and gives the following account of it: "The Levant whet-slate is brought in masses to Marseilles, and is there cut into pieces of various sizes. It is ground by means of sand or sandstone,

*Handbuch der Oryktognosie, 1811.

†Minéralogie, par J. C. Delametherie, Paris, 1812, Vol. II., p. 174.

‡Vol. I., p. 423, 1816.

and polished with pumice and tripoli. These whetstones, or hones as they are called, ought to be kept in damp and cool places; for when much exposed to the sun, they become too hard and dry for many purposes."

Jameson states what one may have already suspected from a study of previous writers, that whetrock is treated as a distinct mineral species, with several varieties. This is of course unsatisfactory, since the possession of common mechanical properties by whetstones does not imply uniformity of composition.

The following is an extract on whetstones from the "Mineralogy of the Chinese Empire" by Herr Hofrath.* "A Chinaman of Urga used as a whetstone to sharpen his tools a very pretty piece of whetstone of an asparagus green color. He called it *Piluh*, and gave me to understand that it is found in that country, which is not improbable, since one finds among the boulders of the mountain streams clay-slates which pass into whetstones."

Aiken.—Aiken follows Jameson in the use of the term "whetslate,"† and makes it synonymous with the "wetzschiefer" of Werner. As the description given applies strictly to whetslate, and does not include other whetstones, there can be no objection to its use. His description is as follows: "Occurs massive; structure slaty; longitudinal fracture splintery; almost dull; color grayish, yellowish, brownish, or muddy green; translucent on the edges; yields to the knife; somewhat unctuous to the touch; specific gravity 2.7. Before the blowpipe it becomes white, and acquires a vitreous glazing." This is essentially the description of novaculite, so these two words can be considered synonymous.

Nouveau Dictionnaire d'Histoire Naturelle.—Considerable attention is given in the Nouveau Dictionnaire d'Histoire Naturelle‡ to the subject of abrasive materials. The general word used corresponding to whetstone, including all the others, is

*Taschenbuch für die Mineralogie, Dr. Carl Cæsar Leonhard, 1818, p. 414.

†Manual of Mineralogy by Arthur Aiken, 1815, p. 258.

‡Paris, 1818.

pierre à aiguiser. The scythe-stone variety (*pierre à faux*) is here designated as a sandstone grit. This is the common stone used for sharpening scythes, and not the fine grained stone described by De Bomare under the same name. Under polishing stones, (*pierre à polir*), are mentioned pumice, tripoli, and emery.

Ree's Encyclopædia.—Ree's Encyclopædia, 1819, treats the subject of whetstones under the various headings, slate, whetstone or hone, oil-stone, hone, and *cos.* Of the hone it says: "It is of a yellowish color, and is vulgarly but erroneously supposed to be holly-wood petrified or changed into stone, by lying in a petrifying water for a certain season."

Mohs.—Haidinger's translation of Mohs' Mineralogy presents some new facts in regard to the relation of whetstone to other rocks. "Whetslate is a slaty rock, containing a great proportion of quartz, in which the component particles (the same as in clay slate, mica slate, and gneiss, but in different relative quantities) are so very small as to withdraw themselves from observation. This may serve for explaining on one hand the passage of whetslate into clay slate, on the other hand to the employment it allows for grinding, which is impossible in any mineral that in reality is soft. Whetslate occurs in beds between clay slate, particularly in the older rock."

Hartmann.—There is an entertaining theory to account for the origin of the polishing slate of Bohemia and Saxony, given in Hartmann's Mineralogy.* He offers no theory himself, probably considering the stone merely as a variety of slate; he simply says: "Some think that it is derived from the ashes of burnt coal." The basis of this notion was probably the ashy color and powdery feeling of the stone. As a theory to account for hones it will hardly compare in value with the petrified wood theory, which has retained such a strong hold on popular opinion even to the present time, for there are well authenticated cases where silicified wood has been used for hones.

Beudant.—The general subject of abrasive materials is

*Dr. Karl Friedrich Alexander Hartmann's Mineralogie, 1829, p. 153.

treated much more fully in Beudant's Mineralogy* than in any of the early works. The author's treatment of the subject has given considerable attention to the economic uses of the different stones. He says that whetstones are most commonly of gray or blackish sandstone grit obtained from the coal formation, the red sandstone from the Tertiary. "Sometimes they use these fine varieties of grit directly, cutting them out in square prisms, in shuttle form, etc.; sometimes they grind them in order to make a paste which they mould, and afterwards bake in order to get the necessary degree of hardness. For the latter kind of stone, varieties of micaceous quartz are employed, the quartz particles of which are fine, and well intermingled with spangles of mica."

"They use still other mineral substance to burnish metals; that is to say, to give them brilliancy by rubbing the surface, previously polished, by a substance harder than themselves, polished, and incapable of scratching as polishing substances do. For this purpose they use hematite, some varieties of agate, quartz, and in general all hard stones.† These are often replaced by polished steel, which they fashion to suit the needs cf the different arts."

The manufacture of artificial whetstones mentioned by Beudant shows how the need for good stones was not entirely satisfied by the natural rock, which is very liable to be of uneven texture. At present the abundance and cheapness of good natural stones have almost entirely stopped the manufacture of the coarser artificial whetstones.

Knight.—The Transactions of the Society of Arts, London, 1833–35, Vol. L., p. 231, record the thanks of that society to Richard Knight, Esq., for a collection of hone-stones and

*Minéralogie, par François Sulpice Beudant, Paris, 1830, Vol. I., p. 738.

†Burnishing may be said to represent one extreme of the process of abrading, just as sawing represents the other; sawing contains an element of cutting; burnishing is largely a simple smoothing accomplished by rubbing, while abrading implies the actual removal of particles by a scratching process. Since burnishing does involve a little abrading, it seems fitting to allow a consideration here of burnishers, especially since the relationship between the stones used for burnishing and the finest qualities of abrading stones is so very close.

grindstones, a descriptive catalogue of which is given. In this catalogue Mr. Knight divides the collection, which he says contains "all the principal stones used in the mechanical arts," into arenaceous and schistose stones; the few that do not come under either of these heads are separately described. Under the sandstones are mentioned the carpenters' and engravers' rub-stone; the shoemakers' sandstone, also used by cork cutters; the scythe-stone; a whetstone called the "Devonshire batt;" and the two softer "grits" for polishing marble, and copper plates for engravers.

The schistose rocks include the Norway ragstone; the Charnley Forest stone; the Ayr stone, Scotch stone, or snake stone; Idwall or Welsh oilstone; Devonshire oilstone; cutlers' green stone; German razor-hone; blue and gray polishing stones from Ratisbon; and Welsh clearing stone, a soft variety of hone-slate cut in circular form and used by curriers to give a fine smooth edge to their dressing-knives.

"In addition to the above," Knight says, "we may here notice the Turkey oil-stone, although from the absence of a lamellar or schistose structure, it can scarcely be considered as a hone-slate. As a whetstone it surpasses every other known substance,—abrading the hardest steel,—and resisting the pressure necessary for sharpening a graver, or other small instrument of that description. Little more is known of its natural history than that it is found in the interior of Asia Minor, and brought down to Smyrna for sale. The rough, irregular pieces of oil-stone scarcely ever exceed about three inches square and ten inches long, and are generally about one third smaller. When cut into rectangular forms, it is done with the lapidary's slitting-mill and diamond powder. The blocks are then rubbed smooth with sand or emery on an iron plate. The piece of oil-stone is generally inlaid in a block of wood, in which it is cemented with putty, and to avoid the deposition of dust a wooden lid is usually added. Sperm or neat's-foot oil, or an oil not disposed to thicken should be used."

This catalogue by Mr. Knight is a valuable one in the his-

tory of whetstones, on account of the completeness of the collection, and the confirmation it gives to the work of previous writers.

The Blackdown quarries.—Mention is made in the Transactions of the Geological Society of London* of some of the most extensive whetstone quarries which have ever been worked, those of Blackdown Heath in Devonshire, England.

The stones were in the form of concretions in sand strata of Cretaceous age, and were obtained by tunnelling into the Blackdown hill. These quarries were worked long previous to 1813, for a letter written in that year says: "The whetstone business was a very injurious one, so much so that in the little village of Punchey Down, inhabited exclusively by stone cutters, he saw but one elderly person, and was told that few reach the age of forty."

Further mention is made of these quarries by Mr. Downs, who says:† In 1836 "pits were being worked at Blackdown almost continuously for a mile and a half, and at intervals still further. At the present date (1882) three only are being worked on the eastern side of the ridge, and all have been closed on the western escarpment. Some few of the latter, however, have been open since my residence in the neighborhood."

This shows a great falling off in the production of whetstones at Blackdown, but they are probably still quarried there, for they were mentioned in 1887 as follows:‡ "The upper greensand of the Cretaceous at Blackdown in Devonshire yields whetstones. They have here been quarried for many years and the tunnels were so extensive as to cause considerable subsidences. The whetstones are known also as Devonshire Batts and in Dorsetshire as Rubber-Batts or Balkers."

These accounts show that these quarries have been worked

*Series 2, Vol. IV., 1836, p. 237.

†The Zones of the Blackdown Beds * * * * By Rev. W. Downs; Quart. Jour. Geol. Soc., 1882, Vol. XXXVIII, pp. 75-94.

‡Geology of England and Wales by H. B. Woodward, p. 393.

for at least a hundred years, and it is possible that they have been worked several hundred, so that in age they may be second only to the quarries of Turkey stone, and at least rank with the Belgian and Swedish quarries.

Russian stone.—The whetstones used nearly all over Russia are quarried near the village of Sariu, near the Petchora River, in northeastern Russia, west of the Ural Mountains. The stone is pepper-colored and the bed is not over three or four feet in thickness; it is of Carboniferous age, and is very largely developed along the western flanks of the Arctic Ural.*

D'Halloy.—"Coticule" is given by D'Halloy as a sub-variety of schist,† and is made synonymous with novaculite, *pierre à zoir, pierre à lancette, wetzschiefer.* He says it is "formed in beds, sometimes in viens, presenting sometimes thick leaves which appear very compact and with a conchoidal fracture."

Tomlinson's Cyclopædia, 1854.—In the article on hone in Tomlinson's Cyclopædia a stone called Peruvian hone is mentioned as having been recently introduced into England from South America.

Blum and Zirkel.—In the words of the eminent lithologists, Blum and Zirkel,‡ novaculite (*wetzschiefer*) is classed as a clay slate impregnated very uniformly with a large amount of silicic acid, which causes the rock to lose its schistose structure.

Page.—Many of the stones described by Mr. Knight are mentioned by Page.§ The coarse whetstones at this time were known as "batts," and England's supply came from Blackdown, from the millstone grit and Gannister beds of Yorkshire, and from the Lower Carboniferous sandstones of Fifeshire. The Norwegian, Russian, and Scotch ragstones are described as tough and highly siliceous portions of mica schist. The Russian varieties are generally softer. The Arkansas stone had a good reputation in England at this time, for Mr.

*Murchison's Geology of Russia and the Ural Mountains, 1845, p. 410.

†Géologie, Introduction et Éléments, par Omalius D'Halloy, 1838.

‡Lithologie, Dr. J. Reinhart Blum, 1860, p. 231. Petrographie, Dr. Ferdinand Zirkel, 1866, Vol. II., p. 600.

§Economic Geology, by David Page, London, 1874.

Page says: "The Arkansas stone, consisting of very fine white amorphous silica, has an excellent bite, but is rather brittle and expensive."

Roth.—Some facts concerning the chemical composition and microscopic structure of whetslate are given by Roth.* "By whetslate (wetzschiefer) is meant a very compact, clear-colored, greenish or reddish modification of a clay-slate rich in quartz * * * In thin slides one sees the silica in part in lenticular concretions, in part in little crystals between the remaining ground mass of glimmering feldspar."†

Von Cotta and Kalkowsky.—By Von Cotta‡ and Kalkowsky§ novaculite is still pronounced a highly siliceous clay-slate. Von Cotta makes novaculite synonymous with whetslate, whetstone, hone and oilstone. Kalkowsky gives some new facts about the occurrence; he says: "A substance rich in quartz can appear in clay slates in many ways. Independent of a rich lead of accessory quartz-slate, a clay-slate can include pretty thin layers and lamellæ of tolerably pure quartz; in such a quartzose clay-slate the quartz layers and clay-slate layers rich in quartz can unite into a great veined stone. But the quartz substance can be distributed farther and placed in the stone so as to form a homogeneous mass; one can distinguish this stone as a quartzose clay-slate. A very fine-grained stone of this sort could find use as a whetstone, as, for example, many in North America called novaculite slate."

Von Cotta speaks of the Lydian stone and regards it as a variety of black chert. "It contains carbon which gives it a greyish coloring, inclining to black; usually stratified in thin laminæ, and hence of a laminated texture; generally penetrated by numerous white veins of quartz; much rent by angular fissures, sometimes containing laminæ of clay-slate. It

*Allgemeine und Chemische Geologie, Justus Roth, 1877, Vol. II., p. 587.

†This is credited to Gumbel, Fichtelgebage, 1879, p. 290.

‡Lithology, by C. Bernhard Von Cotta. Translated by Philip Henry Lawrence, 1878, p. 257.

§Elemente der Lithologie, Dr. Ernst Kalkowsky, 1886, p. 252.

occurs with tolerable frequency as a subordinate stratum in clay-slate, slate clay, or even mica schist."

Rothpletz.—The *kieselschiefer* (quartzose or siliceous shale) is a member of the Silurian strata of Germany, lying above two beds of shales, carrying graptolites. The stone agrees very closely in physical characters with the siliceous shales of the Arkansas novaculite formation. Rothpletz, as stated in his article upon the "*Kieselschiefer* of Saxony," finds* almost no trace of amorphous silica in the siliceous shale, but reports that the rock consists of exceedingly fine grains of a thready chalcedonic structure, and that these thready masses are arranged around particles of carbon. The chalcedonic form of the silica he regards as a result of metamorphism by ordinary interstitial waters acting upon silica having almost entirely an organic origin. Traces of organic forms are, however, exceedingly rare, comprising some round bodies, from 0.1 to 0.3 of a millimeter in diameter, found particularly in the darker rocks; these bodies Rothpletz thinks are the ovarian capsules of graptolites.

Belgian hone.—An account is given of the famous hone from southeast Belgium in the Géologie de Belgique.†

More detailed, however are the investigations into the nature of this stone by M. Renard.‡ These studies revealed the fact that the finer properties of the Belgian hone are due to the presence of microscopic garnets thickly and evenly distributed. Fine crystals of tourmaline and chrysoberyl are also present, and assist considerably in the process of abrasion. The stone is classed as a garnetyte by Renard.

Woodward.—The Welsh oilstones are probably still on the market, for mention was made of them by Woodward in 1887.§ The Welsh stones are found in the Bala or Caradoc beds of the upper Cambrian; hone stones come from the Devonian rocks of

*Zeitschrift der Deutschen Geologischen Gesellschaft, XXXII., 1880, p. 447.

†Vol I., 1881, p. 33.

‡A. Renard, Bulletin du Musée Royal de Belgique, Vol.. I, 1882, p. 1, and Vol. II., 1883, p. 127.

§The Geology of England and Wales, by H. B. Woodward, London, 1887, p. 76.

the London area;* and at Hestercombe the slate has been metamorphosed to a honestone by contact with a dike. The Carboniferous strata are mentioned as furnishing scythe-stones at Talacre quarry in Flintshire, in South Lancashire, and in Derbyshire.† From the same strata come the Sheffield bluestones.

Conclusions.—From this sketch of the whetstone industry in foreign countries in the past, we see how not only each nation, but also frequently each province and district, especially in early times, had its own locality for obtaining whetstones. The progress made in the arts, and the increase in commerce in later times tended to give the better qualities of stone an international reputation. This necessarily stopped the production of inferior stone, so that later writers do not mention as many localities as the older ones.

There has been a noticeable confusion in the matter of names all the way through, resulting from the use by scientists of the popular and commercial names, which are unsuited for scientific purposes; while on the other hand, terms scientifically exact were used loosely by artisans and merchants. It was natural that the arts, having the precedence, should influence science when the two came into contact; but no confusion exists from the use of the same terms both for the stones used in the arts for abrading purposes and for the rocks from which they are derived. Thus the English *whetstone*, synonymous with the French *pierre à aiguiser* and *coticule*, and German *Wetzstein*, are essentially commercial terms for the general class of abrasive stones used in small pieces, and in a particular sense they apply to coarse stones only. Unfortunately *coticule* has been used by M. Renard in his writings on the Belgian hone, and the word will probably continue in use as applying to that stone. The word *whetslate* (German *wetzschiefer*, French *argile schisteuse novaculaire*) is a scientific rather than an economic term. The French and English words have very definite meanings, but the German *wetzschiefer* is made to include other fine-grained rocks besides shales. The word hone car-

*Op. cit., p. 141.

†Op. cit., pp. 173, 184 and 186.

ries a distinct meaning, and causes no confusion in scientific literature. Novaculite (French *pierre à rasoir*), however, has been much abused; it originated as a scientific term, but its indefinite meaning made it an easy prey to commercial language, so that now it may denote a mica schist, a gritty shale, or a fine sandstone, to say nothing of its general application to all whetstones. In the absence of a synonym for novaculite the Germans use *wetzschiefer*.

Linnæus applied the word novaculite to that peculiar, dense, highly siliceous and, as he says, "not opaque" rock generally associated with clay slates. Many writers since his time have adhered to this application of the term, while others have shown little agreement in their application of it to any single rock. It seems practicable, then, to revive the word as a scientific term, in its orignal sense, to denote a fine-grained, gritty, homogeneous, and highly siliceous rock, translucent on thin edges, and having a conchoidal or sub-conchoidal fracture. If this definition is strictly adhered to no confusion will arise from the use of the word in commerce.

The French *pierre à lancette* seems to be a true novaculite used for a special purpose.

CHAPTER II.

The History of Whetstones in North America.

A very early mention was made of whetstones in North America by Thomas Merton,* an Englishman, who came over with the early settlers of Massachusetts. The strictness of the Puritans in Boston proving irksome, he moved to Wollaston, and there started a kind of pleasure resort. In a book describing the country to his friends in England he dwells much on the resources of the country in whetstones. In point of fact, however, only inferior stones are found in the region with which he was acquainted, though they may have been considered superior in his time.

Arkansas.—The first authentic mention of whetstones in America concerns those of Arkansas. In a letter on the region of the lower Mississippi, written by Mr. Bringier of Louisiana in 1818,† mention is made of a quarry of hone-stone which had been worked several years, a few miles above the "Cove of Wachitta," which place, from his description, is undoubtedly the present Magnet Cove. He wrote: "The hones have been found so good in the States, to which four hundred pounds were taken last year, that the same man who discovered the quarry is now loading a flatboat with them. He sold the first at one and two dollars per pound. Those taken out of the lower strata are of a coarser grain, and are found by carpenters who use them superior to those imported from Turkey. Some are red, some of a flesh colour, others tranparent with a grayish blue cast."

In 1819 Henry R. Schoolcraft's work on the "Mineralogy,

*The New Canaan, by Thomas Merton, edited by C. F. Adams, 1884.

†American Journal of Science, Series I., Vol. III., 1821, p. 26.

Geology, etc., of Missouri and Arkansas," was published.* In this book (page 183) a much more definite account of the Arkansas whetstones is given. It reads as follows: "A quarry of this mineral (novaculite), three miles above the Hot Springs of Washitaw, has often been noticed by travelers for its extent and excellency of its quality. A specimen now before me, is of a grayish white colour, partaking a little of green, translucent in an uncommon degree, with an uneven and moderately glimmering fracture, and susceptible of being scratched by a knife. Oil stones, for the purpose of honing knives, razors and carpenter's tools, are occasionally procured from this place, and considerable quantities have been lately taken to New-Orleans. It gives a fine edge, and is considered equal to the Turkish oil stone. It appears to me, from external character, to contain less alumine and more silex than the common novaculite, and, hence, perhaps, its superiority."

These two accounts show that the whetstones of Arkansas were discovered very early in this century, and immediately gained great favor for both fine and coarse tools. The two writers differ in the location of the quarry, but as Mr. Bringier's knowledge was derived entirely from hearsay, while Schoolcraft's account agrees much better with later reports, the location given by the latter is probably the correct one. Schoolcraft's observations are in the main correct, but in testing the hardness he must have mistaken the metallic streak of the steel for a scratch, or else have tested a stone different from the one described.†

*A View of the Lead Mines of Missouri, including some Observations on the Mineralogy, Geology, Geography, Antiquities, Soil, Climate, Population, and Productions of Missouri and Arkansas, and other sections of the western country. By Henry R. Schoolcraft, New York, 1819.

†From a description found in Cleveland's Mineralogy, by Parker Cleveland, 2d Ed., 1822, p. 452, it is evident that the Americans accepted the foreign definition of novaculite. He mentions the Arkansas stone, giving Schoolcraft as his authority.

Other localities given are "Maryland, on the Patuxent River, near the road to Washington. (Hayden.)

"In Pennsylvania, Berks County, at Oley; it is explored, and sells for 25 cents a pound." (Cooper.)

"In Vermont at Thetford. (Hall.)

"In Maine, near the forks of the Kennebec, eighty or ninety miles from Hallowell, where it is abundant."

In this book, page 335, a new stone is proposed as a whetstone, but it is not mentioned in any other work so far as we have been able to discover. The paragraph reads as follows: "Some varieties of compact feldspar are susceptible of a high polish. When homogeneous, the softer kinds may be employed as honestones; indeed it is said that the Turkey stone often belongs to this variety of feldspar. * * * According to Mr. Godon, the vicinity of Boston furnishes compact feldspar analogous to the Turkey stone." The author appears to doubt the statement, for he cites the analysis of Holme to show that at least one variety of Turkey stone was not a feldspar.

Lake Memphremagog.—In the American Journal of Science for 1822,* there is a notice of the discovery of two oilstone quarries on an island in Lake Memphremagog, Vermont and Quebec. The island is about seven miles west of Stanstead Village. One quarry is now entirely under water and the other partly so. At this early date the stone had the reputation of equaling the Turkey stone, and large quantities were quarried. They have not been worked now (1890) for many years.

North Carolina.—In the same volume† the occurrence of novaculite in North Carolina is noted. It was found in slate in Orange county and was preferred to the finest oil stones of the market. Further mention is made of this stone in the same journal.‡ It is reported to occur in great abundance in the slate formation. The most valuable bed is about seven miles west of Chapel Hill, at M'Cauley's quarry. It is on the summit of a hill, one of a northeast and southwest range, composed of chloritic slate. The honestone occurs in distinct perpendicular beds. In color it is a soft olive green, looks like horn, and on thin edges is transparent. It acquires smoothness and hardness with use and is best adapted to carpenters' needs, though sometimes employed as a razor-hone.

M'Pherson's quarry in Chatham county, five miles west of

*Series I., Vol. V., p. 406.

†American Journal of Science, Series I., Vol. V., p. 262.

‡American Journal of Science, Series I., Vol. XIV., 1828, p. 238.

Woodin's ferry, on Haw River, is next in importance. The stone is lighter colored, softer and has a finer grit, probably fine enough for razors. Several varieties occur in the same bed, ranging from transparent to opaque, through bluish and yellowish-white tints. The bed is extensive. A similar bed is found near Deep River in Randolph county. At Barbee's Mill there is a great amount of straw-colored stone. The extent of these beds is commensurate with that of the great slate formation. It is found from Flat River, in the eastern part of Person county, to the Narrows of the Yadkin.

There is a specimen of this stone from Chatham county in the cabinet of whetstones in the National Museum at Washington. It is of a light yellowish-green color and looks like serpentine, but is hard. The "Useful Minerals of the United States for 1888," by Albert Williams, Jr.,* reports that novaculite is extensively quarried a few miles west of Chapel Hill, Orange county; near Roxborough, Person county, and near Wadesborough, Anson county, in quarries which are in Huronian strata. There are other quarries elsewhere, the products of which are employed for local uses.

Georgia.—Novaculite is found in Georgia, in Lincoln and in Oglethorpe counties.† In Lincoln county it occurs on a low hill two miles from Lincolnton court-house. It projects nearly vertically from the ground over an area of four or five acres. It has several colors; where exposed it is straw-colored, below the surface it is greenish-white. According to the authorities of the time it is probably identical with the North Carolina stone. The Lincoln county novaculite is mentioned in "The Commonwealth of Georgia,"‡ and is there reported to be the most important whetstone grit in the state, and to be found in immense beds near Graves Mountain. Whetstone grit has also been noted in McDuffie, Heard, Troup, and Merriweather counties.§

*Mineral Resources of the United States, 1887, page 772.

†American Journal of Science, Vol. XVI., 1829, p. 185.

‡The Commonwealth of Georgia, by J. T. Henderson, 1885, Part I., p. 139.

§Mineral Resources of the United States, 1887, p. 722.

South Carolina.—In South Carolina novaculite has been reported in Abbeville and Edgefield counties, and on Turkey Creek in Chester county.*

Mississippi.—The sandstones on Big Bear Creek in Tishamingo county are said to be suitable for whetstones.†

Tennessee.—In Tennessee the sandstones in the vicinity of Knoxville were used in 1819 for millstones, grindstones, and whetstones.‡ Grindstones were cut from the sandstones on the Frenchbroad, a mile above Dandridge, Jefferson county, about 1856. No more recent mention of the use of these stones for whetstones has been found.

Alabama.—Whetstones are made from sandstone quarried near Eldridge, Walker county.§

Ohio.—Oil-stone of fine and uniform grain is mentioned as occurring in Ohio in Rocking county.‖

The Berea grit at Mesopotamia and Farmington, Trumbull county, is suitable for coarse whetstones,¶ and the Berea grit at Berea is also used for whetstones.** Only the finest grained material can be used for whetstones, and the manufacture can only be carried on in connection with production of the stone for other purposes. Amherst is the only place at which it is manufactured in large quantity. There are three specimens of scythe-stones from Berea among the whetstones at the National Museum; also a fine grained whetstone of mica schist from Berea county.

In an article on the siliceous buhr millstones of Ohio by Dr. S. P. Hildreth,†† a peculiar siliceous stratum on the Hocking River is noted as being suitable for whetstones. The silica in the form of fine powder "is mixed with lime and oxide of

*Mineral Resources of the United States, 1887, p. 788.

†Report on Geology and Agriculture of Mississippi; Eug. W. Hilgard, 1860, p. 57.

‡American Journal of Science, Series I., Vol. I., 1819, p. 62.

§Mineral Resources of the United States, 1887, p. 693.

‖American Journal of Science, Series I., Vol. XVI., 1829, p. 374.

¶The Geology of Ohio, Vol. I., 1873, p. 604.

**Geology of Ohio, Vol. V.

††American Journal of Science, Series I., Vol. XXIX., 1836, p. 143.

iron, and disposed in veins of yellow and white." This variety, when fresh, can be cut with soft iron into whetstones and hones. It does not appear, however, that this material ever had extensive use, for no mention of it is found elsewhere.

Mesopotamia, Trumbull county, produces scythe-stones, and Manchester, Summit county, whetstones.*

Massachusetts.—Robinson's Catalogue of American Minerals, 1825, gives a number of localities for novaculite in Massachusetts. Citing the "Minerals of Boston and Vicinity," by J. F. and S. L. Dana, 1818, he records it as occurring in clay slate at Charlestown, Dorchester, Malden, Quincy, Concord, and Dedham. It occurs at all these localities also in the form of "rolled masses," as well as in Brookline and Cambridge. Novaculite and greenstone are found at Brighton and Milton.

These stones are probably all novaculites, but of poor quality and in very small quantities, for they have never been quarried.

Another kind of stone, the mica schist, has been quite extensively worked. The Pike Manufacturing Company states that the founder of their business, Isaac Pike, operated quarries at Cummington about the year 1830; these quarries have been worked at intervals ever since. Hitchcock† reports that "mica slate" is quarried in large quantities at Enfield and Norwich, and is extensively used for whetstones. In 1833‡ he writes that the Norwich stone is by far the best and that the Enfield locality is nearly or quite abandoned.

On page 34 of the same work the author says that he has found a specimen of feldspar in the town of Newberry, corresponding to that described by Mr. Godon,§ but that no fair trial has been made of it as a hone.

In his final report, 1841, Hitchcock mentions extensive quarries in the northeastern part of Bellingham. These stones are not considered equal to those obtained at Smithfield in Rhode

*Mineral Resources of the United States, 1887, p. 775.

†Geology of Massachusetts, 1832, Economic Geology, p. 23.

‡Geology of Massachusetts, Hitchcock, 1833, Economic Geology, p. 329.

§See foot-note on page 21.

Island, yet they answer well for shoe knives. "In 1838 not less than 22,800 were got out." The scales of mica in this rock are so fine as scarcely to be visible without the aid of a glass, and the rock might be mistaken for argillaceous slate.

"The brightly banded altered sediments at the east end of the peninsula" of Nahant contain good whetstones* "The darker bands are a lydite or indurated quartziferous slate, in which the microscope reveals, besides a ground mass of minute quartz grains, rusty flecks of ilmenite and mica. The lighter bands are largely made of microscopic garnets, to which calcite, epidote, quartz, and other minerals of less importance are added. Chlorite tinges the rock green, hematite turns it red. The black lydite is a good touchstone. The lighter bands take the streak of minerals well. Both are good whetstones when of sufficient size and of even grain. The light bands are much like the Belgian whetstone."

According to the mineral resources of the United States for 1887, no whetstones were quarried in Massachusetts for that year. A new quarry, which is still worked, was opened, however, in 1888, at Cummington.

Rhode Island.—The mica schist formerly quarried in Bellingham, Mass., is an extension of a delicate "mica slate" which has long been known as producing whetstones at Smithfield, R. I.†

A locality for this stone is noted‡ half a mile northeast of Woonsocket village extending a mile southwest. Six to eight thousand dozens of scythe-stones were quarried annually and exported into the other states. The virtue of these stones is attributed to the presence of fine quartz grains. They are not now manufactured.§

Among the whetstones of the National Museum there is a specimen of light gray sandstone scythe-stone from Rhode Island called Indian Pond stone.

*Geology of Nahant, by Alfred C. Lane, Proc. Bost. Soc. Nat. Hist., 1888, p. 92.

†Geology of Massachusetts by Hitchcock, Final Report, 1841, p. 213.

‡Geological Survey of Rhode Island, 1840, pp. 29 and 71.

§Mineral Resources of the United States, 1887, p. 786.

Maine.—"A very compact sandstone is found at Nutter's Head (Machias Bay?) which makes excellent hones for fine tools.* "Hone slate or novaculite, useful for oilstone, is extremely abundant in Maine, and may be advantageously wrought upon Little Deer Island and the Western Island in Penobscot Bay. It is equal in quality to that brought from the Mediterranean, known under the name of Turkey oil-stone, which sells in Boston for 50 cents a pound. If this rock is extracted and shaped as required, for sale, it will meet with a ready demand, and the locality is amply sufficient in extent to supply the world with oil-stone."† There is a specimen of novaculite from Little Deer Isle in the National Museum. It has the appearance of a hard splintery serpentine. In the Third Report of the Maine Survey, 1839, mention is made of novaculite from Temple‡ and from the Penobscot River at Phillips where it occurs in boulders associated with "argillaceous slate, greenstone trap and granite.§

In the report of the Maine Board of Agriculture, 1861, the novaculite of Deer Isle is remarked as well worth working. Kennebunk and York also have novaculite, but inferior to the Deer Island variety. Abundant bands of mica schist and sometimes of talcose schist would furnish whetstones in quantity.||

It does not appear that the manufacture of whetstones has ever been established in Maine.

New Hampshire.—According to the records of the Pike Manufacturing Company, which originated in 1827, the whetstone industry began in New Hampshire in 1823. The first stone was quarried at Orford in Grafton county on the shore of a small pond known as Indian Pond, from which comes the name of the brand "Indian Pond"¶ on the scythe-stones best

*Geological Survey of Maine, Jackson, 1837, p. 98.

†Second Report of the Geological Survey of Maine, Jackson, 1838.

‡No. 1497 of Catalogue of Specimens for 1838; Third Report, 1839.

§Geological Survey of Maine, Jackson, Third Report, 1839, p. 27.

||Report of the Board of Agriculture of Maine, 1861, p. 226.

¶The "Indian Pond" stone of New Hampshire should not be confused with the "Indian Pond" stone of Rhode Island. The latter is not now commonly known in the market.

known in this country. Since that time some twenty or more quarries have been worked at different times in the towns of Haverhill and Piermont in Grafton county. The product has been almost exclusively scythe-stones, though a quarry of very fine grained stone called "chocolate," opened about 1840 at Lisbon, has been used for oilstones to some extent. All these stones are mica schists; but four quarries exclusive of the chocolate stone are now worked in Grafton county.

The first mention of New Hampshire stones in literature is found in the Geology of New Hampshire, by Jackson, 1844. This allusion reads as follows:

"Novaculite is quarried for oil-stone at Littleton and brings 25 cents a pound. The ledge affords several varieties of hone slate of various degrees of hardness and fineness. The blue kind, argillite, is the softest, but not in so good repute as the greenish and buff-colored stones. The novaculite is regularly stratified."* This mention noticeably refers to slates called novaculite; and the manufacture of the mica schist stones is not recorded.

Hitchcok speaks† of quarries of whetstones in Piermont and Haverill, and oilstone at Littleton and at the north base of the Ossipee mountains.

The stones mentioned above are all mica schists, but among the specimens at the National Museum is a stone from Tamworth, almost black in color, which looks like true novaculite.

Large quantities of the mica schists are still quarried and manufactured into scythe-stones, axe-bits, and whetstones at Pike Station. This is the commercial center as well for the various stones quarried in Vermont, and the Pike Manufacturing Company located here is one of the most extensive producers of whetstones in America.

Vermont.—Rock suitable for whetstones of various grades is found over a large part of Vermont. The best qualities are found in the middle and northern parts of the state, especially in the vicinity of Lake Memphremagog.

*Geology of New Hampshire, Jackson, 1844, p. 109.

†Economic Geology of New Hampshire, Hitchcock, 1878, p. 92.

The Lake Memphremagog stone was actively quarried about 1820, but lack of good facilities for transportation soon caused the industry to be abandoned. It was revived, however, about 1840, and has been a steady business ever since. The Pike Manufacturing Company now controls these quarries.

The Geology of Vermont* treats of the whetstone formations quite fully. Novaculite slate is said to differ much from clay-slate, being a schist rather than a slate. But "its thickest beds are found in clay-slate, as in Guilford, where the bed is a quarter of a mile in thickness. We have also regarded a rock still more extensive in the northern part of this state as this rock."

A specimen of novaculite from Irasburg, near Lake Memphremagog, is very homogeneous and occurs in talcose schists. The writer here argues from a fancied resemblance between chemical analyses of the Irasburg stone and a hard, compact sandrock, that talcose schist may be derived from the sandrock. A consideration supporting another theory is the interpenetration of the schist and gneiss. These with the origin from clay-slate make three theories for the derivation of novaculite.†

The term "novaculite schist" is introduced on page 510, together with a dissertation on the use of the word novaculite. The writer complains that the word has been misapplied on account of its indefiniteness. "It is regarded as a sort of unknown genus to which everything doubtful can be thrown as to a general receptacle. We understand by the term novaculite what is popularly known as honestone or whetstone; a mineral of perfectly homogeneous but not crystalline structure, with the composition * * * of silica, alumina, and alkalies, not very different from the most homogeneous of talcose schists. It is generally unctuous like talc, and the purest portion of the novaculite would perhaps be called talc were it not too hard. We use the term novaculite schist to embrace all the pure and impure varieties of novaculite in Vermont.

*Hager's Geology of Vermont, Vol. I. 1861, p. 490.

†Loc. cit., p. 506.

They are * * * connected with all the ranges of clay-slate, * * *" as well as with the talcose schists. The definition is somewhat modified to suit the case, for the clay-slate novaculite is not generally unctuous like talc, and unfortunately for the whole supposition a microscopic examination of one of the finest grained stones of the region shows that it is a crystalline schist;* this fact would tend to exclude the greater part of the novaculites of the region according to the definition given.

A new term, "whetstone talcose schist," is coined to apply to an arenaceous variety, almost a sandstone in some cases, which is widely used for the purpose indicated by the name. It is of a light gray color, compact and softer than sandstone.†

On page 721, it is stated that a whetstone quarry which had been opened at Newport, near Lake Memphremagog, was worked with profit for several years.

The novaculite of the clay-slate region is thus dscribed: "At Guilford the clay-slate region is bounded on the west by a bed of impure novaculite, which imperceptibly unites with a calcareous mica schist. The same is true at Thetford, but at Waterford no traces of novaculite are found, but the slate is succeeded on the west by the mica slate, having interstratified beds of siliceous limestone."‡

It has not been learned that these clay-slate novaculites have ever been worked for whetstones; but the tough mica schists have long furnished an abundance of scythe-stones and whetstones. At present the best quarries are controlled by the Pike Manufacturing Company.

New York.—The first item of interest in regard to whetstones in New York state is given by Eaton, who reports:§ "I did not find any good locality of hone-slate or grit sandstone. But such rocks frequently occur in limited patches in various parts of the county."

The Geological Survey of the state made in 1838 developed

*Mineral Resources of the United States, 1886, p. 586.

†Geology of Vermont, p. 511.

‡Geological Survey of New York, W. W. Mather, 1838, p. 162.

§Geological Survey of Rensselaer County, New York, by Eaton, 1821, p. 22.

the extent of this whetrock.* The stone is a modification of the slate rocks and might furnish either fine or coarse whetstones. It occurs at Stuyvesant, Stockport, Greenport, Livingston, Germantown, Clermont, and on Rogers Island. The siliceous slate in which it occurs is common from Kinderhook *via* Hudson to Thompson's Landing below Rhinebeck. It assumes almost every variety from common siliceous slate through basanite or touchstone, to honestone and petrosilex. There is not demand enough for the basanite to justify any exploration for it.

The Survey of 1841 reports that some of the grit rocks of the Catskill series are adapted for grindstones and whetstones;† and in part 14, p. 316 of the Report for 1843, it is noted that rocks of the Catskill group have furnished whetstones at Monticello, on both branches of the Delaware, and on the Beaverhill and Willewoemack River.

No mention is made in the Mineral Resources of the United States for 1887 of any of the above mentioned stones. A fine homogeneous sandstone has been worked, however, for ten years on the shore of Labrador Lake in Courtland county and manufactured at Manlius station. This is a hard, tough sandstone of keen grit, particularly suitable for glass-workers' and carvers' files, since it does not break easily. It occurs in abundance interbedded with green shales.

Pennsylvania.—Oley in Berks county, the locality mentioned in Cleveland's mineralogy, is not referred to in the reports of the Geological Survey of Pennsylvania, though several others are given.

Chloritic schists impregnated with fine sand and a series of beds of black decomposed sandy slate are found in Hayes' whetstone quarry on the Newlin township line in Chester county.‡

Whetstone schists compose a variety in the middle or micaceous belt of Chester county. These are greatly developed

*Geological Survey of New York, 1838, p. 791.

†Geological Survey of New York, W. W. Mather, 1841, 77.

‡Second Geological Survey of Pennsylvania, Report C4, 1883, p. 314.

along the northern rim of the belt in the interval between the soapstone and the hard feldspathic gneiss of the northern belt. This variety is a more schistose, gray, fine-grained mixture of granular quartz and minute mica scales, a kind of whetstone, many layers breaking up into long narrow pieces, with smooth sides and very ragged ends like rotten wood. "Towards the middle of the syncline these whetstone schists are interstratafied with more or less frequent and thick bodies of the twisted mica schists full of garnets. Towards the northern side they alternate somewhat with the greenish talc-slates, *i. e.*, talc replaces mica in some of the layers."*

Gray, slaty mica schists occur in abundance in Delaware county and have been quarried for whetstone in several places. Micaceous gneiss and feldspathic micaceous gneiss suitable for whetstones, occur in several places, and have been quarred to some extent.† The stone from Darby creek in this region seems to have gained considerable reputation, for the name Darby is still used to indicate a commercial variety of scythestone, though the original locality is not worked. Specimens of mica schist whetstones from different localities in Pennsylvania are exhibited in the National Museum. No mention is made of these whetstones in the Mineral Resources of the United States, so the production has probably ceased.

Michigan.—Foster and Whitney record the occurrence of novaculite‡ on the northern peninsula of Michigan near where the town of Marquette now stands. The description is: "Portions of these slates take into their composition minute particles of quartz, forming novaculite. The beds at L'Anse afford very good whetstones, but are too coarse to produce a fine edge on razors, surgical instruments, etc. The novaculite however, of Carp river, is superior to any article which has fallen under our notice, not excepting the Arkansas, Turkey or Scotch stone, for producing fineness of edge." This stone is suitable for engravers' use; the coarser materials for scythe-

*Op. cit., p. 51.

†Second Geological Survey of Pennsylvania, Report C5, 1885, pp. 50, 53, 84, 87.

‡Report on the Lake Superior Region by Foster and Whitney, 1851, p. 83.

stones are also abundant. The novaculite is found along the valley of the Carp, between Jackson Forge and Teal Lake. A factory had been started in 1851 near Marquette Landing. The stone contained a good many flaws, but the manufacturers hoped to find improvement on going deeper into it.

This stone is mentioned again in the Mineral Statistics of Michigan for 1879, pp. 13, 43, where it is stated that there has been no manufacture of whetstone for some time. It was not sufficiently profitable at the beginning of the enterprise. The quality of the stone is said to be excellent; the reason given for the cessation of manufacture is that few men know enough about the business to undertake it.

In the shales of Huron county occur bands of bluish, fine-grained, somewhat argillaceous sandstone, which have been manufactured into whetstones at many places.* At Grindstone City in this county the Cleveland Stone Company now manufactures 7000 gross or more of scythe-stones per annum from this material.

Indiana.—About 1850 some surveyors discovered a good whetstone at a place called Hindostan Falls in southern Indiana and soon after exploitation began.

The industry proved profitable and further search in the surrounding country revealed many other ledges. Numerous quarries have been worked, but those near French Licks and Orangeville have proved the most profitable and are the only ones worked at the present time.

At the time of the first Geological Survey of the state by Owen in 1859 and 1860, several quarries were worked in Orange county for whetstones. The finished whetstones brought 6 cents a pound.†

At present (1890) there are but four quarries of Hindostan stone worked; competition is so sharp, however, that prices average only about two cents a pound for the finished stone, though some special kinds bring 10 cents a pound. The stone is a fine-grained homogeneous sandstone. It was thought that

*Geological Survey of Michigan, 1860.

†Geological Reconnoissance of Indiana, D. D. Owen, 1859-60, p. 144.

the Hindostan stone was identical with the oilstone of Arkansas, since the geological age was supposed to be about the same, and also because the Arkansas stone was thought to be an altered sandstone.* Both these suppositions are now disproved. The Hindostan is a good cheap stone and the demand for it is large.

Missouri.—Micaceous sandstone found in Randolph county, Missouri, was locally used for whetstones between 1855 and 1871.† Sandstone of Carboniferous age was also used locally in Barton and Madison counties in 1873 and 1874.‡ In Madison county, stone of particularly good quality came from F. O'Bannon's quarry.

A fine-grained yellow sandstone found near Pierce City has had for many years a local reputation as a whetstone. Within a few years it has been shipped east in small quantities and manufactured into whetstones; but recently a stock company has erected a factory at Pierce City, and is putting the stone on the market under the name of the Adamascobite grit. The quarry is about five miles from Pierce City in a rolling prairie country. The sandstone is overlain by chert. A thickness of twelve feet has been exposed without reaching the base of the stratum. Some of the stone is hard, but only the soft kinds are used. It is easily cut with a knife and so wears away rapidly. Thus far, it has not been necessary to resort to blasting in getting out the stone. The ledge has been uncovered for about 100 feet and will run much farther, so there is an abundance of the stone.

Dakota.—Whetstone is found in Custer and Fall River counties, Dakota, near Buffalo Gap (Cretaceous); and in Pennington county near Tigerville (Archean).§ It is not quarried at present.

Canada.—The Geological Survey of Canada has reported good whetstones in many localities. Few have been worked,

*Geological Survey of Indiana, E. T. Cox, 1875, p. 232.

†Geological Survey of Missouri, G. C. Broadhead, 1855-71, p. 108.

‡Geological Survey of Missouri, G. C. Broadhead, 1873-74, pp. 115 and 371.

§Mineral Resources of the United States, 1887, p. 718.

however, on account of the poor facilities for transportation.

The manufacture of coarse whetstones from the Clinton formation was reported; also from the fine-grained sandstone of the Hudson River group.* At Ottawa, carpenters used stones from the sandstones of the Chazy formation. Formerly they were made from the mica schists of the Laurentian. A finer stone is found in many places among the greenish siliceous slates of the lower Huronian. A locality of this kind occurs on Ottertail Lake on the Thessalon River. There are many good localities of a very fine-grained micaceous rock in the vicinity of Lake Memphremagog, near the Vermont line.

Hard shaly sandstones are found on the point of Big Island, west of Smashem Head, and have a local use at Merigomish as scythe-stones.† At St. Mary's Bay, one and one-half miles below Sherbrooke, whetstones have been quarried from some of the bluish-black layers of graphitic slate and sent to the United States.‡ The last two localities are in Nova Scotia, where other localities are also reported.§ Thus scythe-stones made from a sandstone having an argillaceous cement, frequently micaceous, at the Joggins, Parrsboro, Colchester county, Pugwash, Pudsley, and various points in Cape Breton, are used both locally and abroad. The exports were not great; the returns of the "Mines Department" gave the exports of scythe-stones for 1875-76-77 at $8,894. A large part of the exports were to the United States, and the abolition of the United States tariff on whetstones was of considerable benefit to the eastern Canadian Provinces.

Siliceous strata, suitable for honestones, are noted as occurring in the Upper Silurian of Cape Bon Ami, near Dalhousie.|| A siliceous band of very fine texture, admirably adapted for the manufacture of honestones, is found above the Narrows of

*Geological Survey of Canada, 1843-63, p. 809.

†Geological Survey of Canada, 1886, p. 126, P.

‡Op. cit., p. 163, P.

§Report on the Minerals of Nova Scotia, 1880, p. 155; 1882, p. 14.

||Geological Survey of New Brunswick, 1864, p. 128.

the Tobique, about five miles from the river mouth, in Upper Silurian strata.*

The talcoid slates of Sound Island appear in some parts of their distribution to contain a material well adapted for whetstones or hones.† If the rock proves to be of as good quality as those of Eastern Canada, it can be found in Sound Island in inexhaustible quantity.

American nomenclature.—The confusion in the use of terms has not been so great in the American literature of whetstones as it has been abroad. The word novaculite has been used in this country almost exclusively as a scientific term, and, as a rule, correctly; still, the misapplication of the word in European literature has had its effect here, for we find it used to include mica schist, talcose schist, slates, and even sandstones. Later writers, as Hitchcock says, have avoided the word. This was natural, since in the old usage it improperly denoted a mineral species. As a lithological term it is perfectly legitimate, and if understood, would undoubtedly be of common usage in geological literature.

Whetstones in past and present literature.—In reviewing the whole history of whetstones the most striking thing is the much greater length at which the subject is treated by the older writers. There seem to be several reasons for this. In the first place the whetstone was one of the early links binding science and the general industries together, for it was of both scientific and economic interest. Then it was one of the comparatively few things of which the early mineralogists could treat; so it received a much larger share of attention than during recent years. Finally there has been less need of finding more whetstones in later years, both because the old localities furnished a large supply and because the increased facilities for cheap transportation made it possible to distribute widely good whetstones at a low price, so making the existence of many scattered quarries for local use unprofitable and needless.

*Geological Survey of New Brunswick, 1864, p. 131.

†Geology of Newfoundland, 1868, p. 179.

CHAPTER III.

The Geographic Distribution of Rocks Used for Whetstones.

Africa, Asia and South America.—The history of whetstones has shown that stones suitable for ordinary whetstones are found in abundance in all countries. It is probably a lack of knowledge rather than any actual want of the stone which causes the omission of the name of any country of considerable size from the list of whetstone producing countries. Thus we cannot believe that the town of Arsinœ, mentioned by Pliny, is the only locality in Africa where a whetrock is found. Also in South America there must be more than two countries containing whetstones; Peru, having been mentioned previonsly, while Chili is stated in the Mineral Resources of the United States for 1887 to have sent exports of whetstones to the United States for that year to the value of $176. Only four localities have been found in Asia: Persia, mentioned in Chambers' Encylopædia; Urga in China, already noted; Japan, given as an importer of whetstones to the United States in the Mineral Resources of the United States for 1887; and Asia Minor, the source of the Turkey stone.

The exact location of the source of the Turkey stone has not been learned. Pliny's Armenian stone was probably identical with the present Turkey stone, but where was his Armenia? There has been a general agreement among later writers that this stone comes from the interior of Asia Minor and is brought to Smyrna for sale. The specimens in the National Museum, however, are recorded as coming from Syria, Turkey.

Europe.—Europe and North America, in contrast with Asia, Africa and South America, abound in various kinds of abrading stone. The great abundance of the stone makes it un-

profitable to work except in the localities most favored in respect to the quality of the stone, the quantity and ease of attainment, the commercial location, and means of transportation. On account of these limitations there are but few localities which have more than a local reputation for whetstones, and in the majority of cases the stone though suitable is not worked. It is noticeable that almost every nation has within its territory its own supply of coarser whetstones.

The Russian supply of whetstones is derived from the rocks on the west side of the Ural Mountains, particularly at Sariu, near the Petchora River in northeastern Russia.

Austria is well supplied with whetstones. Linnæus mentions Transylvania among his localities; Brongniart gives Bohemia; Blum notes Salzburg; and Chambers' Encyclopædia enumerates Styria among the countries producing honestones. Styria was known also to Brongniart.

Switzerland produces whetstones, though the quarries are not counted among the successful mines of the country. In the report on the Swiss National Exposition at Zurich held in 1883, whetstones are noted from three places in Schwytz canton and two in Fribourg; at three of these places there are quarries, and the other two are called small deposits.

Water stones were obtained in Italy in the time of Pliny. Lombardy, noted by Bomare, is still a producer of whetstones. The Mineral Resources of the United States for 1887, records the importation into New York for that year of Italian whetstones to the value of $348.

Razor hones were found in Spain in the time of Pliny, and that country is enumerated with other countries producing honestones, in Chambers' Encyclopædia.

The Mediterranean islands, Crete now called Candia, Naxos, and Sicily, as well as Mt. Taygetus in Laconia, Greece, mentioned by Pliny, are not now known as producers of whetstones. The Island of Elba is mentioned by Bomare for its sandstone whetstones. A doubtful locality in the Mediterranean region is given in Knight's Mechanical Dictionary, which notes "a celebrated deposit which exists near Constantinople and has been quarried for centuries." No other mention of this locality has been found, unless the Hællessors (Hellespont?), of Linnæus refers to the place. It is probable that this confusion is a result of ignorance of the location of the Turkey stone.

France does not appear to be so well supplied with whetstones as the other European countries. Bomare mentioned that a fair razor-stone came from Lorraine, the Lotharingia of Linnæus, also that Turkey grit was found between Morlaix and Carhaix in Lower Brittany, now Finisterre; and Beudant noted the use of grits near Paris in the manufacture of tools. The Belgian stone is the one best known to French writers, however, and it is probable that the French people get most of their whetstones from Belgium.

Good whetstones, and in particular razor hones, have been found in several places in southeastern Belgium. In the time of René D'Hauy they came from near Liége; Brongniart, a little later, noted stone from the vicinity of Namur; Salm Chateau, the chief source of the Belgian hone at the present time, was mentioned by D'Halloy; Ottrez and Bihain in the Ardenne region are named by Blum; Zirkel added Petit Sart in Liége; and in the Géologie de Belgique, Stavelot and Salm Chateau are noted.

Twelve dollars worth of whetstones were imported into New York in 1887* from the Netherlands, but it is doubtful whether they were produced in that country.

Germany has numerous localities where whetstone is found. The two principal regions are those of the Harz Mountains and the Thuringian Forest. In the Harz region whetstones are quarried near Zorge and at Lautenthale, according to Steffens; D'Halloy mentions Altenau, and Blum gives in addition Lerbach. The Thuringian region may be regarded as including Lauenstein in Meiningen, mentioned by Linnæus, and apparently the best known of the German localities; Sonneberg in Meiningen given by Steffens; Probstzelle and Lichtetanne in Saalfeld, Meiningen recorded by Mohs; and Katz-

*Mineral Resources of the United States, 1887.

hutte noted by Zirkel. In the southeastern part of Prussia are Reichenstein in Breslau, noted in the Taschenbuch for 1818, and Kupferberg in Silesia, according to Blum. Other localities are Seifensdorf and Freyberg in Saxony (Brongniart); presumably Nuremberg in Bavaria, since Beudant wrote of the "Nuremberg stone," without giving any locality, and Hesse (Hassia of Linnæus). Linnæus mentioned in addition several countries, presumably in Germany, whose locations are doubtful. They are Megalopolitane Ducatu (Duchy), Holsatia, Leodio, Westrogothia, Scania, Polonia, and Lusatia.

Norway and Sweden have long had reputations for whetstones. Bomare mentioned the province of Dalecarlia in Sweden, and the town of Boda at the northern end of the Island of Oeland. Whetstone is found in the parish of Orsa in Dalecarlia according to Wallerius; in addition to these localities Linnæus gave Norway; and the Norway ragstones are well known now, though the exact location of the quarries has not been ascertained.

Numerous localities have been reported in the British Isles, though few have been worked. Keredge, Brownedge and Uttoxeter in Staffordshire, England, furnished sandstones for whetstones according to Kirwan. Blackdown and Penzlewood* near Stourton in Devonshire, as well as Yorkshire† and Fifeshire, also furnish sandstones suitable for whetstones. Scythestones are made in Flintshire, Talacre quarry in Wales, South Lancashire and Derbyshire. Oilstones are found in Charnley Forest, on the Ayr River in Scotland, at Llyn Idwall near Snowdon in Wales, and Tavistock in Devonshire according to Knight;‡ at Bethgellert and Snowdon in northwest Wales, Hestercombe near London, and Truro in Cornwall, according to Woodward;§ and in Ree's Encyclopædia the occurrence of stone is noted at Woodthorp and Codnor, Upper Park in Derbyshire, and at Upper Long Sleddale in Westmoreland.

*Geology of England and Wales by H. B. Woodward, 1887.

†Economic Geology by David Page, London, 1874.

‡Trans. Soc. Arts, London, 1833-35, Vol. L., p. 231.

§Geology of England and Wales by H. B. Woodward, 1887.

The occurrence of honestone at the promontory of Howth in Dublin Bay and near Drogeda, north of Dublin in Ireland, is also mentioned in Ree's Encyclopædia. Other localities in Ireland are Sheep Island, Tullimore Park, Rostrevor and Warrenpoint in county Down, Killicreen in Donegal county and Clare Island in Mayo county*.

Polishing slates.—The polishing slate, which is closely allied to the whetslate, occurs in many places in Europe. Linnæus mentioned Tauna, an island in the Southern Sea (Mediterranean), Naples, Russia on the Uda River, Fedotiewa and Casimova in Sweden, Oudenard in Belgium, near Crems in Austria, near Ditfurt in Bavaria, near Calw in Wurtemberg, Schillingsfurst in Bavaria, Potschappel and Naumberg in Prussia, Furstemburg and Duisburg in Westphalia Circle, Grunsberg and Darmstadt in Hesse and near the walls of Francofurtum. He also gives Tunis in Africa. Bilin in Bohemia and Zwickau in Saxony are given by Jameson; Habichtswalde in Hesse, by Hartmann; Ratisbon in Bavaria, by Knight; and by Blum, Kassel in Hesse, Planitz in Saxony, Menat in Auvergne, France, with Oran in Algeria, Africa.

Australia.—No mention has been made in Australian scientific works of the occurrence of whetstone in that island, but the importation into New York of Australian whetstone to the amount of $175 is recorded in the Mineral Resources of the United States for 1887.

Canada—Canada has an abundance of whetstones, both coarse and fine, and has exported considerable quantities to the United States. Nova Scotia and New Brunswick lead in the production of whetstones. They are manufactured at the Joggins,† Parrsboro, in Colchester county, Merigomish, Pugwash,‡ Pudsleys, and at various points in Cape Breton. The Geological Survey of New Brunswick for 1864 reports good honestone at Cape Bon Ami near Dalhousie, and above the narrows of the Tobique about five miles from the river mouth.

*Catalogue of Minerals of Royal Dublin Society, 1832.

†Report on the minerals of Nova Scotia, 1880.

‡Report on the minerals of Nova Scotia, 1882.

Scythe-stones for local use are obtained on the point of Big Island west of Smashem Head, Nova Scotia, and whetstones have been exported from St. Mary's Bay, one and a half miles below Sherbrooke.* The rocks of South Island, on the west coast of Newfoundland, are reported to abound in good whetrock.†

In the eastern townships of Canada, near Lake Memphremagog, good whetrock has been noted in several places. A band of very fine-grained micaceous rock yielding good whetstones in many places, has been traced from Whetstone Island in Lake Memphremagog, by Lee's Pond to the head of Massawippi Lake in Hatley, twelve miles. Whetstones are also found in the fourth lot, ninth range of Stanstead, on the twenty-third lot, sixth range of Bolton and the seventh lot, second range of Kingsey. A range of slates suitable in some parts is found on each side of the valley from Melbourne to Danville; and slates on the ninth lot, range eighteen, of Orford, have yielded a very fine honestone.‡

The region of the Ottawa River furnishes whetstone at Nottawassaga, Collingwood, Whetstone Point on Chaudiére Lake, Sheriff's Mills at the Chats, the Allumette, Falls and Ottertail Lake, on the Thessalon River.§

Mexico.—Whetstones to the value of $19 were imported into New York from Mexico in 1887.|| This is the only notice which has been found of stone from that country.

United States.—The occurrence of whetrock in the United States is presented in the table below.

Since almost all the localities given in this table are mentioned in the chapter on the history of whetstones in North America, the authorities are not cited here, but may be found by turning to Chapter II. New localities given in this table will be found in the works already cited, of those states in

*Geological Survey of Canada, 1886.

†Geology of Newfoundland, 1868.

‡Geological Survey of Canada, 1843–63, p. 809.

§Geological Survey of Canada, 1843–63, p. 809.

||Mineral Resources of the United States, 1887.

which the localities are found. When no quarry has been noted at a locality it is regarded as not worked, and the column of exploitation is left blank. When more than one quarry is at present worked, the number of quarries is indicated by an index figure in the column of location. Very often the geological horizon in which the whetrock occurs has not been mentioned by the author, consequently many determinations in the column showing the age of the rocks are only approximate.

Table Showing the Occurrence of Whetrocks in the United States.

State.	County.	Locality.	Exploitation.	Geological Horizon.	Kind of Rock.
Alabama	Walker	Eldridge	Before 1884–1890	Carboniferous	Sandstone.
Arkansas	Garland	Hot Springs	Before 1818–1890	Lower Silurian	Novaculite.
	Hot Spring			Lower Silurian	Novaculite.
	Howard			Lower Silurian	Novaculite.
	Montgomery			Lower Silurian	Novaculite.
	Pike			Lower Silurian	Novaculite.
	Polk			Lower Silurian	Novaculite.
	Pulaski			Lower Silurian	Novaculite.
	Saline			Lower Silurian	Novaculite.
Dakota	Custer	Near Buffalo Gap		Cretaceous	Sandstone.
	Pennington	Tigervillle		Jura Trias?	Schist?
Georgia	Heard			Huronian?	Novaculite.
	Lincoln	Lincolnton		Huronian?	Novaculite.
	McDuffie			Huronian?	Novaculite.
	Merriwether			Huronian?	Novaculite.
	Oglethorpe			Huronian?	Novaculite.
	Troup			Huronian?	Novaculite.
Indiana	Orange	French Licks 9	1840?–1890	Carboniferous	Sandstone.
	Orange	Orangeville 2.	About 1840–1890	Carboniferous	Sandstone.
Indian Territory	Choctaw Nation			Silurian	Novaculite.
Maine	York	Kennebunk		Cambrian	Novaculite.
	Franklin	Phillips		Silurian	Novaculite.
	Franklin	Temple		Silurian	Novaculite
	Hancock	Little Deer Island		Huronian	Serpentine novaculite.

Table Showing the Occurrence of Whetrocks in the United States—Continued.

State.	County.	Part of County.	Exploitation.	Geologic Horizon.	Kind of Rock.
Maine	Hancock	Western Island		Huronian	Serpentine novaculite.
	Washington	Nutters Head		Silurian ?	Sandstone.
	York	York		Cambrian	Novaculite.
Maryland	Anne Arundel or Prince George	Patuxent River near Washington's Road.		Cambrian	Novaculite.
Massachusetts	Essex	Nahant		Silurian	Novaculite.
	Hampshire	Cummington	1830–1890	Cambrian	Schist.
	Hampshire	Enfield	Before 1832–1841+	Lower Silurian	Mica schist.
	Hampshire	Norwich	Before 1832–1833	Lower Silurian	Mica schist.
	Middlesex	Cambridge		Lower Silurian	Novaculite slate.
	Middlesex	Charlestown		Lower Silurian	Novaculite slate.
	Middlesex	Concord		Lower Silurian	Novaculite slate.
	Middlesex	Malden		Lower Silurian	Novaculite slate.
	Norfolk	Bellingham	1838–1841+	Lower Silurian	Mica schist.
	Norfolk	Dedham		Lower Silurian	Novaculite slate.
	Norfolk	Milton		Lower Silurian	Novaculite slate.
	Norfolk	Quincy		Lower Silurian	Novaculite slate.
	Suffolk	Brighton		Cambrian and Silurian	Novaculite slate.
	Suffolk	Brookline		Cambrian and Silurian	Novaculite slate.
	Suffolk	Dorchester		Cambrian	Novaculite slate.
Michigan	Baraga	L'Anse	?	Huronian	Novaculite slate.
	Huron	Worked at many places	1860 ?	Lower Cambrian	Argillaceous sandstone.
	Ontonagon	Carp River, Teal Lake.	1851 before 1879	Huronian	Novaculite slate.
Mississippi	Tishamingo	Big Bear Creek		Carboniferous	Sandstone.

Table Showing the Occurrence of Whetrocks in the United States.—Continued.

State.	County.	Part of County.	Exploitations.	Geological Horizon.	Kind of Rock
Missouri	Barton	In many places	Used locally before '73–4	Carboniferous	Sandstone.
	Lawrence	Pierce City 1	1889–1890	Lower Carboniferous	Sandstone.
	Madison	Y. O'Bannon's quarry	1873	Lower Carboniferous	Sandstone.
	Randolph	In many places	1855–1871	Lower Carboniferous	Mica sandstone.
New Hampshire	Carroll	Tamworth		Silurian	Novaculite.
	Grafton	Haverill 2	1830–1890	Huronian	Mica schist.
	Grafton	Lisbon ?	1840–1880	Huronian	Mica schist.
	Grafton	Littleton ?	1844–1890	Silurian	Mica schist.
	Grafton	Piermont ?	1830–1890	Silurian	Mica schist.
New York	Columbia	Clermont		Silurian	Novaculite slate.
		Germantown		Silurian or Cambrian	Novaculite slate.
		Greenport		Silurian or Cambrian	Novaculite slate.
		Livingstone		Silurian and Cambrian.	Novaculite slate.
		Rogers Island		Silurian and Cambrian.	Novaculite slate.
		Stockport		Cambrian	Novaculite slate.
		Stuyvesant		Silurian or Cambrian.	Novaculite slate.
	Cortland	Labrador Lake	1880–1890	Silurian	Sandstone.
	Delaware	Monticello		Devonian	Sandstone.
	Delaware	Beaver Kill River		Devonian	Sandstone.
	Rensselaer			Silurian	Whetslate.
North Carolina	Anson	Wadesborough		Huronian	Talcose novaculite.
	Chatham	5 miles W. of Woodin's Ferry on How River		Huronian	Talcose novaculite.
	Orange	Near Chapel Hill		Huronian	Talcose novaculite.
	Person	Roxborough		Huronian	Talcose novaculite.
	Randolph	Near Deep River		Huronian	Talcose novaculite.

Table Showing the Occurrence of Whetrocks in the United States.—Continued.

State.	County.	Part of County.	Exploitation.	Geological Horizon.	Kind of Rock.
North Carolina	Randolph	Barbee's Mill		Huronian	Talcose novaculite.
Ohio	Cuyahoga	Berea	1873-1890	Carboniferous	Sandstone.
	Lorain	Amherst	1873-1890	Carboniferous	Sandstone.
	Hocking	Hocking River		Carboniferous	Sandstone.
	Summit	Manchester	1887-1890	Carboniferous	Sandstone.
	Trumbull	Farmington		Carboniferous	Sandstone.
	Trumbull	Mesopotamia		Carboniferous	Sandstone.
Pennsylvania	Berks	Oley	1822-?	Lower Silurian	Sandstone.
	Chester	Newlin Township Line	1883, before 1887	Cambrian	Mica schist.
	Chester	Middle of County		Cambrian	Mica schist.
	Deleware	Avondale	1885, before 1887	Cambrian	Micaceous sandstone.
	Delaware	Darby Creek	1836, before 1887	Cambrian	Micaceous sandstone.
	Delaware	Marple, Township 2	1885, before 1887	Cambrian	Micaceous sandstone.
	Delaware	Springfield	Before 1885	Cambrian	Micaceous sandstone.
	Delaware	East of Swathmore	1885+	Cambrian	Micaceous sandstone.
Rhode Island	Providence	Smithfield	Before 1835	Cambrian	Micaceous sandstone.
	Providence	Woonsocket	Before 1814–1840+	Cambrian	Mica schist.
South Carolina	Abbeville			Huronian	
	Chester	Turkey Creek		Huronian	
	Edgefield			Huronian	
Tennessee	Knox	Knoxville	1818+	Carboniferous	Sandstones.
Vermont	Franklin	Berkshire		Huronian	Mica schist.
	Franklin	Fairfield		Huronian	Mica schist.
	Orange	Thetford		Cambrian	Novaculite slate.
	Orleans	Brownington 4	1840–1890	Cambrian	Mica schist.

Table Showing the Occurrence of Whetrocks in the United States.—Concluded.

State.	County.	Part of County.	Exploitation.	Geological Horizon.	Kind of Rock.
Vermont	Orleans	Trasburg		Cambrian	Mica schist.
	Orleans	Newport	Before 1861	Cambrian	Mica schist.
	Washington	Northfield	1861	Huronian	Talcose schist.
	Windham	Guilford		Cambrian	Novaculite slate.
	Windham	Marlborough		Cambrian	Novaculite slate.
	Windsor	Ludlow	1861	Huronian	Mica schist.
	Windsor	Plymouth		Huronian	Mica schist.
	Windsor	Stockbridge	1861	Huronian	Mica schist.

Conclusions.—The preceding tabular statement brings out the fact that the number of localities where good whetrock has been reported or worked is very large. The whetstone industry cannot be considered a great one, however, for while the whetstone is a common necessity in every household and the most highly prized of the artisan's implements, still, one good stone will last for many years, and a single quarry can provide an immense number of stones annually. Then too, a very large number of whetstones, perhaps the majority, are stones which have been found by the owner, and do not come from a quarry. For these reasons an ordinary whetstone is very cheaply bought, so that only those quarries which produce stones of good quality with the greatest advantages for manufacture and for shipment can survive the competition in the business.

It will be noticed that over half the localities enumerated have been classed as not worked; that is, no quarry has been started there with a view to putting the stone on the market. Some have furnished, and continue to furnish, whetstones for local use only. A considerable number have had widespread reputations, in times past, but have been abandoned because other, and generally better, stones have been found elsewhere and manufactured at a lower cost. At the present time there are about five or six quarries in the United States which have only local reputations, and a dozen localities which furnish whetstones for more than local use; not more than two or three of these are known abroad.

It is noticeable that the whetstones come from the very old rocks; no stone in this country which has been rightly denominated a novaculite occurs above the Silurian strata. The stones of Carboniferous and Cretaceous age used for whetstones are, except in the Rhode Island locality, sandstones. The highly metamorphosed rocks of very great age are the ones found to contain the kind of stone best adapted to the the finer abrading purposes. It would seem from this that metamorphism produces a finer-grained and more homogeneous rock than simple sedimentation.

The geologic ages to which the various whetstones belong have not been ascertained so accurately for foreign countries as for the United States; but so far as learned, the Russian whetstone, placed by Murchison in the Carboniferous, is the only fine-grained whetstone above the strata of Silurian age, which has been noted or worked. Sandstones from the Carboniferous or Cretaceous are very commonly known, however.

Volcanic rocks have not proved suitable for abrading purposes, and no instance has been found of a whetstone made from an igneous rock. Pumice, however, is well known as a scouring and polishing material.

Since the sedimentary rocks to which grit rocks seem to be limited, are so universally distributed, it is hardly possible to conceive a country of any size which does not have a supply of some kind of whetstones within its borders. So it is very probable that many foreign locations have not been noted at all by the various writers, especially since whetstone is so insignificant commercially; however, the localities named in the above chapter include those best known.

CHAPTER IV.

The Methods of Using Whetstones.

The whetstone is so common an implement that its most obvious qualities and uses are well known to everybody, yet there are few persons who understand selecting stones, know what to expect of a stone, or how to take care of one. It is from its commonness and apparent simplicity that it is generally passed over without thought, when a little attention to the subject would save time, money, and energy.

It is a usual mistake in choosing a whetstone to try to get one which will answer many purposes. This is manifestly wrong, for a stone with a coarse grit will never produce a fine edge, a fine-grained stone is suitable only for finishing, while the stone of medium grit will be found unsuitable for either rapid or fine work.

Effect of the size of grit grain.—Before making suggestions in regard to the purchase and care of stones the mechanical properties of the different kinds of grit-stones should be considered. It has already been said that the sharpening qualities of whetstones depend on their ability to scratch off particles of metal from the implement which is being sharpened. The grains of grit may be regarded as sharp teeth, which are of comparatively large size in stones of coarse grit and very small in those of the finest grit. In coarse stones the spaces between the cutting points are so large that the scratches made on a steel tool are comparatively far apart; the large points also make deep scratches; so for these two reasons, because the furrows are both far apart and deep, it is not possible to obtain a fine edge with a coarse stone. The fine-grained stone on the other hand shows small particles of grit crowded closely together, so closely that each grain can make but a very tiny scratch and the furrows are so close together

that the eye cannot distinguish them, and the result is a polished surface. These little grains, however, cannot work rapidly, and for this reason the amount of work given them should not be large; it is therefore advisable to sharpen a tool as well as possible on a coarse whetstone before using a fine one.

Since both rapidity and fineness of abrasion depend on the diameters of the cutting grains, a comparison of the effectiveness of two stones can be made, provided the average diameters of the grain are known. The diameter of each scratching grain influences the distances of its next neighbors' furrows from its own, and thus also the size of the furrows according to the size of the grain, which depends upon the three dimensions necessary to express solidity; thus the effectiveness of two stones will be as the cubes of the average diameters of the grains. A stone with grains of an average diameter of 1 will abrade steel one-eighth as fast as a stone having grains of twice that diameter, but on the other hand its work will be eight times as fine; supposing of course that the grains of each stone are uniformly 1 and 2 in diameter.

Effect of form and mineral composition.—There are other things than the mere size of the abrading grains to be considered before it can be decided what the properties of a whetstone are. Thus the grains should be uniform in size in fine stones, for many large grains among the fine ones will make it impossible to produce a fine edge, even though the majority of grains are fine. The grains must be angular, or they will not scratch; it is the rounded character of the grains which causes some stones to glaze after a short usage. The presence of foreign matter between the abrading grains has considerable influence, since by the separation of the grains the scratches are too far apart. Thus of two stones of equally fine grain the one having the smaller amount of foreign matter will do better work, other conditions being the same. A final consideration is the hardness of the stone, depending both on the structure and on the material. In all but a few cases the abrading substance is silica, though its form is different in the various kinds of whetstones. Thus in sandstones it is in rough, irregular grains, in schists in irregular massive grains which scratch by means of angles and points; or it may be in the form of minute angular grains as in the Arkansas stones. These are all anhydrous forms of silica, yet it does not follow that the stones of this single form of silica are of equal hardness, for the hardness is determined by the manner in which the particles are joined together.

Effect of structure.—Particles may be consolidated, first, by a simple jamming together to form hard rocks, with or without the addition of earthy material; second, the particles may be cemented together, also with or without other mineral matter; third, they may be both jammed and cemented together. The shoemakers' sandstone seems to be a good example of a stone composed almost entirely of siliceous particles slightly pressed together, while the Adamascobite grit illustrates the same structure with the addition of a large amount of earthy matter. The Arkansas stone is a fine example of one in which the pressure has been great with no extraneous matter. The Hindostan and Labrador stones are good instances of stones in which cementation is the important factor in consolidation, though both have been subject to pressure also. The Labrador stone has a strong cement and little earthy matter, while in the Hindostan stone the cement is weaker and the quantity of earthy matter is greater. In both these cases the cement is iron; frequently, however, it is silica as in the case of some hard sandstone scythe-stones. When the amount of siliceous cement is large the stone has a tendency to glaze, as in quartzites. The schists used for whetstones may be regarded as both jammed and cemented.

The rapidity of wearing away of the whetstone in use depends on its structure. It might seem on first thought that the tool should wear away faster than the stone, since the stone contains the harder particles; but this should not be the case in any instance, for when the wear on the stone is less than the wear on the steel, the stone becomes glazed. The glazing may be caused by the scratching points becoming worn away and smooth, a condition more likely to happen

with a coarse-grained, strongly cemented stone; or it may be caused by the filling in of the spaces between the grains by particles of metal so that the stone loses its scratching power; or it may be caused by a combination of both processes. In the last two cases the earthy matter present in the stone hastens the filling of the spaces. Hard, fine-grained stones are the ones more likely to glaze from the second and third causes. Arkansas stone often furnishes an example of this when improperly used. Glazing may be caused also by the use of poor lubricants, with perhaps one of the above mentioned conditions combined. This will be considered in explaining the use of lubricants.

The reasons why the whetstone should wear away faster than the steel are easily understood. There must be a constantly renewed supply of scratching points, and this supply can only be renewed by loosening and rubbing out the grains on the surface of the stone. The ease with which a stone wears away is the final consideration which determines to what uses it is adapted. Fast wearing or "fast cutting" stones, as they are called in the trade, may be used for all sharpening purposes, provided the character of the grit is right, but their use is not always economical: for example, a narrow chisel or an engraver's tool would cut a soft stone to pieces in a short time. The Belgian hone and the shoemakers' sandstone are the best examples of fast cutting stones, and from their use it has been learned that fast cutting stones are best suited for sharpening broad edges held very flat, and usually moved backward. The wearing should be rather slow, so the two stones mentioned above are extreme cases when considered from the standpoint of ordinary use. Fast wearing indicates waste of the stone, while slow wearing will soon glaze it. Thus we see how the quality of a stone depends upon its structure, the strength of its cement when it has one, and the existence of extraneous matter cohering sufficiently to hold the abrading grains, and yet allowing them to wear away with sufficient rapidity to expose new grains.

Sandstones.—When the structure, firmness of grain, etc., are known, it is easy to understand what the properties of a given stone are, and to what uses it is best adapted. Almost all sandstones are good abraders, provided their cement is not too strong, but the grit is usually too coarse for any except the coarsest whetstones or scythe-stones, though even these coarse whetstones may be used to advantage to prepare an edge just from the grindstone for a finer whetstone. The presence of earthy or mineral matter in sandstones may be beneficial or injurious; a little increases the solidity of the stone, and assists in producing a finer edge than the clear grit would give, while much earthy material interferes with the free abrasion by the silica grains and injures the stone. The qualities of coarser sandstones are more easily judged than those of the finer ones. Of the latter class there are three found in the United States, which have more than local use, the Labrador, Hindostan and Adamscobite stones.

The Labrador stone.—The Labrador stone is the coarsest and also the hardest of the three. The grains of silica average about .05 of a millimeter in diameter; in the sandstone scythe-stone they are perhaps .2 of a millimeter in diameter. The fineness of the work done is not directly proportional to the diameters of the grains, but rather to the cubes of their diameters. From this we find that the Labrador stone does work sixty-four times as fine as a common scythe-stone, that is, it will produce sixty-four furrows or scratches to one of the other stone. The diameters of the grains in Hindostan and Adamscobite stone is only .02 of a millimeter; thus their fineness is more than 15 times that of the Labrador stone. The Arkansas stone, with grains less than .01 of a millimeter in diameter, is more than eight times as fine as Hindostan stone, more than 125 as fine as the Labrador stone, and more than 8000 times as fine as sandstone scythe-stone. The Labrador stone does not therefore give a fine finish, though it improves greatly on a rough scythestone edge, and gives a good cutting edge for some kinds of work. The strength and resistance to wear of this stone are important factors; so we have here a strong, slowly wearing stone of grit about medium in fineness. It is a

handsome stone and is admirably adapted in every respect for kitchen stones. Its strength and sharp grit give it use in the form of files, though unless the wear is hard it soon fills up and becomes glazed. It can well be employed as a whetstone for tools which are applied with considerable pressure and do not require very fine edges, or as an intermediate stone before using Arkansas stone.

Hindostan stone.—The Hindostan stone is softer and finer than the Labrador, and it is therefore a better finishing stone. It is not strong enough for kitchen stones and files, but is better adapted for sharpening the ordinary tools of carpenters and mechanics. Fine tools should not be applied to it, however, for it is easily cut by a narrow edge. The finish given by this stone is good enough for the tools used in ordinary carpentering, but those used in higher grades of woodwork need a finer finishing stone. The low price of the Hindostan stone makes it popular. It is poorly shaped and finished, and this detracts much from its value in the eyes of a good workman. The cause of this is the low price paid the quarry owners for their finished stone. This low price means poorly paid and inefficient labor employed in working the stone, consequently the whetstones are poorly shaped and hastily finished.

Adamascobite grit.—The Adamascobite stone has the same degree of fineness as the Hindostan stone, but it is much softer. It can be used advantageously only with broad-edged tools; it is well adapted to sharpening knives. Edges applied at a sharp angle wear the stone away rapidly, and as the stone is expensive, it is not an economical carpenter's stone. It has a very sharp grit, however, and gives a good edge in a short time. The expense of manufacturing this stone cannot be very much greater than for the Hindostan stone, and if the price were reduced it would doubtless find a ready market. Owing to its quality of rapidly wearing away, it makes a good rough-polishing stone for marble workers.

Schists.—Next to the sandstones the schists furnish whetstones in largest quantity. The range in quality of stones is fully as great as in sandstone, though they furnish more fine-grained stones than the sandstones, and not so many coarse-grained ones. The grit of the schists is not so sharp as that of the sandstones for two reasons: First the form of the grains is different; the sandstone has sharp angular grains, while those of the schists are more massive, tending toward lenticular, and as a rule, do not have such sharp angles. This is because the grains of sililca in a schist conform in a measure to the forms of the other minerals of the rock in which they occur.* Secondly, the schist contains much material other than silica, which prevents the grains of silica from abrading freely. While for these reasons the grit of the schist is not so sharp as that of the sandstone, yet it is often preferred because it gives a finer edge. For the same reasons, in order to do effective work the abrading grains in a schist must be renewed rapidly; in other words, the stone should be a fast wearing one. The necessity of this rapid wearing is not sufficiently recognized as a rule, consequently whetstones made of mica schists very often glaze, sometimes because the manufacturer does not understand his own stone, sometimes because the whetstone has been wrongly used. The tendency to glaze is not so strong in the fine as in the coarse schists. Coarse hard schists will glaze even when used as scythe-stones; they are manufactured, however, because they are stronger than sandstones. The fine schists do much better work than the coarse ones, and from them carpenters' stones are made which give a well finished edge. As they are subject to the defects of a rapidly wearing stone, they are not well adapted to sharpening fine tools, Schist is often a more homogeneous rock than sandstone, having the grains more nearly of equal size, and is less likely to contain hard spots and concretions. From these facts it is seen that the schist is a good stone when a strong, rapidly wearing one is needed. The scythe-stone requires these qualities, and naturally the schist is made very largely into scythe-stones. Its homogenity makes the fine-grained varieties desirable as carpenters' bench-stones for the larger tools. In a few instances

*Rosenbusch's Microscopical Physiography of the Rock-making Minerals, Idding's Translation, 1888, p. 171.

part or all of the abrading power of the schist is due to the presence of hard minerals other than silica; thus in the Belgian hone microscopic garnets do the work of abrasion.

Whetslates.—The whetslates form an important class of stones, though not so well known as the others. They are generally fine stones used as oilstones by carpenters and mechanics, but have been used to some extent as scythe-stones; in the latter use, however, they are too slow in wearing away the steel. The whetslate is more homogeneous and more siliceous than the ordinary slate; it does not show the stratification so plainly, and grades into a rock like novaculite, which shows no internal evidence of stratification. The true whetslate is opaque, while novaculite is somewhat translucent. Novaculite is always very hard; whetslate may be hard or soft. The Water-of-Ayr stone is a soft variety of whetslate, and the German razor hone has the appearance of soft slaty rock. The grains of silica in whetslate and novaculite are of equal size. the difference being that whetslate contains much earthy matter and is not so homogeneous.

Since the development of the Arkansas quarries of novaculite there seems to have been no whetslate worked in the United States, unless the scythe-stones mentioned in Pike's catalogue as quarried at Guilford, Vermont, are whetslates. The whetslates are adapted to finishing edges on tools but not to much else, and as a good quality does not seem to be common, there is no cheap stone which will do the work of the much more efficient novaculite.

Arkansas stone.—The mechanical properties of the Arkansas stone are due to its very fine grain and great hardness. It is so hard that the point of a knife will not scratch it, and the finest pointed tools may be applied to it with strong pressure without danger of injuring the surface. This property makes the stone a valuable one to engravers, carvers, jewelers and dentists. The grains of silica are less than .01 of a millimeter in diameter, and are so densely packed together that they give a maximum effect of fineness; the Hindostan and Adamascobite stones, with grains but little more than twice as large, are considerably more than eight times as coarse because the grains are separated by earthy matter and so cannot accomplish their work of maximum fineness. The fineness of the Arkansas stone, as well as its hardness, makes it valuable to those for whom its hardness is not essential. Where used constantly to sharpen broad edges only, the stone is liable to glaze in a short time, and it should not therefore be used in this way.

Ouachita stone.—The Ouachita stone has grains equally as fine as the Arkansas stone, and so will give equally as fine an edge when properly used; its porous structure, however, renders it unsuitable for fine instruments, but makes it much more effective with larger tools. It is a hard stone but wears away comparatively fast, and both cuts away the steel rapidly and produces a fine edge. Owing to the peculiar cutting property of the edges of the pores this stone,* the finest results will not be obtained by both a forward and backward movement of the tool edge over the stone. With the Ouachita stone the forward movement invŏlves considerable irregular cutting, while the backward movement produces scratches alone; thus a fine edge can be obtained by the backward movement. Since this movement is the one employed in honing razors, the Ouachita stone can be and is utilized as a razor hone; it is better indeed for this purpose than the Arkansas, which will glaze under a honing treatment.

The Turkey stone.—The Turkey stone is so well known, and has so long been the standard of excellence for whetstones, that these descriptions would not be complete without it. Hitherto it has been uncertain to what class of rocks this stone belongs. It has been called a dolomite, but a specimen tested in this Survey's laboratory gave no appreciable amount of magnesia. It surely is not a novaculite, and has been separated from the whetslate by other writers. It might be called a siliceous limestone from its chemical analysis, and there seems to be no strong objection to using this name. The silica is in the form of fine grains of a little more than .01 of a millimeter in diameter, so that in size they are between the

*This is explained under "Structure" in Part II.

grains of the Hindostan and Arkansas stones. There is a little iron and earthy matter in the stone, but its hardness seems to be due chiefly to the interlocking of the grains of silica. The lime is generally in the form of irregular calcite veins, forming flaws in the stone and rendering it liable to break. Like the Ouachita stone it contains some cavities, but they are large and irregularly distributed. The veins of calcite injure the stone for sharpening fine-pointed instruments, since they mar the evenness of texture desirable, and render it liable to uneven wear. Altogether it does not seem that the Turkey stone would do such fine work as the Arkansas and Ouachita stones. It is much cheaper than the Arkansas stone, but not so cheap as the Ouachita. Sometimes, however, Turkey stones are found without the calcite veins; these must be excellent stones, though not so fine as the Arkansas nor so fast cutting as the Ouachita.

The purchase of whetstones.—Now that the properties of the different kinds of stone are understood, some facts for guidance may be given to the purchaser. The use for which the stone is wanted must always be considered carefully, for then the general character of the stone desired is easily decided, and it only remains to find a suitable stone. A few tests to decide what sort of a stone is being offered one by the dealer are often useful. The hardness may be tested with a pocket-knife. If the stone is soft, like the water-of-Ayr stone, the knife edge will cut it easily on its flat sides without injury to the knife; stone of medium hardness, like the Hindostan, will cut on the edges with some difficulty; a hard stone, the Ouachita for example, can be scratched by the knife point; while a very hard stone, like the Arkansas, receives no scratch from the knife point. The fineness of the grit can best be judged by drawing the edge of the finger nail backwards over the stone; the sensation produced indicates well the coarseness of the grit, and a little practice with various stones soon gives one expertness in judging their fineness. The finger nail will tell whether the stone is coarse or contains coarse particles by showing scratches; a fine gritted stone will make no visible scratches. The sharpness of the grit also will be indicated by the amount of the nail worn away.

The general appearance in shape and color also afford valuable means of judging a stone. The sides should be perfect planes, and the angles right angles, though for special purposes the edges may be beveled. Good stones seldom have a poor finish, uneven sides and irregular angles; on the other hand some poor stones are well-finished, so entire dependence cannot be placed on these criteria. The reason why the finish should be a good one, is that a poorly finished stone is very sure to wear unevenly, and as soon as a stone has worn to an uneven surface it ceases to do good work. Soft stones are more liable to an uneven wear than hard ones, but care must be exercised in using hard stones, for when worn unevenly, they give much worse results than the soft ones.

The color also is a good indication of the character of a stone. In a good stone the color should be very even, whatever shade it is; an even color denotes a homogeneous stone. Slight yellowish, reddish or brownish iron stains in light-colored stones are not objectionable, but strongly marked spots or areas indicate a change, generally toward hardness, in the quality of the stone. Stones may also have hard spots which are white. It is difficult to detect these spots when they occur in white stones, especially in the Ouachita stone, since that is whitened artificially by rubbing with pumice. If the pumice is dusted off, however, and the stone wet, the spots appear. These white spots are due to a closer aggregation of the grains of silica. If these spots can be seen at all, they look denser and harder than the groundmass. They are of occasional but not frequent occurrence; so far as known they are chiefly found in the Ouachita stone, though sometimes in the Arkansas. Soft spots have an earthy, soft appearance, and may be tested with the knife. They are more likely to occur in sandstone. Wetting the stone, which is given as a method for detecting the spots, is a good method of showing the character of any stone.

A new whetstone, fresh from the rub-wheel, has the sharpest

"bite" it will ever have. Purchasers should remember this, and not be disappointed because their stones do not cut so well after the slight roughness given it by the sand in grinding has been worn away. Some stones are rubbed with pumice by the manufacturers to make them look whiter and more attractive, and sometimes also to hide defects. The pumice gives to the stones a feeling of much sharper grit than they really possess. Any stone hard enough to be used as a whetstone is too hard to have a natural powder on its surface, so when a powder is found it may safely be set down as artificial. It should be brushed off and the stone examined in its true state.

Having these points in mind, one can safely select a stone for any special use. A stone for general use, however, is the one most commonly in demand, and as there is no stone which will answer all purposes, the whetstone for general use must be a compromise. If the work to be done is usually coarse, a schist or sandstone of medium hardness and fineness is best used. As the Hindostan stone is fine-grained, a sandstone suiting these conditions is not now known in the United States as a whetstone; schists, however are plentiful. For generally fine work a fine schist or sandstone or the Ouachita stone may be used. The schist and sandstone are both good and cheap, with certain advantages favoring the sandstone. The Ouachita stone is more expensive and requires better care than the others, but will also do better work. It will cut steel fully as fast as either of the others, and will give a much finer edge when properly used. It may be used as a razor hone in addition to other uses. Pointed tools cannot be applied to any of these stones without injuring them for ordinary use, and coarse work will injure the fine stones. It is economy for those using the fine stone to use first a coarse sandstone unless the tool is already prepared for the final edge.

A dull tool with a notched edge should no more be placed on a good whetstone, than a carpenter's chisel should be used to drill rock; yet such a use of whetstones is a common one. The purpose for which a whetstone is bought should be kept in mind, and it must be remembered that if used for purposes widely different from those for which it is best adapted, the stone will be spoiled for its ordinary work. For this reason it is economy to have stones of different grades wherever tools are in constant use, as in carpenter and machine shops. For reasons already given, it must be expected that a whetstone will lose a little of its abrading quality with use; if it loses much, however, the conclusions may be drawn that it is not being properly used, that proper care is not being taken of it, or that it is a poor stone; only do not be too ready to condemn the stone. Many good stones are condemned and given a bad reputation, when the fault lies either in the original choice of the stone, or in the use made of it, or the care taken of it.

The care of whetstones.—A whetstone is worthy of good care and will repay well any trouble taken to keep it in good order. There are three objects to be attained in properly keeping a whetstone: First, to retain the original freshness and general character of the stone; second, to keep its surfaces regular; third, to prevent its glazing. To keep a whetstone in its original state it should be kept moist, just as it is found in nature. Drying a stone tends to harden it. A whetstone should never be left exposed to the weather, for the action of the elements soon affects its surface. Slight differences of temperature will do no harm; provided a stone is not too moist, it will not be injured by a low temperature, and unless dry, will not be injured by a high one. A stone will do well if simply kept in a moist place, but a good stone should have a thick wooden case with a hinged cover. The case is useful not only in retaining the moisture of the stone, but serves to hold it when in use and prevents its being broken. Keeping the surfaces of a whetstone regular simply requires care in using. The tendency is to wear a hollow in the middle of the surface; and this when once begun is increased by the softness which is produced when the lubricant employed settles in the depression. Long usage will produce a hollow in the middle of the stone, but the harmful trough shape can be

avoided by sharpening the tools along the edges of the surface used as well as in the middle.

The use of lubricants.—Much has already been said on the subject of the glazing of whetstones as a result of structure of the stone or of misuse. A poor lubricant may also cause a glaze, so it is fitting to consider here the matter of lubrication of whetstones. The use of a lubricant with a whetstone seems a strange one, inasmuch as the object of using the whetstone is directly opposed to the principle of lubrication; but the effectiveness of the lubricant is small in decreasing abrasion, so that it is of service with whetstones for other reasons than the possession of anti-friction qualities. There is no question but that the dry surface of a new whetstone "bites" more keenly than one which has been covered with some fluid, but a dry whetstone heats a tool, and then too the pores of the dry stone are likely to become filled with the fine dust which is worn off, and in consequence the stone soon becomes glazed. Those stones which are liable to heat tools, the coarse schists and sandstones, are used with water. These are fast wearing stones, and water should be used in abundance to carry off the powder created by the abrasion. A little water with these stones is worse than none, for it only serves to make the powder into a paste, which is ground into the pores of the stone at every movement of the tool. This will soon form a glaze which will damage the stone if allowed to harden. Such a glazed spot on a coarse stone can be made of use, however, to put a finer finish on a tool than the coarse grit would do, but care should be taken to wash or scour off the glaze after finishing the tool edge. The fine-grained stones do not heat very much, but water is of service with them in carrying away the powder formed. The plentiful use of water will prevent glazing on any stone that is used only with tools which are adapted to its hardness. Water will not injure any stone, and can be used to advantage with all.

Oil, however, is better used with fine-grained stones. Being thicker than water it keeps the dirt out of the pores of the stone better. It does not serve like water to carry away the powder, but rather keeps it on the surface of the stone to form a polishing powder, which finishes the edge much more finely than the rough scratching of the stone would do with water. Oil thus delays abrasive action somewhat, but makes up for it in fineness of result. Very little oil need be used at a time, and the stone should be wiped clean each time after using, or the oil and powder will form a glaze. All oils are not suitable for whetstones. Those having the least tendency to form a paste are the most desirable. Sperm oil is considered the best. It is highly necessary that stones on which oil is used should be kept moist, so that the oil may not dry away and form a hard gum. Particular care should be taken with porous stones, like the Ouachita, for in these cases the gum forms completely through the stone, and not merely on the surface where it can be scraped away.

Recapitulation.—The following is a summary of the conclusions reached in this chapter. Whetstones may be divided according to hardness into four classes: first, those easily cut with the knife blade on a flat surface; second, those that can be cut on the edges with the knife; third, those that can be scratched with the knife point; fourth, those that are not scratched by the point of a knife. Having determined the hardness of a stone by these tests, it must be considered whether the use to which the stone will be put will be sufficient to wear it away slowly, remembering that the knife blade test shows an exaggerated amount of wear not given in actual use. The physical appearance of a stone is a good criterion of its quality, and the coarseness can be tested with the finger nail. For coarse work coarse stones should be used with water; for fine edges it is economical to use first a coarse stone and to finish on fine stone with oil.

CHAPTER V.

THE MANUFACTURE AND STATISTICS OF WHETSTONES.

Early manufacture.—The preparation of the whetstone for use has always been a simple matter; the principle is the same for every method of manufacture, though details differ to suit the stone. The machinery at present used to manufacture on a large scale gives the process an appearance of complication. The process may be divided into two parts:

First, the rough shaping of the stone to the desired form.

Second, the rubbing down to a smooth finish, always accomplished with sand and water.

Curiously enough the method of manufacture which must have been the earliest one is still in common use to-day. The stone is found on the surface of the ground either in a suitable form already, or easily trimmed into one; then the rubbing down part of the process is accomplished by sharpening the tool upon the stone. This may be called the lazy man's method.

Hones found in the ruins of Pompeii show that it had become customary to grind them into definite shapes at the beginning of the Christian era, and the process was probably carried on long before. The early writers do not tell definitely the manner of shaping the stones for use. It is probable that grinding with sand and water on a smooth surface made up the greater part of the process at first, and even at the present time this step takes up more time and labor than any other. The grinding was very much reduced, however, when it became customary to use the lapidary's wheel to saw the stones into shape; still, this must have been a slow method of producing whetstones. The lapidary's wheel has been used to shape whetstones since early in the century at least, for Jameson says that the Turkey stone was brought to Marseilles and there cut into shape, then ground with sand and polished with pumice and tripoli. The cutting in this case must have been done with the lapidary's wheel. Sawing marble by the band saw has been practiced in England over a hundred years, and this method of sawing may have been applied at an early time to the manufacture of the softer whetstones; but the hard stones were certainly sawed by the lapidary's saw until comparatively recent times. The use of pumice and tripoli to finish the stone shows that good whetstones were highly valued at that time. Jameson says that these should be kept in a damp and cool place, for when much exposed to the sun they become too dry and hard for many purposes. These directions are applicable to any oilstone.

Knight, in his article on whetstones published in 1833, says, "the Turkey stone is cut in the lapidary's slitting mill with diamond powder, and then rubbed smooth with sand or emery on an iron plate."

The sandstone is much more easily manufactured than the finer grained rocks, since it is easily dressed in the rough, and grinds away faster in the finishing process. The method of manufacturing the Cretaceous sandstones at Blackdown, England, is told in an entertaining manner in the Transactions of the Geological Society of London for 1836.* The writer says: "When first taken the stone is greenish and moist, and can be cut or chopped with ease. The tools employed are a sort of adze called a basing hammer. The others are ordinary picks and shovels. A vertical post or anvil is fixed in the ground, and the workman sits with this between his knees, the left knee protected with leather. He first splits with his basing hammer from the blocks long portions approaching the shape of a scythe-stone. (The stones split best in the line of stratification.) These portions are then chopped down nearly to the required size. After being thus rudely shaped, the stones are 'hewn' to the proper dimensions with a large 'hammer' and then rubbed down with water by women, on a large stone of the same kind, and when dried they are fit for sale. The stones,

*Second Series, Vol. IV., p. 237.

when finished, vary from about ten to twelve inches in length; some have the shape of the portion of an almond, with the ends and sides cut square, and about two inches by one and a half inches in thickness; others are almost cylindrical, but smaller at each end.

"A good workman can cut of these blocks about seven dozen per day. They are sold chiefly to one merchant. The prices in 1825 varied from 2s. per dozen for the finest stone down to 8d. a dozen for the coarsest."

With the exception of this description of the Blackdown manufacture, foreign writers have given few details in regard to the preparation of whetstones for the market, so that knowledge concerning them is gleaned from chance remarks. In this way we learn from Knight (1833) that the shoemakers' sandstone was regarded as a special variety of whetstone in his time, and in form was cut as it is to-day in length of from eight to twelve inches with a square cross-section. The Norway ragstone, according to Knight, was imported in prisms from one to two inches in diameter and from nine to twelve inches in length; these are now imported into the United States, and are quoted at from $14 to $20 per gross. The same author says that the German razor hone is made by sawing the quarried blocks into thin slabs. His description is however, of the Belgian instead of the German hone. It is the yellow portion of this stone which is valued as a hone; and to preserve it from breaking it is customary to cement the pale yellow stone upon thin slabs of the purplish blue schist in which it occurs, unless the two are in contact and naturally united. This established custom of manufacturing the Belgian hone of two very characteristic stones furnishes excellent means of recognizing it. It is the best razor hone known, but it is not well adapted to other purposes. The true German razor hone has a dark gray color, looks like slate, is dense and homogeneous, and has a fine texture. There are specimens in the National Museum at Washington.

The Scotch water-of-Ayr stone is a soft one used chiefly for polishing metals or stone. The harder parts, however, are cut into whetstones, probably with the lapidary's saw. These stones are too soft for tools whose edges are applied at an angle, but are excellent for knives. They are rather expensive for stones of their character, being quoted at 40 cents per pound for whetstones and 60 cents for slips. This stone can be easily identified from its gray color mottled thickly with dark blue spots. This mottled appearance gives it the name of snake stone. One variety of Turkey stone has spots darker than the gray ground-mass, but they are less pronounced than in the Scotch stone, and the Turkey stone is much harder.

The record of the manufacture of whetstones in the United States is almost as meagre as it is abroad. The earliest published item found is that novaculite quarried at Oley, Berks county, Pennsylvania, was selling in 1822 for 25 cents per pound.* In 1822 also two quarries of oilstone in Lake Memphremagog were reported to have yielded profits exceeding $5000 for the two preceding years.† The Geology of Massachusetts, published in 1835, states that over five thousand dozens of whetstones were quarried annually in Smithfield, Rhode Island. The Geology of Rhode Island in 1840 reports the production of the same quarries at from six to eight thousand dozens. Twenty-two thousand eight hundred were manufactured in Bellingham, Mass., in 1838.‡ These figures show that there was a pretty active whetstone industry in New England at this time, particularly when it is considered that whetstones were also being manufactured in New Hampshire, Vermont, Pennsylvania, North Carolina, and Arkansas during this same time. Possibly the business was overdone at the time and a reaction followed, for the Massachusetts and Rhode Island quarries are not heard of after 1841, and nothing is heard from the Pennsylvania quarries until new ones were reported in 1883. The industry has been a constant one since 1840 in New Hampshire, Vermont and Arkansas, and also in Indiana, where the Hindostan quarries were opened about

*Cleveland's Mineralogy.

†Amer. Jour. Sci., Series I., Vol. V., p. 406.

‡Geology of Massachusetts, 1841.

1840; though in all these localities quarries have been abandoned and new ones opened during the intervening years. In North Carolina also it is presumed that the manufacture has been fairly constant; the stone is not known in the northern market, so the demand is probably a local one. Exactly when the Berea grit of Ohio came into use for scythe-stones has not been learned, but its use for this purpose is reported in the Geological Survey Report on Economic Geology, 1873. Only a small part of the grit is suitable for this use, so the whetstone manufacture can only be carried on in connection with production of stone for other purposes.

Present manufacture in the United States.—There are at the present time in the United States the following old established localities for quarrying whetstones: New Hampshire, Vermont, North Carolina, Ohio, Indiana and Arkansas. In addition to these are more recently worked and less important localities in Alabama, Missouri, Michigan and New York. Of these the business may be considered a local one in Alabama and in North Carolina; the New York and Missouri localities have more than a local business, but the product in each case is small; Ohio and Michigan furnish coarse scythe-stones only, but the quantity used is large and the industry is important. The great bulk of the whetstones come from Indiana, Arkansas, New Hampshire and Vermont. The quarries of the last two states may be considered together, since they are all controlled by one company. The New Hampshire and Vermont quarries produce stones for many purposes; scythe-stones are the chief product, but carpenters' whetstones, axe-stones and small stones for other purposes are also produced. In Indiana two stones are quarried, one a shoemakers' sandstone and the other a very fine-grained, compact sandstone, used chiefly for whetstones by carpenters, mechanics and others. Arkansas produces two varieties of stones, the "Ouachita," a fine quality of carpenters' stone, and a very dense hard stone, called the "Arkansas," suitable for sharpening the smallest pointed tools, or giving a very fine edge to surgical instruments.

The manufacture of Labrador stone.—The New York stone is found in Cortland county on the shore of Labrador Lake, from which the stone derives its name. It is a fine-grained dark-green sandstone occurring in beds two or three feet thick, interbedded with shales from two to six feet thick. The formation lies in a nearly horizontal position and is about five hundred feet in thickness. It is tough and sharp-gritted, but feels coarse compared with Turkey or Arkansas grit. A microscopic examination shows that the silica grains vary in diameter from .08 to .01 of a millimeter. There is a large percentage of earthy material present, considerable limonite which forms a cementing substance, and flakes of muscovite, sometimes bent. A little secondary silica is the only indication found that the rock has undergone any metamorphism. Dilute hydrochloric acid gives considerable effervescence, so a large part of the earthy material must be a carbonate. The toughness of this stone, due to the presence of the limonite cement, makes it a valuable one where strength is a necessary quality; thus it is particularly well adapted for kitchen stones and for the coarser kinds of files. This stone is not very well known yet and only about 5000 pounds* are manufactured annually.

Its manufacture was begun ten years ago at Manlius Station, with two small saw-gangs and a rub-wheel. Other kinds of stone have since been used and the business increased until now there are nine saw-gangs and three rub-wheels running constantly. Hindostan and Turkey stones are sawed at this factory to some extent; stone from Arkansas has been manufactured here for six or eight years, and now forms a very large part of the whole product. The sand used in sawing is fine and very purely siliceous, consisting of angular, subangular and well-rounded quartz grains frequently iron-stained. The average diameter of the grains is about .20mm. Water furnishes the power used (forty-horse power turbine wheel), and thirty men are employed. The advantage which this factory has is its cheap power. Its disadvantages consist in the distances to the various localities whence the stone and sawing sand are obtained, on all of which freight is paid. To these may be added its distance of three-quarters of a mile from the railroad. The manufactured stones are shipped chiefly to jobbers and hardware dealers in New York.

*Mineral Resources of the United States, 1886.

Manufacture in Missouri.—The whetstone factory at Pierce City, Missouri, is a small one containing one large saw-gang, a rub-wheel and a finishing wheel. The finishing wheel is simply a two-foot disk covered with sand-paper on which it is claimed a better finish is obtained than on the rub-wheel. This may be a good method to finish a soft stone like the Adamascobite grit which is manufactured here, but it probably would not be so successful if used with harder stones. The sawing sand used comes from Pacific, Missouri, and is fine and white. A twenty-horse power engine furnishes the necessary power.

The stone is compact and heavy, has a dull, yellow color, and resembles closely some varieties of Hindostan stone, but is softer and finer grained and has a velvety feeling. The microscope shows that the grains of silica are about .02mm. in diameter. Mingled with the silica is a large amount of muscovite mica, earthy matter and iron. The soft feeling is probably due to the muscovite present.

The whetstones manufactured here are good for those who like a fast cutting stone. They make excellent rub-stones also for marble polishers. They have not been put on the market in large quantity, but have been sold in small lots at $.50 to $.65 per pound. The manufactory has not run steadily, and five men suffice to do the work while it is in operation. It has a capacity of about 200 pounds of whetstone per day. Some flagging and building stones are also sawed at this factory.

New Hampshire and Vermont.—Since the manufacture in New Hampshire and Vermont is controlled by the Pike Manufacturing Company, and since their product is so similar, the two are considered together. In Grafton county, New Hampshire, the company now works four quarries. The schists in these quarries lie in "rifts" of different thicknesses which come out in sheets of different lengths and widths. The sheets are cut up or "bolted" into slabs about 10½ by 12 inches long by 2 to 4 inches thick. These slabs are then marked and broken into rough stones about 2 inches wide by means of steel knives and hammers. The rough stones are ground into the finished form on a horizontal rubbing bed fed with sand and water. The grinding is done at Pike Station. The stone manufactured here is the Indian Pond scythe-stone. The works in this neighborhood employ about fifty men.

The chocolate stone, quarried at Lisbon, is a finer grained than the Indian Pond stone, and is made into oilstones, knife-stones, or fine scythe-stones. From ten to fifteen tons are produced annually. The chocolate stone is not finished by the Pike Manufacturing Company, but the manufacture is carried on by contract with Lisbon parties.

In Vermont the stone is finer grained, more compact, and a little harder than the Indian Pond stone. Owing to these differences in character, the Vermont stone is sawed into slabs instead of being cut and broken, but they are finished in the same manner as the Indian Pond. At the works in Evansville and Westmore about twenty-five men are employed, and from 4000 to 7000 gross of scythe-stone are manufactured annually. The principal brands of Vermont stone are the "Black Diamond," "Lamoille," "Willoughby Lake" and "Green Mountain." These stones are exported only in small quantities, though of the Indian Pond 5000 gross or more go abroad every year.

The same company owns quarries in Cummington, Mass., the stone of which resembles the Vermont stone closely, but it is a little harder and more liable to glaze. Just at present the company is not working these quarries, though in the past, they have sometimes produced from 1000 to 2000 gross of scythe-stones per annum.*

Ohio and Michigan.—The manufacture of sandstone scythe-stones in Ohio and Michigan is controlled by a single company, the Cleveland Stone Company, and the productions of

*The above account of the manufacture in New Hampshire and Vermont, was kindly furnished the Survey by Mr. E. B. Pike, Vice-President of the Pike Manufacturing Company.

these two states may therefore be considered together. The Cleveland Stone Company is the strongest organization in the whetstone business at the present time, though the whetstone industry, however, forms but a small part of its whole business. It owns a large amount of stock of the Pike Manufacturing Company, and so influences the production of mica schist stones in New Hampshire and Vermont, and also the manufacture of the whetstones from Arkansas. It also has absolute control over the sandstone scythe-stone industry in this country.

The quarries of the Cleveland Stone Company in Ohio are located at Berea, Cuyahoga county; those in Michigan, are at Grindstone City in Huron county. Nine-tenths of the total product is manufactured in Michigan. The method of manufacture consists in sawing the blocks of stone into slabs, which are broken into the required length and then given the slender form of the scythe-stone by breaking again under a knife or "guillotine." The rough strips thus formed are rubbed down on a wheel made of basswood filled with iron scraps driven in edgewise. The wood wears away faster than the iron, so that the projecting edges, with the assistance of sand and water, wear away the stones more rapidly than a smooth rub-wheel would do.

From twenty to twenty-five men are employed in the whetstone business in Michigan; in Ohio but few men are employed, and these only a part of the time. The total product is about 8000 gross per annum, of which about 1500 gross are exported. The stones are worth on the average $3.50 per gross.*

Production in Indiana.—The whetstone quarried in Orange county, Indiana, is a fine-grained sandstone. The microscope shows it to contain much earthy material and limonite, with a little muscovite mica. The grains of silica are about .02mm in diameter and are remarkably uniform in size. There are a few shapeless cavities in the stone. The limonite probably

*Letter of October 11, 1890, from J. M. Worthington, President of the Cleveland Stone Company.

forms the cementing substance in this stone, as in the Labrador stone, though it is not so strong; it is stronger, however, than that of the Adamascobite grit, so this stnoei les between the other two in hardness.

The Indiana whetstones are known in the market by the name of the Hindostan; a variety having a buff color goes by the name of Orange stone, while the finest grade of white stones are called "Washita finish." Most of the stone has a dull gray or yellowish color. Some of it is micaceous, and thin micaceous layers and laminæ of iron ore afford convenient seams along which it is split in quarrying and working. There is considerable variation in hardness among the Hindostan stones coming from different strata.

The natural advantages for working the Hindostan stone are very great. It is found in nearly horizontal strata, interbedded with shales and some other strata not suitable for whetstones. The different quarries show considerable variation in the thickness and character of the beds worked, but in all a thin coal seam marks the lower limit of the good stone. The amount of cap rock to be removed is usually small, and a large per centage of the rock quarried is suitable for whetstones. Some stone not good for whetstone, is used for flagging. The good stone is wedged up in sheets, frequently of just the proper thickness for use; when not of the right thickness the slabs are easily split along the stratification planes. The thin sheets of stone are ruled off into the desired sizes, and the lines are deeply marked by a scribing awl. The sheet is then turned over, marked lightly, and then with a broad-edged stone chisel and hammer the whetstones are broken out in rough form. Rubbing down on a wheel finishes them. This is the greater part of the work, but cheap labor is employed, women, girls and boys attending the wheels. Horse power is commonly used to run the wheels, though a small steam engine has been used for some time at one quarry, and another steam mill is in process of construction. These works give steady employment to about twelve men, while from April to November perhaps eighty persons are at work. Some of the harder and more

massive rocks are shipped in blocks to the manufactories in New York, and at New Albany, Indiana, where they are sawed.

About 400,000 pounds of Hindostan stone was put on the market in 1886, 100,000 of which was exported.* Later reports do not show much change in production, though it has probably increased slightly. The prices in 1886 were considerably higher than they are now, ranging from $3\frac{1}{2}$ to 6 cents per pound; at present a very great part of the stone is sold at $1\frac{1}{4}$ to 2 cents a pound, with higher prices up to 10 cents per pound for special orders of selected stone. These stones are excellent to produce a rather coarse edge; they are much used by English cutlery manufacturers to give the first rough edge before the knife-blade receives its final polish. Their export increases annually.

The manufacturers of Hindostan stone are J. A. Chaillaux and Kirk & Pruett, at Orangeville, T. N. Braxton and William F. Osborn, of Paoli, and Brown Moore, of French Licks. Of these, J. A. Chaillaux is the only one engaged in the whetstone business exclusively. T. N. Braxton and William F. Osborn are merchants who operate quarries. Brown Moore and Kirk & Pruett are farmers who have quarries on their land. These first producers of Hindostan stones and their laborers employed make very little money at the business. At retail, however, the stones command a good price, and in hundred pound cases are quoted at from 6 cents to 30 cents a pound. Many of the Hindostan stones are beautifully marked with mineral stains. Some of these of fine quality have the special brand of Niagara stones, and are quoted at 25 to 40 cents a pound in small lots. The Hindostan stones are commonly used with water, though oil is sometimes used with the finer grades.

The other variety of Indiana stone from which shoemakers' sandstones and glass manufacturers' files are made, is a porous, friable sandstone much coarser than the Hindostan and belonging to the different series of strata. It is more easily worked than the Hindostan; it is sawed by a saw-gang

*Mineral Resources of the United States, 1886.

run by horse-power, and the rubbing part of the process is rapidly done by hand on a large block of the same stone. The stones are made in prismatic form one and a half inches on a face and from ten to twelve inches in length. About the same amount of this stone is put on the market annually as of the Hindostan, and about the same proportion of the total product is exported. The price given in 1886 was 4 cents per pound, but it was only 1 cent in 1890. These stones are quarried by the farmers at dull seasons of the year and traded to the merchants for goods. There are as many as six quarries in the vicinity of French Licks, probably more.

The other American stones manufactured in large quantity are the two varieties found in Arkansas. The method of quarrying and manufacturing these stones is much more complicated than is the case with other stones, the characteristics are peculiar, and the uses various; so a separate chapter is devoted to these stones. (See Chapter VI.)

The gang-saw.—In the manufacture of many of the whetstones the saw-gang and rub-wheel are so commonly used that it may be well to describe them here. The saw-gang or the gang-saw, as it is also called, consists of a rectangular frame in which strips of iron about one eighth of an inch in thickness and three inches wide are placed edgewise at the desired distances apart, parallel to the long side of the rectangle. This gang-saw is suspended in a horizontal position over the bed on which the stone to be sawed is placed. The saws are moved back and forth by machinery, operated by horse, water, or steam-power, and are fed with sand and water. The sand is fed by hand to the saws, one man or boy being able to tend several gangs; the water is continually sprinkled from a pipe perforated with holes which extends across the bed above the stone, and trickling down carries the sand to the saws and then washes out the fine powder produced in sawing.

For sawing whetstones plain iron bands are used; the sand grains fed to the saws become imbedded in the softer iron, and being much coarser than the grains of the stone scratch them away. The saws are kept steadily at work either by a constant weight or by being moved down by machinery at a regular speed. In the first method the gang is suspended by a single rope, attached through chains or otherwise to the four corners of the gang-saw, which passes over some wheels and is attached to a heavy weight at the other end. The weight is less than that of the gang-saw, so the saw works continually with a pressure equal to the difference between the two weights. When the saws are moved down by machinery, the rate is proportional to the hardness of the stone and the rapidity of movement of the saws. Each method has its advantages and disadvantages. The latter one, called screw-feed, is well adapted to rocks of even texture, but when hard spots occur the saws get choked. This method, however, combines a quick and easy way of raising the saw-gang by machinery at any time. The other machine, known as the rope-and-chain-gang, has the advantage of regulating itself to the character of the stone, but is clumsy, and considerable labor is required to raise the saws. It is the machine in common use and is usually better adapted to the whetstone business, because the stone is not sawed in one great homogeneous block, but many small blocks are cemented together in the saw-bed by plaster, so that the mass varies in the resistance offered the saws. The saw-bed may vary in size to suit the gang. The stone in the bed may be nearly as wide as the gang, but must be considerably shorter at either end to allow for the swing of the saws. About four feet by six is the size generally used in manufacturing whetstones, though some are smaller, and the one at Pierce City, Mo., has a bed five by eight feet.

The rub-wheel.—Like the saw-gang, different sizes of the rub-wheel are used. The wheel consists of a cast-iron disk about an inch in thickness, revolving in a horizontal position; running water and sand assist in the abrading operation. A stationary framework is usually formed coming close down to the surface of the wheel and dividing the circle into many parts. Flat surfaces are ground by placing the stone on the wheel next one of the arms of the framework and allowing the wheel to run under it bearing the grinding sand, a weight holding the stone on the wheel meanwhile. Ends, narrow edges, rounded sides or peculiar shapes are ground by holding the stone in the hand, and their manufacture requires considerable skill on the part of the workmen. About a large wheel eight feet in diameter six men may work to advantage, and keep many stones grinding at once. The grinding is faster on the outer edge of the wheel, so the rough stones are first placed here; but as they approach the finished condition they are moved toward the center of the wheel where the grinding is slower.

Another variety of rub-wheel is described in Knight's Mechanical Dictionary. It consists of a wooden wheel studded with scraps of nail plate, used like the cast-iron plate with sand and water. "The wood wears more rapidly than the iron and leaves the latter somewhat salient. It is said to exceed a cast-iron plate in effectiveness three to one." It is possible that such wheels may be effective in rubbing down soft sandstones for rough use, but they could scarcely give the fine finish that is necessary to hard stones. The Cleveland Stone Company employs wheels of this kind in the manufacture of scythe-stones, but they are not known to be used elsewhere in the United States.

Manufactories in the United States.—There are only four manufactories of whetstones in the United States in which both saw-gangs and rub-wheels are used. These are at Pierce City, Missouri; New Albany, Indiana; Manlius Station and New York City, in New York. The works at Pierce City and Manlius Station have been described in connection with the stones manufactured at these place. (See pp. 70 and 71.) At New Albany a factory was started by Mr. F. E. Dishman for the manufacture of Hindostan stone twenty-five years ago; the manufacture of the Arkansas stones was begun and finally became the larger part of the business; but in 1889 the factory closed on account of the competition in the business. Mr. George Chase in New York City has been established as a manufacturer of whetstones, and especially of the Arkansas stones, for forty years. An eighty horse-power engine fur-

nishes the power at his factory; he uses ten gang-saws and two rub-wheels, and employs about twenty men. Some sawing of building stone is done here in addition to the manufacture of whetstones. The sand used comes from Northport, Long Island; it is coarse and sharp grained, very purely siliceous, and for it are claimed more than ordinary qualities as a sawing sand. Any advantages it may have are probably due to its degree of coarseness, coarse grains, as we have found in whetstones, doing faster work than fine ones.

Statistics.—Below are brought together all the available statistics concerning the production of whetstones of various kinds manufactured in the United States.

Statistics of Whetstones Produced in the United States in 1889.

Name of Stone.	Number of Men Employed.	Rough Stone Produced. lbs.	Finished Product. lbs.	Value of Product.	Value of Exports	Prices.
Adamascobite	5	....	8,000	$ 4,000	0	$ .50 — 65 lb.
Chocolate	10(?)	....	25,000	3,750	?	.10 —.50 lb.
Hindostan	30	....	400,000	6,000	$ 1,500	.01¼—.40 lb.
Labrador	(?)	....	5,000	750	0	.10 —.30 lb.
Ouachita	60	800,000	400,000	80,009	20,000	.14½—.50 lb.
Alabama..........	(?)	Product small for local use.				
Indian Pond......	50	2,500,000	1,500,000	$ 40,000	$18,000	$2.50— 7.50 gr.
Lamoille, etc.......	25	....	5,500 gross.	30,250	?	5.50—24.00 gr.
Berea .... Huron	25	....	8,000 gross.	28,000	5,250	3.50— 8.00 gr.
Shoemakers' sandstone	...	....	400,000	$ 4,000	$ 1,000	$ .01—.05 lb.
Arkansas stone	8	60,000	15,000	$ 20,000	$ 5,000	.75—4.00 lb.
North Carolina stone	.....	Product small for local use.				
Total	213	....	2,753 000 lbs. and 13,500 gross.	$216,750	$50,750	

In comparison with the present condition of the whetstone industry the Tenth Census Statistics of the United States on Mining Industries present the following figures:

Production of Whetstones in the United States in 1880.

Source.	Quality.	Quantity.	Value.
Indiana	Oilstone	200,000 pounds	$ 5,350
Indiana	Shoemakers' sandstone	150,000 pounds	2,300
Vermont	Whetstones	2,900 gross	5,800
Vermont	Scythe stones	675 gross	3,388
New Hampshire	Scythe-stones	5,000 gross	16,250
Total value			$ 33,088

The value of the total product in 1880 makes the whetstone industry appear much smaller at that time than it really was. It is probable that some manufacturers in Vermont and New Hampshire were omitted, and there is no mention of the Arkansas or Ohio stones at all. The value of the manufactured product of these stones could not have been less than $30,000 in 1880, and probably $75,000 would have represented more nearly the value of the total product for the year. When compared with the figures for 1889 a very remarkable growth is shown. The whole industry had more than doubled in the value of products, the greatest gains being in the combined New Hampshire and Vermont industry, and in that of the Arkansas stones. This enlargement of the industry was characterized by a very large increase in product with a considerable fall in prices. Prices could not go much lower, so any further increase in product would swell the value of product considerably. It seems doubtful, however, if the industry can be much increased permanently, for whetstones do not wear out fast enough to keep up a steady demand in one district, so it is on the extension of the business that the producers must largely depend to dispose of their product. There is still a considerable chance for extension of the business, but it does not seem probable that there can be any such increase in product in the next ten years as there has been in the past decade. There is probably not very much more opportunity for extension in the United States, and considerable quantities of whetstones are now exported to England, Germany, France, Canada, and Australia. The total value of exports is now only about

one quarter of the total product, so there seems to be an opportunity for enlarging the foreign trade.

Imports.—Whetstones are imported into the United States from many countries, but for most of them the amount sent is small and rather in the nature of experiment, or for advertising purposes, than belonging to an established trade. According to the Mineral Statistics for the United States for 1886, the following imports were made into New York:

WHETSTONES IMPORTED INTO NEW YORK IN 1885–6.

Whence Imported.	*Value.*
Germany	$ 4,608
Belgium	3,915
Scotland	3,646
England	2,630
Italy	348
Chili	176
Australia	175
Japan	134
Mexico	19
Netherlands	12
Total	$15,663*

To this list should be added Canada, Norway, and Turkey. It is noticeable that over half the New York imports are razor hones from Belgium and Germany, and with the Ayr stone from Scotland the proportion of hones is increased to three fourths.

Turkey and, perhaps, England and Canada, are the only other countries beside the three above mentioned which steadily send whetstones to the United States. About three tons of rough Turkey stone are imported annually, and a considerable part of the Ayr stone comes in the rough also. The total imports for the year 1885–6 were divided amongst the various ports as follows:

*This total includes stones imported during the preceding year, and withdrawn from the warehouses in 1886.

WHETSTONES IMPORTED INTO THE UNITED STATES.

Ports of Entry.	*Value.*
Boston and Charleston	$ 483
Chicago	839
New Orleans	1
New York	14,434
Philadelphia	621
San Francisco	150
St. Louis	215
All other ports	6
Total value	$16,749

There has been no duty on whetstones since 1880; the proportion of stones imported in competition with the home product is insignificant.

Prices.—Prices for special articles and imported stone not included in the prices for the standard articles of manufacture are given below. Most of the prices given are taken from late catalogues intended for retail rather than wholesale trade.

Prices of Imported and Special Stones.

	Name of Stone.	Use and Kind.	Amount.	Price.
1	Norway ragg	Scythe-stones	Gross	$ 14.00– 20.00
2	English sandstone	Scythe-stones	Gross	20.00
3	Vienna emery stones	..	Thousand	80 00–100.00
4	Emery scythe rifles	Domestic	Gross	10 00– 12.00
5	Belgian hones	Hones	Dozen	2.00– 50.00
6	German hones	Hones	Dozen	4.00– 12.00
7	Scotch water-of-Ayr	Whetstones	Pound	40–
8	Turkey stone	Whetstones	Pound	40– 1.20
9	Turkey	Slips, round edge	Pound	1.00– 2.00
10	Arkansas	Slips, round edge	Pound	1.80– 6.00
11	Ouachita	Slips, round edge	Pound	25– 90
12	Ouachita	Kitchen and table	Dozen	14.00– 16.00
13	Labrador	Kitchen and table	Dozen	4.00– 4.50
14	Chocolate	Kitchen and table	Dozen	4.00– 4.50
15	Lamoille	Axe stone	Pound	12– 75
16	Arkansas and Turkey	Carving tools, points, files, knife blades	Dozen	1.50– 5.00
17	Arkansas	Wheels ¼ to ⅝ in. thick, diam. 1¼ to 5 inches	Inch	1.10– 2.20

PART II.

THE NOVACULITES OF ARKANSAS.

CHAPTER VI.

ECONOMICS OF THE ARKANSAS WHETSTONES.

HISTORICAL SKETCH.

The discovery in Arkansas of material suitable for different kinds of whetstones was made a short time previous to 1818—while Arkansas was yet a territory. It was first quarried a few miles from Hot Springs, stones of different colors being utilized. The first lot of 400 pounds was carried to the States, presumably in a semi-rough condition, where it sold at from one to two dollars per pound. Encouraged by their success the quarrymen loaded a flatboat with the stone and floated it down the Ouachita River. This was the beginning of exportation and it was in this manner that the business was conducted for many years. The preparation of the stone for market consisted solely in rubbing it flat on one side with sand and water, and in this condition it was sold at New Orleans. Inquiries made at New Orleans concerning the origin of the stone developed the fact that the boats had arrived there from the Ouachita River, and this gave rise to the name still applied to one variety of the stone, the Ouachita—commonly spelled "Washita" in commerce.

Observations of Featherstonhaugh.—In 1834 an examination of the elevated country between the Missouri and Red Rivers was made by G. W. Featherstonhaugh, United States Geologist. In his report upon this examination Arkansas novaculites are several times mentioned. His observations are remarkably accurate and worthy of repetition; the first notice is as follows:* "About three miles northeast from the Hot Springs the country is mountainous and broken, consisting of cones and ridges from three hundred to five hundred feet above the streams, which meander in very narrow bottoms. If in Missouri and the north parts of Arkansas, I had observed the singular propensity to substitute siliceous for calcareous matter, here I found the ferruginous hills of old red sandtone, sometimes consisting of solid masses of flint, at other times of a beautiful novaculite, and again of ferruginous sandstone, with heavy veins of iron passing through them, and imparting a chalybeate character to many springs issuing from their slopes. These hills contain that beautiful mineral substance called the Washita oilstone. * * * The curious gradations of this siliceous matter, in the forms of old red sandstone, flint, novaculite, hornstone, and quartzose rock, are surprising. For many miles these lofty hills present a succession of these minerals, in various forms. * * * * Beautiful crystals of quartz, of a large size, are also found, with double terminations, and not unusually of a bright topaz yellow color. But the most remarkable mineral I saw was the novaculite, or oilstone, a siliceous stone of a pearly semi-transparent nature, presenting singularly smooth natural faces, and occasionally tinged, in a very pleasing manner, with metallic solutions. Lofty hills are found there, composed entirely of this material. On one of these I saw several large pits, twenty to thirty feet deep, and as many in diameter, resembling inverted cones, the insides of which were covered with broken chips of this beautiful mineral, some white, some red, some carmine, some blue, some quite opalescent. In and near these pits round and long masses were scattered about, of a hard greenstone I had found in place eighteen miles distant, and none of them too large for the hand. They were, un-

*Geological Report of an Examination made in 1834 of the Elevated Country between the Missouri and Red Rivers, By G. W. Featherstonhaugh, Washington, 1835, p. 69.

doubtedly, Indian tools, and these were the quarries from whence the Indians had formerly obtained the materials they had used for their arrow heads, and other weapons of offense."

From Hot Springs Featherstonhaugh went by way of Magnet Cove to the junction of the Caddo and Ouachita Rivers. He says of this trip:* "From the Washita to the Caddo River, for about thirty miles, the elevated parts of the country consist of the same siliceous knobs and uplands, some of them approaching to the oilstone of the Washita, and well watered by numerous streams, with limited bottoms of considerable fertility intervening." During this trip it is evident that Featherstonhaugh saw the eastern end of the Trap Mountains since they are the only novaculite mountains which a person travelling in that direction would cross.

The observations and theories of Owen.—Since Owen has been the only geologist who has given much attention to the Arkansas novaculites his observations on this subject should be presented here in full. In the introduction to the second volume of his report he places the novaculites among the important mineral resources of the state, and says of them that they cannot be excelled in "fineness of texture, beauty of color, and sharpness of grit." The following is his description of the stone:† "This ridge (Hot Springs Ridge) * * * * * is made up of the most beautiful variety of Novaculite ('Ouachita oilstone or Arkansas whetstone'); equal in whiteness, closeness of texture, and subdued waxy lustre, to the most compact forms and white varieties of Carrara marble; and, though of an entirely different composition, it resembles this in external physical appearance so closely, that, looking at specimens of these two rocks together, it is difficult to distinguish them apart. Indeed, the finest quality of the razor honestone variety of this formation is even superior in purity of whiteness to the celebrated Carrara marble. Except in being less translucent, it approaches in lustre and fineness of

*Op. cit., p. 71.

†Second Report of a Geological Reconnoisance of the Middle and Southern Counties of Arkansas, by David Dale Owen, Philadelphia, 1860, p. 23.

structure to Chalcedony. It is, in fact, the most beautiful variety of Novaculite that can be imagined, when taken dry and fresh out of the quarries."

An account is given of the quarries which shows the condition of the whetstone business in 1860:* "The great mass of the Whetstone Mountain (now called Quarry Mountain) * * * is composed of different varieties of Novaculite Rock, which is quarried extensively to supply the neighboring Whetstone mills; but the greater quantity is transported to mills located at New Albany, Indiana, where it is sawed and fashioned into whetstones of every description, and razor honestones; the finer and harder varieties are reserved for the use of the engraver. * * *

"On account of the fissured and fractured condition of the rock it is difficult to obtain large perfect blocks, free from hard quartz veins. Were it not for this circumstance it could be afforded at a much cheaper rate; I believe it is worth at the quarry, at present, about 6 cents per pound. For the same reason it is difficult to distinguish the dip from the cleavage joints. * * *

"The height of Whetstone Mountain is about five hundred feet above the road leading from Hot Springs to Chalybeate Spring. * * * About $3000 worth of this rock is cut out annually. The razor grit makes, also, a good whetstone for bench-tools, but is not so much used for this purpose, on account of its high price, which is 7 cents to 8 cents per pound delivered in Little Rock. In some instances solid masses of the Novaculite rock have been got out, weighing about 1200 pounds, which sold at the quarry for $2.50 per 100 pounds, or $3.00 delivered at Little Rock. The coarser varieties are usually wrought up into whetstones for bench tools.

"The old Ouachita quarries are situated two and a half miles north of the Chalybeate Spring; but very little is quarried there now, the rock being almost exclusively obtained, at present, at this Whetstone mountain."

This account by Owen gives a very good idea of the extent

*Op. cit., p. 103.

of the whetstone business in his time; though he does not distinguish clearly between the two varieties of stone, the Arkansas and Ouachita, yet he mentions both names. The resemblance which he noted of the white novaculite to marble has been often remarked. Owen noted the occurrence of novaculite near Magnet Cove, at Rockport, in Pulaski county, west of Little Rock, and in the Cossatot Mountains of Polk county. His theory of the formation of this stone is considered in Chapter IX of the present report.

Owen's account is well supplemented by the statements of the late Mr. A. L. Barnes of Hot Springs, whose father engaged in the whetstone business about 1840. At that time the stone was quarried about four miles above Hot Springs, on the Mountain Valley road; these are the old quarries mentioned by Owen. The stone was called locally "the Ozark stone," but abroad it was known as Ouachita, for it was still shipped down the river. In these early times there was no ownership of quarries or quarry land, but every man quarried where he chose so long as he did not interfere with others. The elder Mr. Barnes was compelled, through the exigencies of the business, to abandon the Ozark quarries, and in hunting for other deposits of this stone he discovered the lead on Quarry Mountain, near Hot Springs. The new stone gained an excellent reputation, and the Ozark quarries were abandoned. But in 1875 quarrying was forbidden on the United States reservation, and as the reservation included the greater part of the mountain these quarries were abandoned, though there have since been a few worked on the mountain beyond the reservation limits, and one has recently been opened on deeded land within the reservation. Since that time operators have controlled the quarrying of whetstone by purchasing the land on which there was workable stone, thus holding a quarry by law instead of by mere active possession. The lead from which the greater part of whetstone is at present obtained, running across sections 24 and 13 of 2 south, 19 west, and sections 18, 7, and 8 of 2 south, 18 west, was known and worked before the civil war, but not so extensively as at present.

Foreign demand.—The first mention of the Arkansas stones abroad is found in Tomlinson's Cyclopædia, published in London in 1854. They did not have so good a reputation there at first as they did at home, but later foreign writers have given them an excellent reputation; at present both kinds of stone are in demand abroad in the finished condition, and the Arkansas is shipped in small quantities in the rough state.

The output of stone.—Cutter's Guide to Hot Springs, published in 1875, contains some facts showing the progress of the whetstone business at that city. It is there stated that over three hundred tons of the rough whetstone had been shipped annually for three or four years. The stone known as "Ouachita" was worth $40 per ton in Little Rock, and the "Arkansas" was worth $80.00; both were called novaculite. The elder Mr. Barnes and his son were then operating the mill where whetstones were finished, about two miles from town. The finished stone sold at from 25 cents to $1.00 per pound. Besides this factory, there were, in 1875, four firms manufacturing whetstones in the northern states.

This account shows a very large increase in the business between 1860 and 1875, both the quantity shipped and its value approaching the figures of the present business. The decline of prices with the increase in business is noticeable; and the subsequent building of the railway to Hot Springs does not seem to have reduced them further, even though the expense of hauling sixty miles on wagons was no longer necessary.

Prices.—The prices paid for the Arkansas stones have always been high, but those paid for the first lot of semi-rough stones were probably the highest. In 1869 a catalogue of a large eastern hardware firm gave the following figures: Arkansas oilstones, first quality, per pound, $1.50; Ouachita, first quality, per pound, 35 cents; Hindostan, 8 cents. The repeal of the duty on whetstones in 1880 seems to have had a curious effect on prices. Before the duty was taken off Turkey stone commanded $2.50 per pound, while Ouachita, the stone most closely competing with Turkey, was only 50 or 60 cents

When the tariff was taken off, Turkey stone dropped to 30 or 40 cents, but Ouachita rose to $1.50. From this it would appear that an inferior stone had an inflated value in consequence of being subject to duty; there must have been causes other than the tariff operating, for Turkey stone is now (1890) 45 cents a pound, while Ouachita is down to 25 cents. The present low price of Ouachita, however, is due to the active competition which did not exist in 1880.

THE ARKANSAS STONE.

It has already been stated that there are two kinds of whetstone quarried in Arkansas, each suited to a different kind of work; but what these stones are and in what respects they differ have not yet been made clear. The Arkansas stone is the better known and more clearly understood and is moreover a typical member of the formation in which the two stones occur; it is therefore discussed first.

The Arkansas stone is a true novaculite, satisfying all the necessary conditions regarding homegeneity, grittiness, finely granular structure, and siliceous composition; it is translucent on the edges and has a marked conchoidal fracture. It occurs associated with shales into which it grades through opaque flinty layers. Thus the stone meets all the requirements of the definition of Linnæus (see p. 6), and is besides, the only true novaculite quarried in quantity in this country. The only other stone in this country which resembles the Arkansas stone and is worked, is that of North Carolina, but the greasy talcose appearance of the latter suggests that its internal structure differs from that of the true novaculite.

Abroad, the true novaculites may be represented by the cutlers' greenstone of Wales, the *pierre à lancette* of the French, whose locality is not known to us, some true novaculites found in Germany, and one found in China. These stones are not known to this Survey, but there is good reason to believe that they are not extensively quarried, and they are probably all inferior to the Arkansas stone in purity of composition and sharpness of grit.

Composition.—The following is an average of several chemical analyses made of the Arkansas stone:

Average Analysis of Arkansas Novaculite.

Silica	99.50	per cent.
Alumina	0.20	" "
Iron (ferric) oxide	0.10	" "
Lime	0.10	" "
Magnesia	0.05	" "
Potash	0.10	" "
Soda	0.15	" "
Loss on ignition (water)	0 10	" "
Total	100.30	per cent.

These determinations are about the average, and though when summed up they make a total of a trifle over one hundred (100.30), they show the composition of the stone very accurately. The complete analyses are given in Chapter VIII. The remarkable fact demonstrated by the analyses is the very constant, high percentage of silica. Experiments on the solubility of the silica in caustic potash show that it is almost entirely in the anhydrous form. There would therefore be but little silica in the rock having the chalcedonic structure, since chalcedonic silica is partly hydrous and pretty soluble in caustic potash. Five per cent is about the average of soluble silica in the Arkansas stones as obtained by these tests. This may seem rather high, but when it is considered that by the same tests quartz crystals, which are supposed to be practically insoluble, give an average of about 4 per cent of soluble silica, the conclusion is reached that the silica of the novaculite is in a very stable form. Two specimens of chert tested in the same way gave over 30 per cent of soluble matter, most of which was silica; at least it was in one case, for an analysis of the same specimen gave 97 per cent of silica, and it may be presumed that the percentage of silica in the other case was not very different. A specimen of opalized coral tested in the same way gave over 88 per cent of soluble silica. These

cases prove that the percentage of soluble silica would be much larger in novaculite if it contained chalcedonic or amorphous silica.

In an article on novaculite Mr. George M. Turner thus describes the Arkansas and Ouachita stones:* "They are both composed of nearly pure, very fine-grained quartz, and differ from each other only in that the grains of quartz are finer and the spaces between them much smaller in the 'Arkansas' than in the 'Washita' stone. * * * The structure of the Arkansas rock, from its appearance under the microscope, is similar to that of marble. The crystals in forming have so run into each other as to prevent the natural crystalline faces from appearing, but have left minute cavities between the quartz grains." According to Turner† the sharpening quality of the rock is due to the exposed edges of these crystals; the faster cutting Ouachita stone having larger edges and larger cavities in consequence of possessing larger crystals than the Arkansas stone.

The above statements hint at the truth, but they are evidently based on too little observation, for the true explanation of the qualities of these stones is not revealed by them.

Mr. G. P. Merrill questions the theory of interlocking crystals to account for the grit of the Hot Springs novaculite. He says, that as a result of his own investigations it is composed of "a very fine and compact mass of chalcedonic silica in which are imbedded widely scattering angular grains of quartz."‡

Structure.—The microscopic examination of thin sections of the rock gives results agreeing with the conclusions drawn from the chemical analyses. Nothing but silica is seen, so the other elements present and indicated by the chemical analyses are probably chemically combined with the silica. In form the silica is in minute, irregular grains which are closely crowded together to form a dense groundmass. The grains are very uniform in size and average less than .01 of a

*Mineral Resources of the United States, 1885, p. 434.

†Mineral Resources of the United States, 1886, p. 589.

‡Stone, July, 1890.

millimeter in diameter. Occasionally they are as large as .04 of a millimeter, while others are no more than .001 of a millimeter. These grains are so minute that they do not give the polarization colors by which quartz grains are commonly distinguished under the microscope; but the distinct outlines which they present separate them clearly from amorphous silica, and since there is no indication of a fibrous structure, there can be no chalcedony present. As the silica of novaculite is neither crystalline, amorphous, or chalcedonic, it must be classed with those minerals which are structurally too fine to show distinctive characters and are called cryptocrystalline. Thus novaculite becomes a member of the same class of rocks with chalcedony, flint, basanite or touchstone, chert, and jasper, a group of rocks to which novaculite would, from its physical appearance, seem naturally to belong.

Silica is the only mineral seen in the microscopic section of novaculite, but its arrangement is a matter of interest and importance. The groundmass is composed of densely crowded grains of silica, but here and there are little cavities generally appearing on first sight to be irregular, but which on closer examination are found to have rhombic outlines. These cavities show that lime in the form of calcite was formerly present in the stone, but that it has been leached away. The cavities are very small, averaging about .05 of a millimeter in diameter; a large one measured .12 by .07 of a millimeter. Sometimes they are filled with secondary silica, forming a grain of larger size than usual; other large grains of silica are occasionally found having a jagged outline and a diameter of about .05 of a millimeter.

These larger grains of silica may have some influence on the abrasive quality of the Arkansas stone, though it would appear that the cavities had more, since stone which is identical in other respects, but is almost entirely without cavities, has a finer grit. Thus in the Arkansas stone the abrasion by the minute silica grains is materially assisted by the sharp cutting edges of the rhombic cavities about which the grains are closely packed.

Color.—The Arkansas stone which is placed on the market has, when fresh, a white color with a slightly bluish watery tint. Oil, however, soon gives it a greenish color. Sometimes the stone is tinged brownish or reddish by the diffusion through it of iron oxide, and though the color may become as deep as that of jasper, yet the stone retains its translucency on the edges and is suitable for whetstones. There is a prejudice in the trade against colored stones, so that they are not manufactured to any extent. There is some reason for this prejudice, however, for very often a difference in color denotes a change in the hardness of the stone, and only an expert can tell whether the coloring affects its character. The bluish tint and the translucent properties of the marketable stone give it a strong resemblance to chalcedony. We have learned, however, that it contains no chalcedony.

Specific gravity.—A determination of the specific gravity of Arkansas stone made by Prof. C. E. Wait gave 2.649. A re-determination at the standard temperature made by the Geological Survey gave 2.648. If allowances are made for the excess of weight caused by the presence of the heavier elements the specific gravity of the silica becomes 2.643. This falls within the limits given for silica in the form of quartz,* which places the specific gravity at from 2.64 to 2.66. The specific gravity of novaculite may be a trifle lower than the average for quartz since some air may remain in the pores of the stone and decrease its weight in water by a small amount.

Hardness.—The Arkansas novaculite cannot be scratched by a knife point. Quartz will scratch it, however, and in turn it will scratch quartz; hence its hardness may be considered identical with that of quartz. It is not a tough stone like flint, but is brittle and easily chipped with a hammer, though its fracture is quite as irregular as that of flint. The stone drills at about the rate of a foot in two hours, $1\frac{1}{4}$ inch drill with two men striking. Ouachita stone drills nearly three times as fast.

Absorption of water.—It is well known to the quarrymen of Arkansas stone that it loses weight after quarrying in conse-

*Chemiker Kalender for 1888.

quence of drying, but the loss as estimated by them—7 per cent—is much too high. Experiments have been made on this stone in which the samples were weighed when fresh from the quarry, carried in damp cloths from the quarry to the balances, weighed, and then allowed to dry. They were afterwards weighed several times during the course of a year and the smallest weight obtained was selected as the one from which to compute the loss. Under these conditions Arkansas stone from Whittington's quarry lost .06 per cent, and a specimen from Smith's quarry, worked by Sutton, lost .07 per cent. This loss of water indicates the porosity of the stone and so, in a measure, its adaptability to abrasive purposes. The figures show that both stones are very dense and practically the same so far as the effectiveness of abrasion depending on porosity is concerned. The stone is somewhat more porous than the above figures would indicate, however, for they represent the weight of water compared with the total weight of the rock; now as the rock is about 2.65 times as heavy as water the percentage of space occupied by the water in the rock is about 2.65 times the percentage of weight. So the actual space in the Arkansas stone is about .0017 of the total bulk. This is a very small amount but it seems to be sufficient to give the stone considerable advantage as a whetstone over the perfectly dense stones.

Occurrence.—The Arkansas novaculite resembles chert not only in structure and composition but also in the manner of occurrence. Both occur as stratified rocks, but there are some general differences. The novaculites are much more homogeneous than cherts. Chert beds are commonly associated in a nodular form with limestone strata; the novaculites, on the other hand, occur in massive strata, usually presenting plane surfaces and having only thin layers of shale interbedded.

Five or six hundred feet is the common thickness of the novaculite formation, which generally includes some flinty shales and soft shales or sandstones. The novaculites proper are the prominent members of the formation, however, and occur in massive beds from a few inches to twelve or fifteen feet

in thickness. When thinner than about four inches the beds generally lose their novaculite character and are more like flinty shale. The massive beds are so closely associated that there often appears to be no parting between them, but stratification lines are indicated in quarries by thin seams of clay. All the highly siliceous rock of the formation, except occasional sandstones, is novaculite or flinty shale; there is no true chert or flint, although hard spots or masses in the formation are called flint by the quarrymen. These are nothing more than denser portions of the same rock, in which, perhaps, the siliceous cement is stronger; occasionally a cement of iron increases the toughness and deepens the color of the stone. The hard spots are not large but are thickly distributed through almost the entire mass of the formation thus making the location of quarries a matter of very careful prospecting.

Obstacles to quarrying.—There is no objection to greater density and greater hardness in the Arkansas stone, for in some uses it would be beneficial in producing a finer edge, but when the rock becomes tougher the little particles are less easily scratched away, and, as a result, the stone soon becomes glazed. The denser rock which would be suitable for abrasive purposes is always spotted in this irregular manner so that it is doubtful whether any material of finer quality than the present Arkansas stone will ever be put on the market though pieces of the denser rock large enough for single stones can be obtained here and there. The hard portions vary in size from a few feet to a small fraction of an inch for one dimension; the shape of the larger bodies cannot be determined readily, but the smaller ones are generally lenticular or globular; there also occur very irregular patches of both large and small size. The irregular patches and sometimes the small spots have a vitreous appearance while the ordinary lustre of novaculite is waxy or dull resinous. Under the microscope the vitreous portions show no characteristic difference in composition, but it is very likely that there is present a siliceous cement not distinguishable in the microscopic section, and producing a lustre like that of quartzite.

The novaculite region of Arkansas has been subjected to such pressure that the strata are commonly found in a position nearer vertical than horizontal. The natural result of such great disturbance on the brittle novaculite has been to crush it into fragments in many places, and in others to form natural planes of cleavage, called by the quarrymen "splitting seams," but commonly known in geology as joint planes. These joint planes form systems of parallel planes dipping at all angles; at any point in the novaculite formation two or three well marked systems may be found, and six have been observed in a single quarry. These systems become so pronounced that their planes are often mistaken for stratification planes; one instance is recalled where it seemed as though the stratification might be in any one of three sets of planes when it was really in none of them.*

With so many systems of joint planes traversing the rocks it may well be imagined that it is difficult to quarry sound blocks of large size. Frequently the planes are only a fraction of an inch apart so that the stone is broken up completely into small pieces by the intersection of several sets of planes; a pick and a shovel are the only tools necessary for removing the rock when in this condition. A little of this fine material might be utilized for whetstones, if manufactured at home, but small stones cannot be shipped to advantage.

Besides the joint planes, irregular, sometimes conchoidal planes of fracture exist in the stone, developed apparently by the same pressure that produced the joint planes. The stone may often remain whole in spite of these cracks, but it may break easily along one of them. Stones containing them cannot be considered sound though their grit may be good. Similar cracks and even fractures are produced in novaculite where it is exposed to the weather, in consequence of freezing in winter. Though there is but little water in the rock, there is enough to produce this result, and quarrymen say they can hear the rock snap when, after rainy weather, the temperature falls suddenly to below the freezing point. If fresh Arkansas stone is exposed to a temperature much below the freezing point, it breaks into small rectangular or cuboidal blocks; in a gradually falling temperature, it "sweats" but does not break; once thoroughly dried, however, and kept dry, there is no danger of it breaking in any low temperature. Arkansas stone has been known to break up at the manufactory after sawing in cold weather, the expansion by the freezing of water absorbed during the sawing process being the cause. An Arkansas whetstone used with water, if exposed to the sudden cold, is in the same danger of breaking. It is the freezing process which gives the very broken appearance to the novaculites wherever exposed in bare ledges; within the rock beyond the frost line the quality of the stone is better, though it is still much broken.

*These joint planes are considered as compression and torsion phenomena; at least, it does not seem necessary to seek other causes for their existence than the pressure and movements involved in the folding of the area. When the planes are very close together the structure is comparable with cleavage.

The existence of latent joint planes in the stone which are developed by freezing into planes of fracture is noteworthy. Another noteworthy fact probably depending in part on the expansion of water, but caused by heat instead of cold, is that the Indians formerly split off novaculite chips for arrow heads by building fires against the ledges.

With hard spots and cracks to avoid in obtaining good stone it might seem that there were difficulties enough before the prospector, but there are still others. Fine quartz veins intersect the rock in all directions and in great numbers. Many of these veins are so thin that they can scarcely be distinguished by the eye, yet since they will nick a fine tool-edge they render the stone worthless. They commonly lie along joint planes, so that their extent can often be determined and the stone sawed in such a manner as to secure a minimum loss. However, since they do not appear at the surface, they are frequently not found until the stone has been sawed; in such cases the loss of stone is generally large. On account of the occurrence of these small quartz veins manufacturers prefer blocks of medium size to large ones.

Finally, the rock may be injured by the presence of small cavities called "sand holes." These holes vary from the size of a pin head or smaller to holes over an inch in diameter. The small, microscopic, rhombohedral cavities are beneficial in producing an edge on a tool more rapidly than is possible with a perfectly dense stone; the larger "sand holes" will notch an edge applied at a sharp angle, though an edge laid flat is not damaged by them. In the Arkansas stone these sand holes are not nearly so common as in the Ouachita, and they are of much smaller size as a rule, so that of the various defects this is the least to be feared. The origin of these cavities cannot be determined with certainty. The most plausible theory is that they represent former aggregations of lime which have been dissolved out, leaving a little loose silica in the holes. This seems the more probable inasmuch as the Ouachita stone which originally contained much more lime in the form of calcite than the Arkansas stone has more numerous and larger "sand holes" than the latter. It is possible that the lime originally came from fossil shells, but no organic form has yet been recognized in the outlines of these cavities.

Prospecting.—Unlike the fractured bare ledges, the soil-covered rocks are but little broken; and in prospecting for Arkansas stone an earth-covered "lead" has been followed between harder strata which show now and then in bare, much fractured knobs. The quality of the stone is determined by removing the earth covering which is almost always thin, noting the surface appearance, and blasting if the surface indications are favorable. No cheaper method of prospecting seems likely to come into use, for when the stone is hard enough to project through the soil, it is pretty certain to be a spotted variety; the good stone is almost always covered up. The prospector's drill might be used to determine the quality of stone below the surface, but a single core of rock is not a trustworthy indication of the character of such an uncertain stone. Deep prospecting is useless because the price of the stone does not warrant the removal of a large amount of cap-rock, and finally, as the business is at present conducted, the quarry owners cannot profitably incur the expense of much machinery.

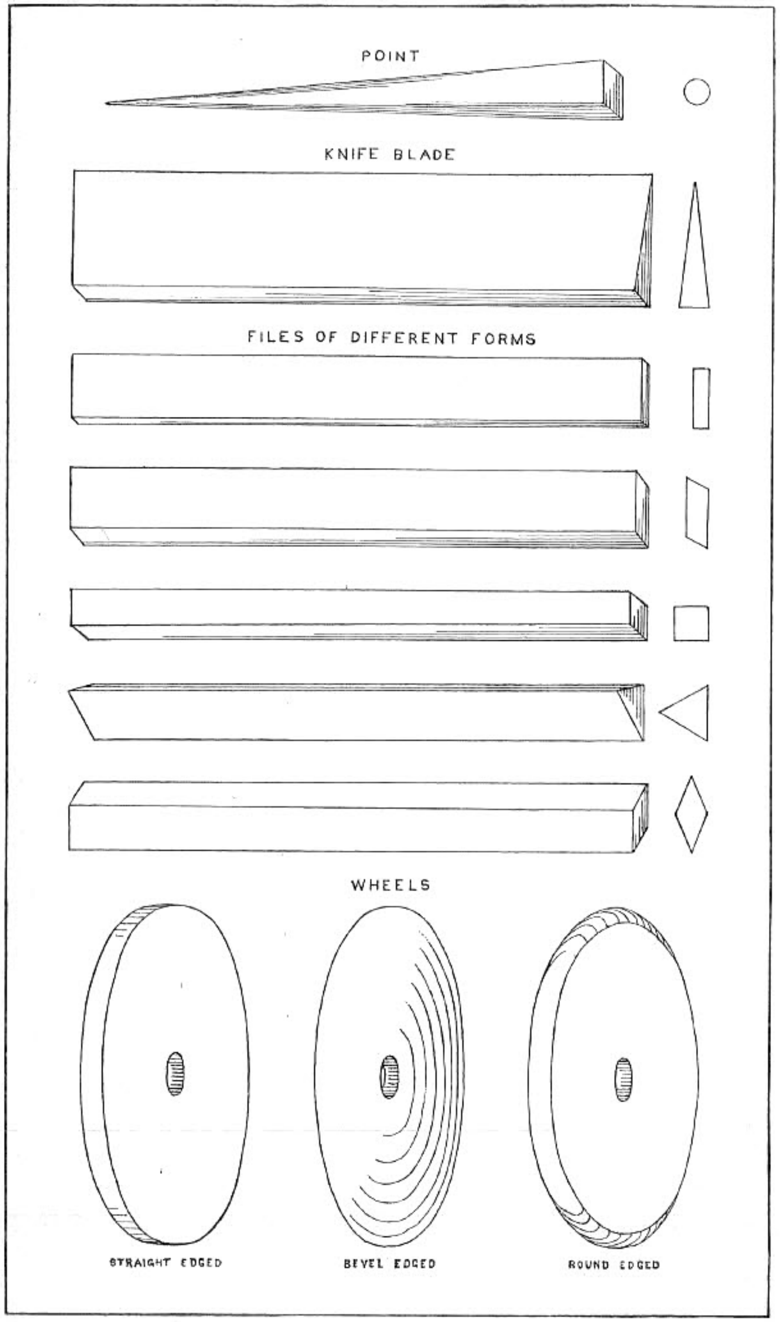
Quarrying.—With so many difficulties in the way it is not surprising that quarries of good Arkansas stone are not easily found. Only one quarry, Whittington's on Quarry Mountain, has afforded any large amount of stone. This has now been worked for nearly ten years and does not promise very much more marketable stone, because the strata have become considerably cracked at the back of the quarry, necessitating deep work, and the removal of the cap has become expensive. This quarry has produced a large amount of very fine stone, and it is possible that more may be obtained by enlarging the opening at the sides, though the rock at present is not of first quality. Smith's quarry, worked by Sutton, has been opened but two years and has not produced a large amount of stone. The workable stone has been obtained for the most part in rather small pieces, owing to the presence of inequalities in textures; but the quality has been improving and yet there has been but little cap-rock to remove. The waste in both these quarries is several times larger than the amount of good stone taken out. In view of the uncertainty of finding more workable material when these quarries are exhausted, the price of 10 cents per pound delivered at the railway must be regarded as very low. About 60,000 pounds, 40,000 of which come from Whittington's quarry, are now produced each year.

Manufacture.—The stone goes to the factory of the Pike Manufacturing Company at Manlius Station, New York, or to George Chase, New York City. The methods of manufacture and articles made are the same in both factories. The blocks of stone, having been trimmed at the quarries, are first laid in plaster of Paris in the bed of the gang-saw. This work requires experience in order to arrange the stones so as to have as little waste as possible and to avoid loss from spots, quartz veins, etc. The saws are placed in the gang to suit the arrangement of the blocks in the bed, generally two inches apart to suit the first cut. The Arkansas stone is very slow sawing; saws going at the rate of eighty swings per minute will only penetrate the stone in the gang bed at the rate of one and a half inches in ten hours. Marble is sometimes sawed at the rate of nearly eight inches per hour, though for dense marble two inches per hour is a closer estimate.

After the cutting is completed the slabs are taken out and sorted; defective and useless pieces are thrown on the waste pile, but small pieces of good stone are kept to be manufactured into small articles. The first cutting determines the width of the whetstone. The second one, which is made after laying the slabs crosswise in the bed in plaster of Paris, as before, determines the length, which may vary from eight inches down. If after the first cutting good slabs are found which will give stones larger than eight inches they are generally reserved for special orders. The slabs are again re-sorted and then laid in plaster of Paris for the third cutting, which gives the stone its third dimension of thickness, generally one inch. The third sorting reduces the amount of available stone to nearly one quarter of the original bulk of that placed in the first gang bed. There is a further loss in the rubbing process which reduces the total of marketable stone to about 25 per cent of the original bulk. All stones are finished on the rub-wheel, generally with the powdered sand from the gang-saws. Not very much labor is necessary to finish the flat faces for the stones are simply laid on the rub-wheel and held by weights until finished. Ends, however, are finished by hand; all rounded faces also require skilled hand labor, as does the manufacture of all the smaller articles.

Uses.—The Arkansas stone is now used for many purposes. The whetstones are used by engravers, surgeons, carvers, dentists, jewelers, cutlers and other manufacturers of fine-edge tools, and by machinists and wood-workers of the more skilled class. In short, for all artisans who use small pointed or very fine-edged tools, the Arkansas stone is the best made in the world. Small whetstones for penknives are made in considerable quantity, and some stones are sold for razor hones.

The Arkansas stone is also used by wood carvers, jewelers, manufacturers of fine machinery and metal work and by



ARTICLES MADE OF ARKANSAS STONE.

dentists in various forms of files and points. Dentists use particularly the "knife blade," a very thin, broad slip of stone, triangular in section, with one short side, the other two forming a thin edge as they come together. They are used for filing between the teeth. Carvers use wedge-shaped, flat, square, triangular, diamond-shaped, rounded, and bevel-edged files for finishing their work. Jewelers, especially manufacturing jewelers and watchmakers, use all these forms of files and also points. Points are sometimes made the size of a lead-pencil, having a cone-shaped end, and sometimes are about three inches long with one and a quarter of an inch square and tapering to a point, with circular section at the other end. Points are used chiefly in manufacturing watches, to enlarge jewel holes. To grind the flat sides of these small articles, the rough slips of stone are cemented on a board in such a way that the grinding will bring them down to the proper face, and a weight is placed on the board to hasten the grinding. Considerable skill is required to arrange these small slips so that all shall be ground just enough and without waste.

The Arkansas stone is well suited for small files and points, for it is a strong stone when sound; but small articles made from it must be used with care on account of its brittleness. Some of the articles manufactured from this stone are shown in the accompanying plate.

The prices given in catalogues for 1889 for small pieces, from three to five inches in length, vary from $1.50 to $5 per dozen.

Wheels are also made from Arkansas stone of various thicknesses and diameters. They are used chiefly by jewelers and dentists, but they could be made of service in all workshops where an Arkansas whetstone is used. The difficulty of obtaining pieces of clear stone large enough for wheels several inches in diameter makes the price of Arkansas wheels very high, and the difficulty of cutting out a circular form increases the cost. Wheels are quoted at from $1.10 to $2.20 per inch of diameter.

Arkansas stone is used for finishing and polishing metal rolls, journals, crosshead slides, piston rods, crank pins, and all kinds of lathe work.

"Novaculite is found at Hot Springs, Arkansas, and has been used to a very limited extent for cutting figures, such as owls and birds, for jewelry. It is pure white, and makes a very pretty ornamental stone. The amount sold is now less than $100 worth per annum."* The stone is not now thus manufactured, but some of it is beautifully colored, and might readily be used for small ornaments.

Fragments of the Arkansas stone are saved at the factories, and now and then sent away to be ground for polishing powder. In the manufacture of this powder millstones are worn out so rapidly that the process is rather expensive, but as waste stone is utilized, the powder can be sold by the barrel at ten cents per pound. It makes a very fine, pure white powder of sharp grit, suitable for all kinds of polishing work; it is known as "Arkansas powder." A large amount of energy is wasted, however, in the manufacture of this powder, for the silica of the Ouachita stone is in every way identical with that of the Arkansas stone and it would be much more easily reduced to powder than the Arkansas.

Markets and prices.—It has not been possible to find out where the Arkansas stone is used in largest quantities because the greater part of it is sold to hardware jobbers. The manufacturers export a considerable quantity, however, and also sell directly to manufacturers of jewelry, cutlery and the like in this country. A few thousand pounds will cover the amount of rough stone annually exported. The total amount to be accounted for is not large, for if the manufacturers' estimate is correct only about 15,000 pounds of finished stone is put on the market annually. The prices for Arkansas stone are necessarily high, for with a waste of 75 per cent manufacturers get nothing for their labor or freight expenses at 40 cents a pound. The expense of manufacturing is so great that $1 or more per pound is not excessive when the actual cost of the stone is taken into account.

*Mineral Resources of the United States, 1883, p. 492.

OUACHITA STONE.

The Ouachita stone closely resembles the Arkansas stone in all its physical characters, but the Ouachita stone is less dense and its porosity excludes it from the true novaculites. Just as the occasional minute cavities in the Arkansas stone cause it to appear coarser and less translucent than a perfectly dense stone, so the larger and more abundant cavities in the Ouachita stone give it a still coarser appearance and prevent the passage of light except on very thin edges. In consequence of its porosity it lacks the waxy lustre of novaculite and has the dead appearance of unglazed chinaware. It is probably the same cause which reduces the fine conchoidal fracture of the Arkansas stone to subconchoidal in the Ouachita.

Composition and structure.—Analyses of the Ouachita stone show it to have the same chemical composition as the Arkansas stone; and experiments on the solubility of the silica show a percentage of soluble silica slightly smaller than that of quartz crystals, so the soluble silica is reduced to a minimum in this stone. Under the microscope silica is found to form the groundmass as in the Arkansas stone, and its grains are equally fine. Fine particles of iron are visible, and specks of carbon occur, but these minerals are in such small quantity that they do not affect the color, and to the eye the stone appears perfectly white. A very few flakes of muscovite mica are seen. The larger grains of silica seem more plentiful than in the Arkansas stone, and frequently give polarization colors; but this is because the rock sections are thicker than those of Arkansas stone.

The remarkable qualities of the Ouachita stone depend upon the existence of many cavities in a dense groundmass. As in the Arkansas stone these cavities have a rhombohedral form, but they play a much more important part in the Ouachita stone because they are somewhat larger and much more numerous.* On account of the larger size and greater number of the cavities in the Ouachita stone they are much more

*These cavities as seen in the Arkansas stone are described on p. 98.

easily studied in that stone than in the Arkansas; in fact they were first noted in the Ouachita. In size these cavities are very constant and average about .07 of a millimeter in diameter. The outlines are often obscured by the presence of silica which has either been pushed into the cavity since the disappearance of the calcite or has been deposited there from solution, yet the original form of the cavity can usually be traced. Small cavities .03 or .04 of a millimeter in diameter are sometimes completely filled with secondary silica, but the large ones are never so filled. There is a sufficient number of perfect rhombic forms left to prove beyond a doubt that the imperfect forms have had the same origin. Sections of the Ouachita stone seem to contain a large amount of foreign matter in the form of dust, but the chemical analyses do not indicate the presence of such matter, and as it usually appears in the cavities it is probably the dust from the grinding material used in preparing the microscopic sections.

The outline of the rhombohedral cavities is singularly accented in many cases by an arrangement of the silica grains with their long axes perpendicular to the sides of the cavity and very closely packed together. The grains are angular but the arrangement gives an appearance like brick work in a mass of rubble. (See cut in Chapter VII., slide No. 1.) This layer of silica grains is only about .01 of a millimeter thick; beyond it is the usual groundmass of silica. It is evident in almost all cases that the silica is more compact about the cavities than elsewhere though it may not show the brick-like structure. As a result of this compactness the sides of the cavities present fine cutting edges to a tool rubbed upon the stone. That these act as cutting edges must be the case for there is nothing else in Ouachita stone different from the Arkansas stone to render it capable of producing the much faster abrasion which the Ouachita accomplishes. These edges then do the rapid work of abrasion, and at the same time there is a constant fine scratching going on from contact with the grains of silica; so that the Ouachita stone produces a fine edge in a short time. By moving the edge backward over the stone the cutting effect of the edges of the rhomb is lost, and the scratching alone gives a finish to a tool edge as fine as can be obtained on an Arkansas stone. It is for this reason that the Ouachita stone can be used as a razor hone. The reason why the Ouachita stone cannot be used for fine-pointed tools lies in the fact that the partitions between the cavities are thin and easily broken away by a pointed instrument; such use soon produces an irregular surface and ruins the stone.

Tests of quality depending on porosity.—A sample of the most porous Ouachita stone was tested in the same way as the Arkansas stone to ascertain the percentage of water required to fill its pores. Stone from Sutton's quarry No. 6 absorbed a trifle over 7 per cent of its weight when dry. This gives for the space occupied by the water over 18½ per cent or nearly one fifth of the total bulk of the stone. Before these experiments with water had been tried, a calculation of the porosity had been made based upon the microscopic examination of the rock. The average of eight cavities to the millimeter was taken as a basis, though considered at the time as rather low. This gives the following results:

Space.	*Number of Cavities.*
1 millimeter	8.
1 centimeter	80.
1 inch	200+
1 inch cube	8,000,000+

If .07 of a millimeter be taken as an average dimension of a cavity and the size of a rhomb be computed as a cube, each cavity would occupy the space of .000343 of a cubic millimeter. Multiplying by 8,000,000 to find the total space occupied by the cavities, 2744 cubic millimeters, or 2.744 cubic centimeters is the result. A cubic centimeter equals .061 of a cubic inch; then the total space occupied by the cavities according to this calculation, which is based on a low estimate, is .1673+ of a cubic inch, or 16.73 per cent. The two results agree remarkably well and give a good idea of the porosity of the softest and most rapidly abrading of the Ouachita stones now quarried. Most of the other varieties of Ouachita fall between this and the Arkansas stone.

The test of porosity by weighing the water contained in the stone must be a very accurate one, and one which can be depended upon to show the value of a stone for any particular use. Thus, for carpenters' or mechanics' ordinary use, where it is not necessary to apply a pointed instrument to the stone, the most porous one is the best because it will abrade fastest. With tools having a smaller edge a more dense stone should be used, the Arkansas stone serving for the finest tools. A table giving the results of absorption tests for the various whetstones, together with some others, is given below. The specimen in each case where the stone came from a quarry was selected by the foreman as a fair example of the good stone produced in the quarry:

Table Showing the Absorption of Water by Various Stones.

NAME.	Weight fresh from quarry in metric grams.	Mini'm weight after drying in air.	Loss of water.	Percentage of loss.	Weight after soaking in water.	Percentage of gain.	Percentage of space occup'd by water.
Whittington's Arkansas.....	491.96	491.63	.33	.067	492.05	.085	.225
Sutton's Arkansas..........	507.27	506.88	.39	.077	507.38	.098	.259
Quartzose sandstone.	173 33	173.17	.16	.090	173 42	.144	.368
Sutton's No. 3............	329.15	327.55	1.65	.504	332.02	1.37	3.630
Sutton's No. 5............	505.81	470.82	24.99	5.306	485.58	3.14	14.06
Sutton's No. 6............	304.13	285.36	18.77	6.58	305.61	7.09	18.788
Sutton's No. 7............	454.22	426.52	27.70	6.49	449.35	5.35	17.198
Whittington's Red Quarry..	393.07	388.26	4.81	1.24	395.66	1.89	5.008
Whittington's Sec. 8 Quarry.	399.46	398.65	.81	.23	405.8	1.79	4.743
Barnes' Big Quarry........	257.05	251.12	5.88	2.34	*185.53	.733	6.216
Mottled Ouachita..........	279.03	278.2	.83	.298	281 27	1.10	2.91

*Specimen broken; weight of largest piece dry, 184.18 grams.

In the above table of results the weight of the stone dried is taken as a standard by which to reckon percentage. It is noticeable that the different stones do not absorb the same amount of water after drying that they had when taken from the quarry. The cause is easily explained when they take up more water, for the stone in the quarry was probably not saturated; but when less water is absorbed the explanation is not so simple,

for the stones were soaked and weighed a second time. The only suggestion that can be offered in explanation is that a body of air was confined in the stone so as to prevent the complete infiltration of water, but it is not clear why this should take place in one case and not in another. It is clear, however, that the weight showing the greatest amount of water present is the one which indicates most clearly the porosity of the stone, so the percentages of space occupied by the water are calculated from this maximum weight. The results obtained are about what one would expect from an examination of the various stones by the eye. In spite of the small size of the cavities they produce a more or less porous appearance in the various stones according to their number, and with a good magnifying glass their rhombic form can sometimes be distinguished. It is noticed that the various stones called Ouachita present wide differences in porosity, yet, in comparison, the Arkansas stone is sufficiently dense to leave a decided gap between it and the Ouachita. Thus while the cavities of the Arkansas stone amount to one fourth of 1 per cent or 1-400th of the total bulk, in the densest of the Ouachita stones the pores comprise about 5 per cent or one twentieth of its bulk. The quartzose sandstone was tested in order to institute a comparison with some familiar rock. The mottled black and white Ouachita is called a poor stone by the quarrymen, so it too was tried to ascertain whether any reason for this judgment lay in its porous qualities; it is noticeably inferior to the other Ouachita stones in porosity.

The microscopic examination of the various Ouachita stones gives tests which coincide with the tests of their qualities already stated. The detailed description of the microscopic characters of each will be found in the next chapter.

Occurrence.—The Ouachita stone resembles the Arkansas in its mode of occurrence. There is nothing in the structure of the two stones to render impossible a gradation from one into the other in the same bed, though such a transition has not yet been observed. The two extremes of the Ouachita stone, however, have been found on the same "lead" about three miles apart. (Sutton's quarries No. 6 and No. 1.) In an abandoned quarry on Quarry Mountain, formerly worked by Whittington, different beds afford Ouachita stone and one which, though lacking in density, is almost an Arkansas stone. This locality shows the closest stratigraphic relation yet observed between the two stones.

The bottom of the Ouachita "lead" of stone is usually well defined by a hard flinty bed on which is ordinarily a thin layer of clay. Above the clay there sometimes occurs a soft, friable stone of variable thickness. This member may attain a foot in thickness or it may be entirely wanting. This soft stone appears to be a Ouachita rock in which the proportion of lime was originally so large that the leaching process has left only a crumbling mass of silica. The gradation from the soft into the Ouachita stone is abrupt, yet there is no distinct line of bedding between them. The lead of Ouachita stone generally varies in thickness from four to fifteen feet; in this thickness there are often several beds separated by clay seams. Sometimes the whole mass appears to be a single bed. There appears to be no distinct upper limit to the Ouachita bed; the stone simply loses the qualities necessary for good whetstone and is quarried no farther.

Defective stones.—It might seem from the description thus far given of the Ouachita stone, that all stone having the fine-grained groundmass of silica, with a sufficient number of rhombodedral cavities is good for whetstones; but such is not the case. The Ouachita stone is liable to have all the possible defects of of the Arkansas stone together with others peculiar to itself. The Ouachita is intersected by joint planes in the same way as the Arkansas stone. These planes often divide the stone into fragments too small for any use, but as a rule the Ouachita is much freer from them than the Arkansas stone, so that blocks of stone several tons in weight are sometimes quarried.

The spots in the Ouachita stone are of a slightly different nature from those in the Arkansas. They depend upon similar causes, resulting either from a closer cementation of the silica grains by ferruginous or siliceous cement, or from a change in the distribution of the rhombic cavities, but as the stone is different in the beginning there is also a difference in the character of the spots. In the Ouachita stone the spots do not have a flinty appearance; some of them appear to be simply dense portions of the stone, and to the untrained eye they denote no difference in the quality of the stone; in use these portions are likely to become glazed. Spots of this sort may be the result of a mineral cement which binds the grains of silica together and prevents the easy renewal of fresh scratching points, or they may be caused by a local change due to a smaller number of cavities in that part of the stone in consequence of which it wears unevenly. When the spots are due to a mineral cement, iron in most cases, they are shown by the presence of a color which may vary from a pale yellow to brown, red or black. All stones tinged with color are not bad, however, for often a stone may have a strong coloring and yet be open in texture and sharp-gritted; it is when the color is associated with a dense appearance that the stone is to be avoided. A remarkable example of spots caused by a change in the number of cavities is furnished by a well known quarry from which a large amount of stone was taken, manufactured and placed on the market before the defects were discovered. In the fresh stone these spots are noticeable to a trained eye, but in the dried stone they are scarcely distinguishable, they show no difference in color and only a slight though sharp difference in density. They are now very distinctly visible in the abandoned quarry where the weathering causes them to stand out in relief. The form of these spots has not been seen, but they always give blunt-ended lenticular sections, so they are probably round-edged disks. They vary from a quarter of an inch to four inches in diameter. These spots have been found at other quarries in the neighborhood, and always cause their abandonment. The unfortunate distribution of these spotted stones through the channels of trade has given the Ouachita stone a bad reputation from which it has not yet entirely recovered.

The cause of these spots is not known; their form is like that of a concretion, but the structure simply indicates the absence of lime in the material originally deposited; but why the amount of lime should be wanting in these disk-shaped bodies while it was evenly distributed in the surrounding mass is not apparent. Vitreous looking spots resembling those found in the Arkansas stone, and probably due to the same causes, sometimes occur in the Ouachita. They are the most noticeable of these spots on account of the lustre which they give in contrast with the dead color of the stone.

The quartz veins are much less numerous in the Ouachita than in the Arkansas stone. The ratio of the quartz veins in the two stones is very similar to that of the joint planes, indicating their interdependence.

"Sand holes" are more numerous and attain a larger size in the Ouachita stone than in the Arkansas. They are more likely to occur in the softer than in the harder ones, that is in those stones which originally contained more lime. Holes an eighth of an inch in diameter will ruin a stone, but if there are but few and of small size the stone is not discarded on their account.

Freezing does not have the splitting effect on water-soaked Ouachita that it does on Arkansas stone because it is sufficiently porous to allow some expansion. Long drying, however, seems to be injurious, for it is noticeable that where the Ouachita stone is so situated that it dries out quickly and has been exposed a year or two, it has lost its easy fracture and become tougher and harder. In this condition it hardly seems possible that the abrasive qualities can be as good as in the fresh stone. This altered condition of the stone is noticeable in the waste piles and is equally an argument against keeping the stone a long time before shipping it to the factory, and against long holding at the factory before sawing. It would seem from the changed character of the stone in the wet and dry conditions that it would saw more easily when fresh from the quarry, for even though the stone will absorb water at any time, a long drying seems to harden it permanently.

Coloring matter in the Ouachita stone has been noted as

generally indicating a defective stone. This is the rule, but there are a few stones of the first quality which are lightly streaked. There are others containing pretty strongly colored parallel bands independent of the stratification. These are known as "calico" stones. When the coloring is not too strong these may be good; but when the color is marked, the colored stripes are likely to show a difference in texture. The colored stripes may be harder, as when the coloring matter acts as a cement; or softer as when pyrite has been decomposed coloring the stone and leaving it more rotten in consequence of the increase in the number of cavities due to the disappearance of the pyrite crystals. The bands of color in the "calico" stone often form beautiful waves and curves which seem to have no order and no dependence on the composition or structure of the stone; they simply curve about in parallel lines. There may be fifteen or twenty of these bands, varying within the distance of a foot, from pale yellow through red and brown to an almost black color, and dividing the space somewhat evenly with the white bands. But little of this stone finds its way into the market, and then only as of second quality.

There is another colored stone, called from its color the "black Ouachita," which has caused some trouble in quarrying Ouachita stone. It is found sometimes intermingled in irregular spots with the white Ouachita, giving a mottled gray and white stone; sometimes the line between the white and black is very sharply marked. In the latter case there is no single continuous line of demarcation, but the two colors irregularly interpenetrate, patches of one occur within the area of the other, giving outlines like those of chert nodules in limestone. There is no apparent difference in hardness in the differently colored parts and to the eye they appear equally porous; the quarrymen say, however, that the black stone is useless for whetstones. A microscopic examination of the two stones shows no apparent difference in the number or size of the cavities present. The groundmass in each of the two stones is of fine silica, but the dark portion contains minute black specks in large numbers. It must be that these small, black specks interfere with the scratching power of the grains of silica by filling in the spaces between the points and thus forming a glaze, for there seems to be nothing else which can account for the difference in the quality of the two stones. Tests made show that the black coloring particles are almost entirely carbon, with a very little iron.

A defect in the stone from some quarries is due to the uneven distribution of the rhombic cavities. In this case the change occurs in the stratification planes and shows clearly that the amount of lime deposited in the original stone varied at different times. As a result the stone is composed of bands generally a few inches in thickness and of different densities. There is no change of color, the stone being uniformly white, and the bands are not easily perceptible. It is the custom to trim the blocks of Ouachita stone at the quarries into a shape convenient for sawing, which is usually rectangular or approaching that shape. No thought is given to the original position of the stone, so that when sawed this banded material is very sure to produce whetstones containing areas of unequal hardness. From this cause the stone has a bad name and the quarry is not worked. If, however, the plane of stratification were marked on the stone as it comes from the quarry, and if the large faces of the whetstones were sawed parallel to these planes, there is no reason why good whetstones should not be made from this banded rock.

Although the number of difficulties against which the prospector has to contend is formidable, the Ouachita stone of good quality has been found in very much larger quantity than the Arkansas. It is fortunate that this has been the case, for there is only a small demand for Arkansas stone, while the annual consumption of Ouachita is many times greater.

Production of rough stone.—The total production of rough novaculite in 1889 was about 1,100,000 pounds. Of this only about 60,000 pounds were Arkansas stone, which gives for rough stone about seventeen times as much Ouachita as Arkansas. In manufacturing, the waste of Ouachita stone is

estimated at 50 per cent; on Arkansas it is 75 per cent, so there is thirty-four times as much Ouachita stone put on the market annually as there is of the Arkansas.

The Ouachita stone is shipped in much larger blocks than Arkansas stone, blocks of forty or fifty pounds weight being about as small as the manufacturers care to buy, for small blocks give more waste. From this minimum the blocks of Ouachita vary in weight up to 1500, or even 2000 pounds. The prices now average about $1\frac{1}{4}$ cents per pound for the rough stone delivered at the railroad.

Manufacture.—The same machinery and methods are used in the manufacture of Ouachita as in that of Arkansas stone, though having a more perfect material to work with there is not much skill required in the laying of the stone in the gang-bed, and being much cheaper than the Arkansas stone there is no necessity for such great care in saving fragments. As the stone is handled in larger quantity a regular system of sawing can be employed; thus the first cuts are two inches apart, the two-inch slabs are cut in eight-inch lengths, and these into whetstones one and one eighth inches in thickness. The great mass of stone is manufactured in this shape, all other forms of stone requiring special adjustment of the saws.

After a careful sorting the stones go to the rub-wheel. The Ouachita stones do not get their final finish on the wheel as the Arkansas stones do. The water absorbed in the sawing and rubbing processes gives the stones a bluish or greenish color which the manufacturers think objectionable, so the stones are carried to a drying room and kept until dry at a temperature of about 90°. With the disappearance of the water the stone takes a pure white color, more attractive to look at perhaps than the color of the water-soaked stone, but obtained, there is reason to believe, at the expense of some of its good quality. After drying, the stone is finished by rubbing with pumice stone. This process the manufacturers call cleaning, and it does have something of that effect, because the pores of the stone are liable to become filled to some extent with dirt in the sawing and rubbing processes, so that the stone may have a grayish appearance instead of the natural white color; the pumice restores the white color. There are other results, however, from this process which do not commend its use. In the first place the powder from the pumice gives a false impression in regard to the grit of the stone; a person unacquainted with the Ouachita stone would imagine from the presence of the loose grit on the surface that the stone was a soft, fast-wearing one like many sandstones, whereas in reality it is a hard stone; the very gritty feeling which the pumice gives it is thus liable to lead to disappointment on the part of the buyer, who may expect much faster work from the stone than it can do. The Ouachita does not cut as fast as the coarser sandstones, but is remarkably fast for a fine-grained stone and needs no external assistance to make known its merits. These are matters of minor importance, however. The most pernicious result from the use of pumice is that imperfections in the stone are frequently concealed by it; the very slight differences in appearance between harder and softer portions of the stone are obscured by the covering of white powder, so that inferior stones can be placed on the market with all outward appearances of good ones. A large amount of poor stone has been manufactured in the past and has tended to give the Ouachita stone a bad reputation in some quarters. This is one reason why the business is not so large as it should be. There is a sufficient quantity of good stone to supply the market; it is very short-sighted policy, under these conditions, to put inferior stone on sale. For these reasons then "cleaning" with pumice should be abandoned. The dirt could probably be fairly well removed from surface cavities by holding the stone under a jet of water immediately after it comes from the rub-wheel, and before the surface has a chance to dry. Then if the stones were sorted while wet, when any imperfections are more easily seen, and packed in boxes before they became very dry, they would come on the market in much better condition than they now do. It may be urged that if full of water the stones will not take up oil; but the surfaces of the stone are almost certain to dry out somewhat, so that all the oil necessary will

be absorbed, indeed, it is better to prevent the absorption of too much oil, for in quantity it tends to "gum up" the stone. There is one slight objection to putting the Ouachita stone on the market while wet, and that is that as the stones are sold by weight there is a small sum paid for water; but in the denser varieties the amount is hardly appreciable and in the most porous it is not over 7 per cent. The price paid for water may be considered as a premium on the more porous stones and as such it is deserved, for the more porous stones are the scarcer ones and the best stones for general use. If compared with other stones, however, the more porous ones are cheaper since the water contained is lighter than the silica which replaces it in the denser stones; these differences of weight are too small to be taken into account except in a large quantity of stone.

The very best stones are now given a trade mark and wrapped in papers before packing; it would be well if all stones were so marked that the purchaser might distinguish between cheap stones and good ones. As things are now, and on account of the ignorance of dealers in regard to the different qualities, there is nothing to prevent the selling of inferior stones for good ones.

Whetstones of the first quality are now quoted at 28 cents per pound net, while the prices for inferior stones range to 14½ cents per pound. Large quantities of Oauchita stone are manufactured into "slips." The stone for the slips is selected and skilled hand labor is required to finish the rounded edges, so the prices are slightly higher, ranging from 25 to 32 cents per pound. Slips are used chiefly by carpenters, the rounded edges serving to sharpen gouges. Small whetstones called penknife pieces sell at 30 cents per pound. Wheels from three quarters of an inch thick up to five inches in diameter are quoted at 45 cents per inch. Files and kitchen stones are also made from Ouachita stone, but while the stone is much faster cutting than the Arkansas it is too brittle to gain much favor in these slender forms. A dense variety of Ouachita stone has been found serviceable in carvers' tools. The estimated waste of Ouachita stone in manufacture is 50 per cent; this seems to be rather high, just as 75 per cent seems so for the Arkansas stone, but all the manufacturers agree on these figures.

Until recently F. E. Dishman, of New Albany, Indiana, bought Arkansas and Ouachita stones at Hot Springs and manufactured all the articles made at the other factories, but not in such large quantities. This factory is not now (December, 1890,) running (see p. 78); but Louis, in Jeffersonville, has started his factory again. The Barnes Brothers, at Hot Springs, manufacture whetstones by rubbing down small pieces of stones on a rub-wheel. They have no gang-saw, so all the work is done on the wheel, which is run in connection with a small grist mill. The amount manufactured is small and the stones are sold principally at Hot Springs.

The chief use of Ouachita stone is for whetstones for the coarser tools. The amount of manufactured stone put on the market annually is about 400,000 pounds, if the estimate of waste is correct. Chase exports annually about 60,000 pounds and the Pike Manufacturing Company probably ships about the same amount. Exact figures cannot be obtained, but if the exports of Ouachita stone be taken at 100,000 pounds, and rated at 20 cents per pound, the exports of Ouachita stone alone nearly balance the total value of imported stones. The total value of imports in 1887 was *$21,479, and it was probably no greater in 1890.

THE WHETSTONE INDUSTRY IN ITS RELATION TO THE STATE OF ARKANSAS.

Estimate of the stones.—From the long time that stones from the Hot Springs region of Arkansas have been known in the market; from the gradual increase in production of finished stone up to about 500,000 pounds at the present time (1890), which indicates activity in the business both at Hot Springs and amongst the manufacturers; from the comparison of the amount of production of these stones with that of other stones for similar uses; from the consideration of the amount of these stones in use in this country compared with

*Mineral Resources of the United States, 1887.

foreign stones; from the amount exported; and finally from the high commendation which they have received by writers at home and abroad, it is evident that the Arkansas and Ouachita whetstones have gained a permanent place and high repute among the important articles of trade. The examination given them by the Geological Survey of Arkansas has revealed the secrets concerning their peculiar efficacy and shows that each stone is in its way unique. The properties of each are so well defined and depend upon such unusual causes that it is scarcely possible to conceive that any stones outside the novaculite formation of Arkansas will be found that can compete with them, for each in its way is as near perfection as things usually become. It may be concluded then that as long as these stones can be found in Arkansas, which will be for very many years, there is a permanent industry established in this State.

The value of the industry.—The whetstone business is not a great industry, but as the stones have not been thoroughly introduced into the home market, and are comparatively little known abroad, there is a possibility of enlarging it. It would seem that this industry should be the property of the State of Arkansas, and that the State should derive the greatest possible benefit from it. This is, however, far from being the case, as the status of the industry at the present time shows. The Mineral Resources of the United States for 1888 estimates the value of rough oilstone produced in the United States for that year at $18,000. This included a small quantity of other stones besides those from Arkansas, so that the estimate from Arkansas may be called about $16,000, which is not far from the present value of rough stones. Sixteen thousand dollars per year then is the income which Arkansas is at present getting from her whetstones. The estimate of the production of rough stone by the same authorities would indicate a total of about 1,300,000 pounds or more, but there is reason to believe that this is exaggerated; it is probably nearer 800,000 pounds of Ouachita and 60,000 pounds of Arkansas, though these figures may be too low. It may be estimated that the manufactured product of Ouachita is 400,000 pounds. Twenty cents per pound is not too high an estimate for the average price of the manufactured stone. At this rate the value of the manufactured product of the Ouachita whetstones is $80,000. If the average price of Arkansas stone is taken at $1.33⅓ per pound there will be an addition of $20,000 from this source. The total of $100,000 should therefore be the annual income to Arkansas instead of the present $16,000.

Manufacture at Hot Springs.—The manufacture of finished stones was attempted at Hot Springs some years ago, but through ignorance of the business and of the stone, through lack of co-operation of quarry owners, and through lack of local encouragement, the business did not succeed. Hot Springs should be the seat of manufacture of the Arkansas whetstones; and an industry which will give steady employment to upwards of fifty men, mostly skilled laborers, and bring into circulation in the city $84,000, as a low estimate, more than it now has annually, is worthy of local encouragement.

There are many conditions existing in the whetstone business at the present time which indicate that it is an opportune one for the transfer of the manufacture of whetstones to Arkansas. There are but few men in the whetstone region who understand the qualities of the various stones, know the manner of their occurrence and their changes, and know how to work them to the greatest advantage. There may be many who think they understand the business, for it appears very simple, but it has been said, and doubtless with truth, that more money has been lost in the whetstone business at Hot Springs than has been made; so that those who have not had long training should beware how they enter a business the details of which they do not understand. The men who have been long in the business, understand it and control the best quarries; they have been engaged in sharp competition for years past, in consequence of which the prices of rough stone have fallen so low that there is but a small margin of profit in its production. The condition among the manufacturers is worse than with the quarrymen. One factory has already closed on account of competition, and the two others are barely covering the cost of production. Both are running under high pressure and crowding the market with stone. In their hot competition the reduction of prices on both sides has obliged them to buy chiefly inferior rough stone. Thus the market is being flooded at the present time with stone of inferior quality which will not give the Arkansas stones the good reputation they deserve, even if the present reputation is not positively injured.*

The reasons why a factory should be established in Arkansas are obvious. At present useless freight is paid from Hot Springs to New York on an amount of stone more than equal to the total manufactured product. And when it is considered that much manufactured stone is shipped back again to Hot Springs for sale, the payment of double freight seems to be a needless part of the cost of production. The Arkansas whetstones would have a much larger market if they could be sold cheaper. Prices are as low now as they can become under existing circumstances, and manufacture at home is the only way to reduce the cost of production. The reduction of freights is only one item to be gained by manufacture at Hot Springs. It is better to locate the manufactory at Hot Springs than in the north, because if located in the north, another company could at any time start a manufactory in Arkansas which would manufacture at lower cost in consequence of being near the source of supply. With an old company already established in Arkansas this would not be so likely to happen. The cost of production should be decreased as much as possible so that these stones can more nearly compete with the other varieties of whetstones. The Arkansas whetstones never can become so cheap as the sandstones and schists, but the price can be so reduced that on account of their superior qualities they will be preferred. With high prices for the whetstones

*Since writing the above it has been learned that an agreement has been entered upon by the two New York manufacturers and the largest quarry owner in Hot Springs by which the prices of stone are advanced a little; but similar agreements have been made before aud cannot be relied upon to place the whetstone industry on a firm basis.

from Arkansas, the preference will be for the inferior stones at low prices. There is a large waste of good stone now at the quarries from the trimming which it is necessary to give the blocks in order to reduce freights; this waste would be saved. As there would be less handling, larger blocks could be used, and so another saving of stone made. The blocks which are now too small to be shipped could also be used. There would be the advantage of sawing the stone while fresh from the quarry when it is apparently softer than it is after drying. The cost of quarrying could be reduced by the use of more machinery; much useless labor could be saved in quarries by the use of prospecting drills, and prospecting for new quarries could be done systematically and less expensively than at present.

The only argument which has been raised against the manufacture at Hot Springs is that sand suitable for sawing is wanting. This cannot be regarded as a strong objection, however, for while sand as good as that used by Chase in New York City may be wanting, the Ouachita River sand is equal to that used at Manlius, New York, or at New Albany, Indiana. If better sand were wanted from elsewhere the cost would not be much greater than it is for the northern factories, while Ouachita River sand could be obtained cheaper than any of the northern sands except that in use at New Albany, Indiana. Excellent sawing sands are reported in Eastern Arkansas along Crowley's Ridge.*

The advantages which would result from having the whetstone business consolidated at Hot Springs are incalculable. The City of Hot Springs is known widely as the commercial center for fine whetstones, and many orders are sent there directly by parties who wish to get the genuine stone, and who are suspicious of stone manufactured at a distance. Thus stones manufactured at Hot Springs and bearing the Hot Springs brand would be received with more confidence in the market. This confidence would be increased in consequence

*Ann. Rep. Geological Survey of Arkansas, Vol. II, 1889, Crowley's Ridge, by R. E. Call, p. 137.

of the manufacture by a responsible company and by the branding of every stone. Such a strong company could do more in the way of trying new machinery, experimenting with the stone and testing it for new uses, several of which are suggested in chapter XIII, and could take more vigorous measures to extend the use of the stone. Thus all the conditions seem favorable for the formation of a stock company with a factory at or near Hot Springs, which could establish a valuable industry for Arkansas. Such a company once established must for its own interests turn out only first-class products; and it cannot well become a complete monopoly, for the novaculite formation is so widespread that other factories could be located if monopoly prices offered an inducement for them. Competition with other stones would be sufficient, however, to prevent any danger of monopoly. The limits to which this company could go seem clearly defined, so that it would in its own interests be a credit to itself and give Arkansas the whole honor of producing the best whetstones known in the world.

CHAPTER VII.

Petrography of the Novaculites and of Allied Rocks.

An idea of the microscopic structure of the commercial varieties of stone from the Arkansas novaculite formation has already been given, but in order to ascertain the origin of the stone it has been necessary to examine numerous thin rock sections from other parts of the formation. These have been compared with sections of similar rocks from other regions and also with numerous sections of rocks of other varieties, to which several writers have thought the Arkansas novaculites were allied. Thus, in particular, cherts from the northern part of Arkansas have been examined. A few descriptions of similar rocks in other localities, taken from various geological reports, are quoted here.

These descriptions are classed with reference chiefly to the origin of the Arkansas novaculites, though abrasive qualities also have been taken into account in some cases. Two large groups are formed; one including the rocks of the novaculite area of Arkansas, the second including all rocks from outside this area. The major groups, together with their sub-divisions, are tabulated in the following scheme:

ROCKS OF THE ARKANSAS NOVACULITE AREA.	POSSIBLE ALLIES FROM OTHER LOCALITIES.
I. Ouachita stones, originally containing a large percentage of lime.	I*a*. Stones resembling the Ouachita.
II. True novaculites, originally containing a small percentage of lime.	II*a*. Novaculites.
III. Siliceous shales, little lime, but with more abundant clay.	III*a*. Siliceous shales.

IV. Sandstones and quartzites.	IV*a*. Sandstones and quartzites.
V. Chert.	V*a*. Cherts.
	VI*a*. Chalcedony.

The following are the descriptions of the microscopic characters of several whetstones examined for the purpose of determining the peculiarities of their abrasive qualities:

Rocks of the Novaculite Area.

OUACHITA STONES.

The stone agreed by the quarrymen to make the best whetstones for general use (see page 106) comes from the No. 6 quarry of Mr. J. J. Sutton of Hot Springs. Since this is the standard whetstone, and since it is found at one end of the great "lead" or bed of Ouachita stone now worked, it is a convenient one with which to begin. Moreover, the change in the character of the Ouachita stone along this "lead" toward the northeast is a progressive one from this point. The various prepared sections are described as slides, and Nos. 1-9 are arranged in the order of their occurrence in the novaculite rocks.

Slide No. 1, from Sutton's quarry No. 6.

Specimen, grayish-white, homogeneous, porous. With a good lens, the angular outlines of the pores can be seen.

Under the microscope the groundmass is seen to be composed of cryptocrystalline silica—extremely fine quartz grains, extinguishing in polarized light, but too small to give any polarization colors or other optical characters. The separate grains average less than .01 of a millimeter in diameter, there being from 6 to 10 grains in a linear distance of .05 mm. The extreme variation is about .01 to .001 mm. in diameter. Coarser grains of quartz having polarization colors of a low order are plentifully scattered through this mass. These grains average .05 mm. in diameter. They have usually a sub-angular form with somewhat serrate outlines due perhaps to the compression of the fine grains of the groundmass into the larger grains, perhaps to the disintegration of the larger grains into the finer cryptocrystalline silica. If this latter process is progressing, however, it is only to a limited extent for some perfectly rounded grains are well preserved and many show part of an originally water-rounded surface. There are also seen occasional very fine black and brown particles, which may be particles of carbonaceous or ferruginous matter; they are probably part of the original rock, though perhaps derived in part from the material with which the section was ground.

The pores are the most interesting features of this slide. Many of them show a rhombic outline, often obscured by intruded silica, yet very evident. By changing the focus it is shown that the outlines are sections across cavities having a rhombohedral form. In some cases the form is quite perfect and the grains of silica are packed about the edges of the cavity giving the appearance of a coursed layer in a mass of rubble as shown in the cut. (Fig. I.) Some of the smaller cavities have been filled by secondary quartz which gives polarization colors. Three measurements of outlines of these cavities were .08 by .08 mm., .06 by .06 mm., and .07 by .07 mm. One rhomb of secondary quartz measured .04 by .03 mm. in diameter.

It is evident that these cavities were once filled with a mineral which crystallized in a rhombohedral form. This was probably calcite, since this mineral would have been more easily dissolved than any other having the rhombohedral form. The presence of the coursed rubble shows that the arrangement of the particles of silica was completed before the calcite was leached out, and probably it was formed at the time of crystallization. The cogent reason for this latter conclusion is that the particles of silica of the "brick work" are not different from those of the groundmass and very likely owe their peculiar positions to the pressure produced by the crystallization of the calcite. In support of this idea we find that the coursed rubble never forms a complete layer, thus occurring as though accidental.

A drawing of the Ouachita stone as seen under the microscope is given in figure I.

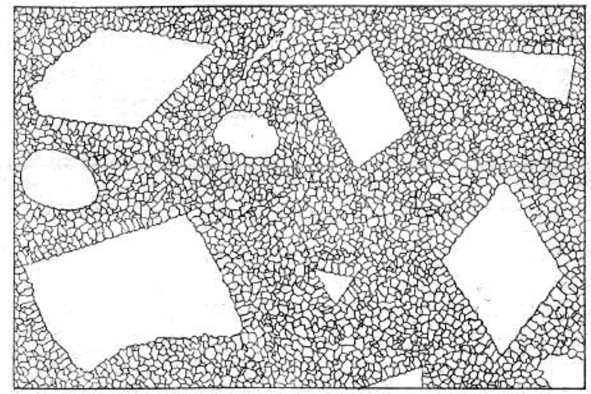


FIGURE I.

Slide No. 2, from Sutton's quarry No. 6.

This specimen is identical with No. 1, but in addition it contains red streaks. These are due to the presence of particles of reddish oxide or hydrate of iron. It is estimated that this stone contains on a low average eight cavities to the millimeter, which equals 80 to the centimeter, or about 200 to the linear inch.

Slide No. 3, from Sutton's quarry No. 6.

Examination shows that the stone is identical with No. 1 in every respect. The coursed rubble structure is very commonly found, and there are some good triangular and pentagonal outlines made by oblique cuttings across the rhombic cavities.

Following the whetstone stratum northeastward from Sutton's quarry No. 6 the rock becomes a little more dense, that is, the cavities are not quite so plentiful. It is also defective in places, the defects consisting of hard spots thickly distributed through the rock and rendering it unfit for whetstones. The spots are particularly abundant in the rock found in the vicinity of the old Polhamius quarry.

Slide No. 4. Hard spot in Polhamius' Ouachita stone.

No structure is visible that will explain the existence of the spot; its presence is only detected by a slight difference in color produced apparently by a somewhat greater density.

The microscope does not disclose any sharp line of separation between one of these spots and the rest of the stone; it all has the appearance of a Ouachita stone. The rhombs are small, averaging .05 mm. in diameter; their number is large, however, ranging from 8 to 16 to the millimeter.

Slide No. 5, from Whittington's "red" quarry.

A hand sample of this rock is pure white in color with a bluish tint. It appears to be a trifle more dense than Nos. 1, 2, and 3.

In the thin section it appears identical with the first three in every respect. It is possible, however, that the cavities are less numerous and that the thinner section makes them appear equally plentiful because they are less obscured.

Slide No. 6, from Whittington's quarry on section 8.

This specimen resembles the last very closely, but appears to be a little more dense. The cavities are noticeably less abundant and also seem a trifle smaller in size. Secondary quartz filling the cavities is well shown. In it were first noticed minute channels connecting one rhomb with another and also seeming to connect with larger channels. These channels have since been detected in the other Ouachita stones. They are interesting as showing that the rocks are subjected to a pretty free circulation of water; it was probably by this means that the lime in the calcite rhombs was carried away.

Slide No. 7, from Barnes' big quarry on section 8.

The stone is identical with No. 6 in physical appearance. The microscopic section is a thin one and so appears more nearly like No. 5 than No. 6, though it should be identical with the latter since the two quarries are very near each other.

Slides Nos. 8 and 9, from Sutton's quarry No. 1.

The stone is chalky white in color and dense in texture. The rhombohedral cavities are much less abundant and are of smaller size in this stone than in Nos. 6 and 7 though the quarry is not a mile distant. This is the last quarry on this lead and the difference between this stone and that from No. 6 quarry is quite striking.* The film of iron commonly outlining the cavities is

*The cavities are filled to some extent with brown particles; these must be derived almost entirely from the grinding material used in preparing the slide, for the natural stone has a very pure white color.

probably derived from the original material. There are many cavities which contain fine silica like that of the groundmass, some of this has evidently been forced in by pressure since the sides of the cavities are often bent in, some may have lodged inside during the grinding process, still others may represent a secondary formation. The last proposition, however, is a doubtful one, for the weight of evidence favors the view that any secondary silica deposited in these cavities forms single pieces which completely fill them.

Slide No. 10, from Wells' old quarry.

The stone is very similar in appearance to the other Ouachita stones, but it has a mottled brownish color due to the presence of more iron than usual. This is regarded as a poor stone; it glazes with use and is called "vitreous."

Microscopic examination shows that the stone is like all the Ouachita stones; it contains no unusual quantity of glassy quartz so it should not be called vitreous, but the iron acts as a cement for the grains of silica and binds them together so that the stone glazes instead of wearing away. The cavities are filled to some extent by intruded silica and iron particles which add to its density and its disposition to glaze.

Slide No. 11. Mottled Ouachita, from township 2 south, 18 west, section 12.

Specimen much like No. 10, but mottled with greyish black instead of brown. The stone is more open than No. 10, but has much black material in fine grains scattered throughout the groundmass of the stone and also collected into the cavities. When grouped thickly they produce the grey color. This stone is considered useless by the quarrymen. Some of its cavities have been produced by the rusting and removal of cubes of iron pyrite; and doubtless some of the black material is derived from this source, but most of the black particles are an entirely distinct mineral as explained in the description of slide No. 12. A little rhombohedral calcite still remains in this rock.

Slide No. 12. Black and white Ouachita, from Sutton's Ten-mile quarry.

This rock is like the last, but the dark portion has a pronounced black color which is sharply defined from the white. There is no apparent difference in the number or size of the rhombohedral cavities in the differently colored portions. The black part, however, contains a large quantity of the black particles noted in Slide No. 11. The chemical analysis of the black rock gives a larger percentage of loss on ignition than for the white,* thus suggesting that the material is carbon. The black stone pulverized and mixed with nitre deflagrates when heated on platinum foil. When heated in the open air the powder becomes white, thus proving that considerable carbon is present. There is some altered pyrite in the stone, but its chemical analysis shows only .03 per cent of ferric oxide while the carbon amounts to .4 per cent or more, so the iron is of less importance as a coloring matter than the carbon.

This stone is considered useless by the quarrymen. Like the last it is not different from other Ouachita stones except in the possession of carbon, so it must be that the black particles decrease the scratching power of the grains of silica by wedging in between them.

Slide No. 13. Ouachita stone of uneven texture, from 2 south, 18 west, section 30.

This stone weathers unevenly along the stratification planes, some layers being hard and some soft; though all the layers have a white color it is difficult to distinguish them on a broken surface. As in all stones from Nos. 6-12 the cavities are fewer and smaller than in Sutton's No. 6 stone; so in the section in question there seems to be a slight difference in the relative number of cavities in the two layers, the bluer or more dense one having fewer cavities.

Slide No. 14. Soft Ouachita, from 2 south, 18 west, section 15, northeast quarter of the northwest quarter.

This stone is pure white and rather friable when fresh from the quarry. It looks and feels coarser than Ouachita stone, and would be considered a sandstone in any other association,

*See Chapter VIII., first table of analyses.

though the bed from which it was obtained is apparently the stratigraphic equivalent of that from which were derived specimens 1 to 9 inclusive. It would not be recognized as a Ouachita from its microscopic characters. It has a groundmass of fine silica, but the grains composing it have several times the diameter of those in the Ouachita stones. The grains moreover are not irregular fragments, but have straight sides and regular angles. They are clearly of secondary formation and have taken a semi-crystalline form. They grade into larger fragments which give low polarization colors and more regular outlines, while these in turn grade into well defined quartz crystals giving hexagonal cross sections and pyramidal points. These large crystals are in groups, and calcite is associated with them in some places. It is clear that the calcite is decomposing and is being replaced by quartz; the calcite does not show the expected outline of large rhombohedrons; instead, it has been so decomposed from the outside that the boundary now consists of a very irregular outline of cleavage planes. The calcite originally formed a much larger proportion of this stone than of the Ouachita stones, and the decomposition processes have penetrated into these masses so deeply that the section shows quartz entirely surrounded by decomposing calcite. The manner in which the calcite decomposes is noteworthy; with a high power it is seen that very fine cleavage cracks are developed at the edge of the calcite, producing a succession of narrow spectra in polarized light and presumably the calcite is dissolved in thin slices. There is one interesting case of replacement of calcite by quartz in which the larger cleavage planes of the calcite are still visible in the quartz, though the mass of quartz extinguishes all at once in polarized light, showing that it is essentially one body. Minute fragments of calcite are pretty plentifully scattered through the mass and have the appearance of particles remaining after a very general decomposition has taken place. No chalcedonic silica is seen, and a test made for soluble silica shows that it is all insoluble. There are a few cubes of pyrite but they are often altered to limonite. The cubes apparently preceded the quartz in the order of crystallization.

Slide No. 15. Bud Jones' Ouachita stone.

The specimen is a surface rock, and consequently is so stained and altered that it is not truly indicative of the rock below. It contains considerable iron and earthy material, and the cavities though abundant have their rhombic outlines much obscured. The silica of the groundmass is exceedingly fine and the individual grains are more clearly defined. The usual larger quartz grains are present. This stone has every characteristic of a good whetrock; and provided the quality in mass below the surface is as good as the surface indications denote, it would prove profitable to work this claim if the facilities for transportation were better.

Slide No. 16. Ouachita stone known locally as "sandstone," from Brazil's postoffice, 1 north, 16 west, section 6.

This stone looks and feels porous and coarse. Its color is dirty white, but it would probably be whiter a few feet below the surface.

This is a very porous Ouachita stone. The groundmass is homogeneous; the cavities are pretty uniformly small and very numerous. Large grains of quartz are not numerous and the secondary quartz is uncommon. If it is homogeneous and free from flaws in large masses this stone should make good whetstones for broad-edged tools requiring a soft stone.

Slide No. 17. Ouachita stone from near Point Cedar, 4 south, 21 west, section 30.

This specimen appears to be identical with Sutton's quarry No. 6 stone. The cavities are of similar size, as numerous and as evenly distributed as those in slide No. 1. The groundmass is composed of the fine cryptocrystalline silica, with some large grains. Chalcedonic silica in small spherulitic spots showing a fibrous structure is pretty commonly scattered through it. This rock should make excellent whetstones.

Slide No. 18. Gray Ouachita, from 2 south, 27 west, section 21.

This is a gray, porous rock looking like a quartzose sandstone, though lacking the vitreous lustre. It is a true Ouachita stone, however, and the cavities are large, showing that the proportion of lime in the original sediment was unusually large, approaching one-third of the total bulk. The outlines show that the lime crystallized in bunches of rhombohedrons more commonly than in single ones. The coursed rubble described on page 104 is common, and secondary silica has been formed to some extent. Larger quartz grains are rather common. The coloring matter seems to be chiefly limonite in the form of dust.

This stone should make good whetstones for the coarser kinds of work.

Slide No. 19. Ouachita stone, called "spongy sandstone," from 4 south, 18 west, section 27.

This specimen has the appearance of a coffee-colored Ouachita stone. It contains a considerable percentage of iron particles, largely in lines and small bunches, and a few pieces of muscovite. The cavities are both large and numerous. Secondary quartz fills some of the rhombohedral cavities. Unless the iron is detrimental, this stone should be a good whetstone.

Slide No. 20. Soft yellow Ouachita, from Hot Springs.

This specimen and the succeeding ones are from what is known as the upper bed of novaculite, from which very probably the four specimens last described were obtained.

The cavities are numerous. The yellow coloring matter is iron arranged to a large extent in parallel lines, which arrangement possibly indicates original bedding. When less weathered, it would probably be of use for whetstones.

Slide No. 21. Novaculite conglomerate, from Hot Springs.

This specimen was found close by No. 20. It consists of small whitish novaculite pebbles of various sizes, generally rounded and often containing a red nucleus. This gives the stone the appearance of a concretionary formation, which appearance is strengthened by the presence of a black metalliferous cement binding the pebbles together. The section shows that the pebbles are novaculites, and composed largely of cryptocrystalline silica; but they contain also a large amount of coarser grained quartz, chiefly of secondary origin. From the presence of one striated grain, it is inferred that some of the large grains are original. The reasons for this belief are: First, the striations show that the grain has been subject to pressure; second, the pressure was exerted in some older rock from which this fragment was derived, for the grains formed in this stone are not striated. The red nuclei of the pebbles are simply dense aggregations of iron particles.

Slide No. 22. Soft Ouachita, from township 4, south, 26 west, section 12.

This stone occurs in a soft bed of silica powder, and constitutes its harder portion. It is identical with the Ouachita stone. It is present only as lumps in the powder, and furnishes a connecting link between the powder and the Ouachita stones. The section made is extremely thin, so that the grains of silica are but dimly seen; they also appear smaller than in the thicker slides, and show more nearly their true dimensions. The cavities are very numerous and render the stone weak. These three grades of siliceous rocks may be considered as showing variations in the original sediments; thus the Ouachita stone contained a little carbonate of lime, but the stone remained comparatively strong after the leaching process had removed the calcium carbonate; the soft Ouachita contained more carbonate, the loss of which made the stone weak; the powder is the remainder of a very calcareous stone of the Ouachita variety, which was not strong enough to retain its rock structure after the carbonate of lime was removed.

Slide No. 23. Cherty stone, from the same locality as No. 22.

This specimen had the form of an ovate nodule, six inches in its maximum diameter. It also came from the soft powder, and closely resembles a Ouachita stone. On the outside, however, it has weathered to a friable rock, having a chalky feeling; inside, the stone becomes harder, and round spots, having a flinty appearance, are very noticeable. The strong resemblance this stone bears to many cherts, together with its

evident connection with the Ouachita stones, makes its examination under the microscope important.

With a low power, the round, flinty spots are seen to represent organic forms, probably crinoid stems, and have angular instead of rounded outlines. These outlines have been somewhat obscured, but one an eighth of an inch in diameter has ten sides. Smaller imperfect forms seem to have had about the same number. There is one clearly defined pentagonal form.

The groundmass of the rock is fine silica, as in all novaculites. Rhombohedral cavities are rather scarce. A peculiar feature is a milky, clouded appearance, which is especially noticeable surrounding the crinoid outlines. It is wanting within, except in a core also having an angular outline. The white material resembles calcite somewhat, but no effervescence was obtained with strong hydrochloric acid. This whitish material is described in the account of slide No. 58.

Slide No. 24. Novaculite conglomerate, from Brodie Creek, 1 north, 13 west.

This is a peculiar stone, in which quartz and other pebbles can be distinguished in a siliceous matrix, the whole having a flinty aspect. The microscope shows numerous quartz grains varying up to .5 mm. in diameter. Sometimes the rounded outlines are well preserved, but generally they are jagged, either from decomposition around the edges or from the impressions of the small surrounding grains. The groundmass is silica, mainly, perhaps entirely, quartz; is much coarser than that of novaculite, and much of it is in vein-like form. The large quartz grains are frequently bunched together. There is considerable clay present, and iron in clustered brown and red granular masses is also common; little cubes of brown limonite probably represent former pyrite cubes.

TRUE NOVACULITES.

Slides Nos. 25, 26, 27, and 28. Arkansas stone, from Sutton's quarry and other localities near Hot Springs, in 2 south, 19 west, section 27.

These stones are pure white with a bluish, watery tint and the appearance of chalcedony, translucent on thin edges, dense and hard; lustre dull resinous, or waxy. The groundmass is of cryptocrystalline silica as in the Ouachita stones, composed of grains similar in size. Small rhombohedral cavities are plentiful, but not in such large numbers as in the Ouachita stones. These cavities are often filled with secondary quartz. Other quartz grains of about the same size as the secondary grains, namely, .05 mm. in diameter, have jagged edges and no well marked outline. The average size of the cavities is about .05 by .05 mm. No fibrous structure is seen in the grains of the groundmass.

Slide No. 28 is thinner than the others and the individual grains appear smaller and stand out more sharply. Though the grains of silica are so small they apparently contain fluid enclosures. A little fine muscovite mica is seen.

Slide No. 29. Brown and red Arkansas stone, from the Gulpha gorge, Hot Springs.

This stone is the same as Nos. 25, 26, 27, and 28, but is colored red and brown. The only new features developed by the microscopic examination are those connected with the arrangement of the particles of coloring matter. These consist of reddish brown specks of iron which occur singly, in oval clusters, or in linear form. Diffused through the stone is a reddish yellow powder in rounded aggregates sometimes dense throughout and having an iron particle in the center; sometimes the central particle is wanting; again, the dust forms a ring about the particle, and sometimes there are two concentric rings. The dust aggregates also assume a linear form and surround linear collections of iron particles. In some cases the dust is apparently collected to form the large particles, in others it seems to be diffused from the particles. Some particles and groups of particles of iron have no such concentric arrangement of the dust.

Slide No. 30. A "vitreous" spot in Arkansas stone, from Polhamius' quarry.

To the unaided eye this spot appears to be merely a more

dense part of the stone, though some of the spots have a vitreous lustre. The groundmass is coarser than that of the other sections and there are but few cavities. The "vitreous" spot consists of silica grains larger than those of the surrounding groundmass, and grouped in an oval form having no definite limit but merging into the surrounding mass. The grains of the spot have the closely compact and interlocking appearance common to secondary quartz and very probably have a secondary origin. They are large enough to give weak polarization colors; if still larger, as they well may be in other spots, the faces of the grains might be large enough to give the stone a vitreous lustre.

Slide No. 31. Fine-grained Arkansas stone, from Rockport, 4 south, 17 west, section 16.

This is like other Arkansas stones, but appears to have a finer texture. It resembles chalcedony in outward appearance even more than the other Arkansas stones do. The microscopic characters do not show as much difference between this stone and those previously described as one would expect from its physical appearance; the groundmass is no finer grained, and the only difference is in the number of cavities, which are rare. That such a result could be produced by this cause alone is not remarkable when it is considered that the sole difference between the Ouachita and the commercial grades of Arkansas stone lies in the size and number of the cavities; this specimen merely shows the result of their further diminutions.

Slide No. 32. Black and white Arkansas stone, from 2 south, 18 west, section 26.

This specimen is fine, dense, and flint-like in appearance; translucent on the edges, and shows black coloring matter disposed in fine lines. The groundmass is like that of No. 31; there are, however, numerous small pores or channels in which the black particles of coloring matter are found. The quantity of coloring matter is very small; it is probably carbon, as in the black Ouachita stone. According to the chemical analysis of this rock the loss on ignition was .09 per cent; since there is only this very small quantity of carbon present, even with no allowance made for water, it is demonstrated that an exceedingly small amount of coloring matter is necessary to give a deep black color to fragments not more than a few millimeters thick. Quartz has been developed in some of the channels, partly or completely filling them. There are a number of pieces of detrital muscovite mica in the section.

Slide No. 33. Cherty novaculite, from 4 south, 20 west, section 13.

The spongy appearance of this stone is caused by its irregular decomposition and reminds one of chert.

The section shows numerous small rhombohedral cavities, containing more or less iron or dirt derived from the grinding material. There is considerable iron present in small streaks and lumps and in the form of a yellowish brown dust which frequently forms rings, or ovals, and spherical or oval shells. Secondary quartz occurs in veins and irregular bunches, and sometimes lines cavities. A few spherulitic spots of chalcedonic silica are seen. It is the removal of the rusted iron which makes the stone appear so decayed.

Slide No. 34. Cherty novaculite, from 4 south, 20 west, section 16.

This specimen resembles the last one considerably, but is less decomposed. The resemblance is also noticeable under the microscope. The groundmass is the same, and there are the same nodules, lenses, and veins of coarser quartz. It also resembles the tertiary chert, No. 49, from Rockport, but is wanting in the large detrital grains. Iron is abundant, and there is considerable fine muscovite of secondary formation.

Slide No. 35. Banded novaculite, from 4 south, 19 west, section 24.

The specimen shows alternate gray and black layers varying in thickness from a quarter of an inch to mere lines, the gray layers preponderating. The gray layers are translucent even when thick, but the black ones only on thin edges. There are numerous shining specks in the gray bands; similar specks are less abundant in the black ones. The groundmass is of cryptocrystalline silica with occasional spots of fibrous chalcedony; there is also present a little quartz, both detrital and secondary. The black bands are due to the presence of brownish black grains and aggregations which are probably composed of carbon, though some iron may be present.

The shining specks have a rhombohedral form and with cold dilute hydrochloric acid give a lively effervescence, indicating that the mineral is calcite. Some of the rhombs appear to be decomposing, but the process has not gone far enough to exhibit the empty cavities found in the Ouachita stones. In size the sections vary in dimensions from .13 mm. by .12 mm. to .03 mm. by .03 mm. and even smaller. Some other measurements taken were .13 mm. by .07 mm., .16 mm. by .07 mm., .08 mm. by .04 mm., and .04 mm. by .03 mm. Many of the rhombohedrons have more or less foreign matter collected in their centres; this is sometimes sufficiently abundant nearly to fill the rhomb. This is probably iron, and its presence in the calcite in this specimen will serve to explain the iron stain so commonly found defining the outlines of the cavities in the Ouachita stones.

The calcite crystals are much more numerous in this specimen than are the cavities in the Ouachita stone from Sutton's quarry No. 6 (Slide No. 1).

Slide No. 36. Spotted gray novaculite, from 4 south, 19 west, section 24.

This specimen is like No. 31, but contains numerous minute white spots. The groundmass of silica is a little coarser than usual and there is but little coloring matter present. The "spots" are rhombohedrons of calcite, but are much less plentifully distributed than in the last specimen. They are commonly bunched together in complicated masses of rhombs varying in diameter from .3 to .05 mm. A brown streak across the section was formerly a small vein of iron. Bordering it are numerous cubical cavities, showing the former existence of pyrite; a few of the cubes are still entire, though altered to limonite.

Slide No. 37. White novaculite, from Jack Mountain, 4 south, 19 west, section 20.

This specimen is dense, bluish, somewhat cherty looking inside, weathering to an opaque, hard, chalky stone on the outside. The section shows a stone somewhat more dense than Nos. 8 and 9. The dense interior contains the calcite rhombs entire, while nearer the surface the calcite disappears and the stone is opaque.

Slide No. 38. Gray novaculite, from three miles north of Mt. Ida, Montgomery County.

This stone is opaque except on very thin edges, and is therefore scarcely a true novaculite, but its massive structure gives it a place among the novaculites rather than among the siliceous shales. It contains minute cavities also, which fact connects it with the novaculites.

The microscopic examination shows the stone to be essentially a novaculite. It has the usual groundmass of fine grains of silica, and frequent rhombohedral cavities, though not in sufficient numbers to make it a Ouachita stone. There is much dust present and this gives the stone a gray color. Fine quartz veins are numerous; many secondary quartz grains have formed in small bunches; in some spots the shadow of a chalcedonic cross may be observed on revolving the table.

Slide No. 39. Gray novaculite, from two miles south of Oden, Montgomery County.

This specimen is bluish gray, massive, but with parallel lines which indicate the original bedding planes; thus this stone is more closely associated with the siliceous shales than No. 38. Examination of the thin section shows that the laminated appearance is due to the collection of iron particles along parallel lines. The groundmass is of fine silica as usual. Some secondary chalcedonic silica has formed in small spots; and secondary quartz has formed in large spots, in the rhombic cavities, and in veins; it also occurs frequently in fine lines along the planes of lamination. The secondary silica, as in all other novaculite sections, seems to be rather a metamorphic product of the original silica than a deposition of new silica derived from exterior sources. Rhombic cavities are common.

SILICEOUS SHALES.

Slide No. 40. Whetstone, from an old quarry near Blocher post-office, 1 north, 18 west, section 24.

The specimen shows clearly the fissile structure of shales, yet it is purely siliceous, being translucent on the edges. It is almost massive in structure, and in color is yellowish white. The groundmass of silica is coarser than usual, and contains considerable secondary quartz. The few rhombic cavities seen are sharply defined, and about them the coursed rubble structure is shown. Judging from its appearance this stone would probably soon glaze when used as a whetstone.

Slide No. 41. Siliceous banded shale, from Quarry Mountain, Hot Springs.

The specimen looks like a clay slate, being opaque, and having thin, strongly colored layers in the stratification planes. The grains of the groundmass of silica seem generally smaller than in the novaculites, but this may be because the section is thinner. The coloring matter consists chiefly of a fine gray dust, probably clay, which produces differently colored layers according as it occurs in greater or less quantity. Iron is present in some layers and influences the coloring. There are many small elongated grains present, which give brilliant polarization colors and extinguish parallel in polarized light. They most commonly have the longer axes parallel with the stratification planes, but are found at all angles. These are minute flakes of muscovite mica of secondary origin, very uniform in size and not all parallel to the stratification as they would be if they were detrital. These flakes vary from .03 mm. to .01 mm. in length, and are about one-third as wide as long.

Slide No. 42. Siliceous banded shale, from 4 south, 22 west, section 34.

This specimen resembles No. 41 in general appearance, but the siliceous layers are purer, and the other layers less siliceous, so that the contrast in texture is greater.

The softer layers contain much iron, the others are quite free from it. The iron is chiefly in the form of dust diffused through the ferruginous layers, but is often gathered into rounded aggregations and in irregular strings. Fine silica forms the groundmass in all the layers, some of which are largely composed of coarser detrital quartz. The ferruginous streaks in particular abound in this coarser material. Spherulites of chalcedonic silica are common, especially in the ferruginous portion. There are some rhombic cavities, and these are generally filled to a large extent with iron. Considerable secondary muscovite like that seen in the last section is present.

Slide No. 43. Siliceous shale, from Bear, 2 south, 21 west, section 29.

Fissile structure is very apparent in this specimen, and the stone probably owes its strength in a measure to the cement of iron which is present in considerable amount. In the section the groundmass of cryptocrystalline silica is found to consist of very fine particles mingled with considerable ferruginous material and dust. The secondary muscovite is also present. There are no rhombohedral cavities and very few coarse quartz grains.

SANDSTONES AND QUARTZITES.

Slide No. 44. Quartzose sandstone, from Quarry Mountain, Hot Springs.

This is a yellowish-gray, fine-grained, homogeneous, but rather porous sandstone, apparently somewhat altered to quartzite. The microscope shows a groundmass of angular quartz grains of pretty uniform size. The quartz grains are bound together to some extent by secondary quartz, which has increased the size of the original grains and filled up the interstices between them. In size the grains vary from .2 to .01 mm. in diameter, averaging perhaps .05 mm. Striations produced by pressure are visible in a few grains. Cavities are numerous and the majority of them show rhombic angles, indicating that lime crystallized to calcite was leached from this stone as well as from the associated novaculites. There are other cavities produced by the rusting and removal of pyrite.

Slide No. 45. Quartzite, from Observatory Mountain, Hot Springs.

This stone is bluish-gray in color, dense and vitreous in texture. The section does not essentially differ from the last except that the quartz grains are a trifle larger and there are but few cavities in the stone. Some pyrite has been removed, as shown by parallel lines of iron particles representing the striations of pyrite cubes on the sides of some of the cavities. Iron is abundant through the stone, and probably cements the quartz grains together so closely that it forms a tougher rock than No. 44.

Slide No. 46. Quartzose sandstone, from Grindstone Ridge, in 5 south, 20 west.

This stone is coarse grained, light gray in color, and more like a sandstone in appearance than the last two mentioned. The section shows that the rock contains less iron and earthy material than do numbers 44 and 45. There are rounded, as well as angular quartz grains, and a few grains of decomposed feldspar are present. The quartz grains appear to have been crowded against and even into one another; many of them exhibit lines or striations, which probably result from pressure. Since these lines are not continuous from one pebble to another, and have apparently no relation to each other, they must have been produced, in some manner, on the original grain and in the original rock. Some of the quartz grains show secondary silica added to the original grain to form crystal faces as described by Irving in his article on quartzites.* One quartz fragment is filled with very fine needles which may be rutile. The quartz grains are larger than those in slide No. 45.

Slide No. 47. Calciferous sandstone from the gorge of the Walnut Fork, 2 south, 22 west, section 32.

Stone bluish black, abounding in small round grains of quartz having a bright vitreous lustre. The microscopic examination shows that the grains are of quartz, but unusually well rounded for detrital grains. There are, however, many subangular and a few angular grains. In size they average about 2 mm. in diameter. The small grains are noticeably angular. Cementing the quartz pebbles is a mixture of calcite with

*Fifth Annual Report of the U. S. Geological Survey, pp. 221-223.

particles of carbon, which give the blue-black color to the stone.

From the examination of these four sections of quartzose sandstones (Nos. 44 to 47) it seems probable that small fragments of quartz, owing perhaps to their lesser weight, are less easily rounded than larger ones, which would have a greater impact.

Slide No. 48. Vein of colored quartz in massive novaculite, from the vicinity of Magnet Cove, 3 south, 17 west, section 1.

The massive novaculite of this specimen is a dense red and white Arkansas stone. In this is a purplish vein containing fragments of the original novaculite and having much the appearance of novaculite itself, though on an unweathered surface it has the vitreous lustre of quartz.

A section cut to expose the contact line of the two shows the novaculite to be of the usual variety of Arkansas stone; the other portion is entirely made up of quartz. This quartz is clearly secondary, as there are no spaces between the grains such as are found in sandstones, while the attempt at crystalline form is apparent in the straight sides of the grains and in their even, hexagonal outlines. A third evidence is found in the size of the grains; along the contact line with the novaculite the quartz grains are very small, but become larger very rapidly away from the contact line, attaining a very much larger size than the sandstone grains in Nos. 44 and 46. This evidence makes it clear that this secondary portion is a true quartz vein.

CHERT.

Slide No. 49. Tertiary chert, from the vicinity of Rockport, Hot Spring county.

This specimen has a vitreous lustre and a flinty fracture; the texture is uneven, with spots and parti-colored areas indicative of differences in the character of the stone. The section shows that the groundmass of silica is rather coarser than in novaculite, and a considerable proportion is composed of larger quartz grains grouped in nodules and sinuous lines. Spherulitic spots of chalcedony are numerous, and there are

a few rhombohedral cavities. The number of larger detrital quartz grains is great; many of these seem to be decomposing about the edges.

Possible Allies from Other Localities.

STONES RESEMBLING OUACHITA STONES.

Slide No. 50. Soft Ouachita stone locally known as chert, from the Brooks mine, Batesville, Ark.

This stone is white and very porous. It is identical with the Ouachita stones in fracture. Microscopic examination of the section proves its identity with the Ouachita stone; the groundmass of fine silica is the same and rhombohedral cavities are very abundant. The stone only occurs as small lumps in a bed of silica powder, so that it has no commercial value.

Slide No. 51. Soft Ouachita stone, locally known as Tripoli, from Seneca, Missouri.

The color of this stone is yellowish white. It is very porous, and as a result is light and friable. The section shows that in structure it very closely resembles No. 22. The grains of silica are minute and the cavities very numerous. This stone is so very soft that it can only be used for polishing purposes.

NOVACULITES.

Slide No. 52. Novaculite, from Dodd City, Marion County, Ark.

Stone yellowish brown, resembling sandstone altered to jasper. The grain is very fine and the stone compact. The planes of bedding are very clearly shown by thin, differently colored layers. The groundmass of silica is coarser than that of the novaculites of western central Arkansas, and the particles are also more closely cemented by secondary silica. The whole mass is very homogeneous. The square outlines of many of the small cavities indicate that they owe their origin to the removal of iron pyrite cubes.

From the closeness with which the grains of silica are packed together it is probable that this stone would soon glaze in ordinary use as a whetstone, though it might be serviceable for narrow-edged tools requiring a coarser stone than the Arkansas.

Slide No. 53. Novaculite from Nahant, Mass.

This specimen resembles No. 52 closely, but is gray in color, finer grained, shows no stratification and is more truly a novaculite, though it is not very translucent on the edges. The microscope shows a dense groundmass of cryptocrystalline silica, with a little lime carbonate in small grains, a little iron and a few small cavities filled or partly filled with iron. Some of the cavities are rhombohedral and are about .02 mm. in diameter. The silica grains average from .002 to .003 mm. in diameter; they are therefore about the size of those in the Arkansas novaculite. They are loosely held together, however, so that the stone is softer than the Arkansas stone. There is some secondary quartz present; also some secondary muscovite. No effervescence with dilute hydrochloric acid could be detected. This stone does not occur in sufficient quantity to be of economic value.

In the reports of the Geological Survey of Michigan for 1869–1873, and of Wisconsin for 1873–1879, a considerable number of thin sections of novaculites are described. These are the most extensive publications of work on the microscopic characters of novaculite that have been made in this country; so the descriptions of these novaculites are quoted here for purposes of ready comparison with the novaculites of Arkansas.

Novaculite is mentioned under the head of "Siliceous Schist," as follows:* "Many varieties of this rock occur, whose colors vary from white, drab, green, brown and iron-gray to black. The structure is sometimes slaty, often banded, and sometimes characterized by a peculiarly sharp rhombohedral cleavage. Its composition and physical properties are varied by the presence of limonite mica and chlorite, or talc, and in the last case becomes a novaculyte, or passes by alternating layers—into talcose schist—into argillite, and—into

*The Geological Survey of Michigan 1869–73, Appendix A, by Alexis A. Julien, p. 22.

hematite schist." He says of this:* "Two kinds occur, the feldspathic and quartzose. The most common form of the quartzose variety is a siliceous schist permeated with talc into minute scales—novaculyte."

The following is the detailed descriptions of the microscopic characters of these rocks:

"Greenish Siliceous Schist (Novaculyte)."†

"A hard, compact, fine-grained schist, made up of the greenish-gray novaculyte, with an almost equal quantity of the reddish-brown argillaceous material, irregularly intermingled. The former is as usual chiefly made up of quartz, with a small quantity of silvery scales of greenish-gray talc, and with films and scales of greenish-gray talc, so arranged as to impart the finely laminated structure. Reddish-white and grayish-white quartz also occurs in segregated veins and spherical bunches of concentric structure, from 1 to 2½ inches in diameter."

"Greenish-Drab Siliceous Slate (Novaculyte)."‡

"A compact, fissile, siliceous slate, whose stratification, at an angle of 45° with the slaty lamination, is apparently denoted by the bands, about an inch thick, of light reddish-brown color, speckled with minute lenticular olive-green spots. A schistose novaculyte, apparently made up of quartz and exceedingly minute scales of greenish-gray talc."

"Another specimen is striped throughout by reddish-brown, parallel and mostly continuous bands, ⅛ to ¼ inch thick. The plane of these layers forms an angle of about 70° with that of the slaty lamination, and their granular material consists of grains of quartz, enveloped in argillaceous laminæ, forming little bunches."

In Appendix B of the same volume are given the lithological characters of various rocks. Among these is a "Talcose Siliceous Schist (Novaculite),§ from Whetstone Quarry, Teal Lake." "Specific gravity of five pieces varied from 2.71 to

*Op. cit., p. 30.
†Op. cit., p. 84, No. 160.
‡Op. cit., p. 85, No. 161.
§Op. cit., p. 203, No. 13.

2.78; average, 2.73. Ash-gray to brownish-gray on fracture greenish on cleavage surface. Like No. 161, but less fissile."

Prof. R. D. Irving names "novaculite" among the sub-divisions of the Huronian strata, associating it with "straw-colored to greenish quartz-schist and argillitic mica-schist."* Novaculite is also mentioned in association with argillitic mica-schist in a formation of slates.†

Among the descriptions of typical rocks of the Menominee iron region are several of novaculite: ‡ "Novaculite (Wright) has also been called chloritic schist and clay slate. * * * A greenish-gray, or chocolate, sometimes mottled, slate, intermediate in character between chloritic and clay slates, with oblique cleavage, moderately fissile. Specific gravity, 2.78 to 2.87."

"Novaculite (Wright).§ Has been called purple clay slate and mottled feldspathic argillite. * * * Specific gravity, 2.71 to 2.88." Differs from the last only in color.

"Novaculite (Wright and Wichmann).|| Has been called clay slate and talcoid siliceous schist. * * * Lighter colored, harder, less fissile and more lustrous than Nos. 10 and 12. Regarded as the most typical form of this rock. Specific gravity, 2.71 to 2.78."

This sample is from a small lenticular bed, associated with quartzite in the Whetstone quarry, Teal Lake.

"Is not like anything in our Archæan formation, but has some resemblance to certain clay slates interstratified in the red sandstone of Dalecarlia, which is believed to be Cambrian. (Törnebohm)."¶

A more detailed description of these same Michigan novaculites by Wichmann reads as follows:**

*The Geology of Wisconsin, Vol. III, p. 6.

†Op. cit., p. 114.

‡Op. cit., p. 538, No. 10.

§Op. cit., p. 539, No. 12.

||Op. cit., p. 539, No. 13.

¶Op. cit., p. 540.

**A Microscopical Study of some Huronian Clay-slates, by Dr. Arthur Wichmann. Quar. Jour. Geol. Soc. for 1879, p. 159.

"Novaculite is a very hard, brittle clay-slate, generally of a yellowish-gray color. The abundant presence of crystalline aggregates, in contrast with the decreased amorphous groundmass, is proved by the microscope. These aggregations, which account for the well-known hardness of this slate, consist chiefly of quartz. Besides these, various kinds of crystals and fragments of tourmaline are found, the latter also appearing in form of microlites. Blood-red laminæ of hæmatite, often possessing a distinct hexagonal form, are not unfrequent. Colorless folia of mica are deposited, mostly parallel to the slate-plane. Garnet appears, in addition to these minerals, in more or less abundance. * * * The comparatively great hardness of novaculite may be accounted for partly by the presence of garnet. * * * The above-mentioned narrow, rod-like, colourless crystals* also appear in novaculite. The crystalline aggregations partly consist of quartz; partly they may represent an indeterminate silicate. The deep gray, dust-like substance is also present, but in much less quantity than in true clay-slate. Typical specimens occur in Whetstone quarry, Teal Lake, and Chocolate-marble quarry, Michigan."

Dr. George H. Williams describes some Michigan novaculites apparently from the same localities as those above mentioned. He says† that near the northeast corner of Teal Lake quartzites have been quite extensively quarried as novaculites, although they are of a different character from the novaculites occurring near Marquette.

"No. 11,785 is a nearly black specimen of the novaculite. Under the microscope the fragmental character of this rock is

*Loc. cit., p. 159. "The occurrence of narrow, rod-like, colourless crystals in some specimens is very striking; but, being very small, they cannot be identified with a distinct mineral. It may be that they belong to the class of feldspars. On an average they are .01 mm. in length. They are deposited parallel to the slate-plane, and appear one-coloured by polarized light. Specimens with distinct crystals occur in the chocolate-marble quarry, Michigan; they occur also very abundantly in the novaculites which are yet to be described."

†The Greenstone Schist Area of the Menominee and Marquette Regions of Michigan, by George Huntington Williams, Bull. No. 62 of the U. S. Geol. Surv. p. 179.

at once apparent. It is composed of irregular quartz and altered feldspar grains in nearly equal proportions. In the finer cement, biotite has abundantly crystallized. An occasional zircon crystal would seem to indicate that the rock is the stratified debris of an old granite." The novaculites of the Marquette region are found along the southern edge of the northern Marquette greenstone area, near its junction with the fissile argillaceous shales of the "Eureka series." They form hard, compact, fine-grained, but decidedly schistose beds. The colour of these so-called novaculites is sometimes reddish, sometimes pale-greenish or yellowish. They are very frequently striped with different shades. Under the microscope, they closely resemble the groundmass of some quartz porphyries. No porphyritic crystals, however, are ever observed, and the structure is too fine grained to appear schistose in a thin section.

From the study of three essentially identical sections of these rocks made from specimens collected at three typical exposures, Dr. Williams draws the following conclusions:* "Apparently only two hypotheses are altogether reconcilable with the observed facts: First, that the rocks are true sediments, like those of the Eureka series, along whose northern edge they lie, which may have been largely derived from disintegrated quartz porphyry material; or, second, that they are consolidated acid tuffs, which accompanied the eruptions of the porphyries in the same manner that some of the green stone schists represent the fragmental diabase material." * * *

"Of the two first mentioned hypotheses, the second is the more probable, first, because of the very constant character of these banded acid rocks; and, second, because of their almost exact identity in chemical composition with the massive acid eruptives. The following chemical analysis of specimen No. 11,684, from the west end of Ridge street, Marquette, was made by Mr. W. F. Hillebrand:

*Op. cit., p. 152.

Silica (SiO_2)	76.99
Alumina (Al_2O_3)	13.92
Ferric oxide (Fe_2O_3)	0.45
Ferrous oxide (FeO)	0.77
Manganous oxide (MnO)	Trace.
Lime (CaO)	0.32
Magnesia (MgO)	1.12
Potash (K_2O)	3 65
Soda (Na_2O)	0.56
Lithia (Li_2O)	Trace.
Water (H_2O)	2.35
Phosphorous pentoxide (P_2O_5)	Trace.
Total	100.13

"It will be seen that this is the composition of an aggregate of quartz and sericite, as the microscope shows our novaculite to be. The sericite is, in all probability, the result of the alteration of original orthoclase.

"The occurrence of similar tuff deposits in connection with eruptive quartz porphyries is well known in Europe, especially in the German dyas."*

The jaspilytes of Minnesota are similar to, perhaps identical with, some of the rocks of Michigan and Wisconsin described above, and these jaspilytes have been regarded as identical with the novaculite of Arkansas. Specimens of the jaspilyte were obtained through exchange, and descriptions of three sections, made from those specimens which seemed to most closely resemble the Arkansas rocks are here given, though from their microscopic characters they might more properly be placed in other groups. The numbers given the specimens are those of the Minnesota Geological Survey.

Specimen No. 867. The rock is white or grayish, dense, with thin bands of hematite which divide the specimen into layers. The surface appears granular and sometimes crumbles, and is sandy to the touch; it gives a vitreous lustre from numerous sparkling points. Examination with a strong lens bears out the conclusion drawn from simple observation by the eye that this rock should be classed as a quartzite.

*Op. cit., pp. 151 and 152.

The microscope shows a compact groundmass of quartz grains of an average diameter of about .1 mm. The grains polarize brightly and extinguish like quartz grains, though there is so much interference about the edges that the extinction is seldom complete. They tightly interlock by means of sharp angles, and many of them have hexagonal or octagonal forms. It seems probable that many of the angles by which the grains interlock were produced by secondary enlargements of original fragmental quartz grains; some instances of this seem clear. The quartz grains contain numerous fluid and gas inclusions. The iron layers consist of very fine particles, which have a reddish color on the outside of the layer and a greenish one inside. No chalcedonic or amorphous silica was noted.

Specimen No. 907. Apple green, dense, homogenous, translucent on thin edges and closely resembling novaculite, yet looking a trifle coarse and vitreous, and so is probably nearer a quartzite. Examination of the thin section shows very numerous rhombohedra of calcite about .02 mm. in diameter gathered into bunches and masses which make up a large proportion of the mass of the stone. The stone as a whole, however, is composed of silica in fine grains, which are seldom large enough to give polarization colors. These grains are of nearly the same diameter as the calcite rhombs and show very numerous rhombic and triangular outlines. Clearly there is here a case of replacement of calcite by silica as noted by Irving.* No silica in other than a cryptocrystalline form was found. Effervescence with dilute hydrochloric acid is rather feeble.

Specimen No. 1277. A dark green, opaque, dense, homogeneous, flinty-looking stone of very fine grain and waxy lustre, resembling closely the siliceous shales of Arkansas. The groundmass of cryptocrystalline silica is identical with that of Arkansas siliceous shales and novaculites, and, like the

*Am. Jour. Sci., Oct., 1886.

siliceous shales, contains rather frequent small spots of fibrous chalcedonic silica.*

SILICEOUS SHALE.

Slide No. 54. Siliceous shale from the Harvard University suite of slides, Brooks' collection, No. 3013, Michigan.

This section shows rather coarse grains of silica, the average diameter being estimated at .01 mm. It contains considerable iron, clay and muscovite, and the stratification is distinctly visible. It would, therefore, seem to be a siliceous slate or shale rather than a true novaculite.

Slide No. 55. Siliceous shale from Penobscot river, east of Mount Katahdin, Maine.

Specimen black or dark greenish-gray in color; fracture subconchoidal. The groundmass is of fine-grained silica, as in the siliceous shales of Arkansas. The dark color is given by abundant particles of iron or carbon arranged in aggregates along the stratification planes, and grouped more thickly in some places than in others. Small, light yellowish spots are plentiful; no effeverescence is obtained with acid, so these spots are probably of limonite, and owe their origin to pyrites.

Slide No. 56. Clay slate from Somerville, Mass.

Specimen light greenish gray and opaque. The microscopic examination shows that it resembles novaculite closely. It has the groundmass of very fine grains of silica less than .01 mm. in diameter, but contains much dust, some iron and lime, a few rhombohedral cavities, and considerable muscovite. Secondary quartz occurs in veins, and also fills certain rhombohedral cavities. Feldspar, probably secondary, is seen.

CHERT.

Slide No. 57. Chert from South Hill, 17 north, 30 west, Washington county, Arkansas.

This specimen is a siliceous rock of uneven texture, abounding in fossils which on the surface have weathered out, leaving moulds. A section of the unweathered stone shows that the

*This rock is called flint in Bull. No. 6 (1891) of the Geol. and Nat. Hist. Surv. of Minnesota, pp. 114 and 123.

carbonate of lime of the original fossil has been replaced by silica, chiefly in the form of quartz in grains sufficiently large to give brilliant polarization colors; some forms are bordered, however, by clouded, yellowish chalcedony, showing a fibrous structure. The groundmass in which the fossil forms are imbedded consists of fine cryptocrystalline silica like that of novaculites, but clouded whitish by particles of dust. The cryptocrystalline silica of the groundmass is more enduring than the secondary quartz and chalcedony, as proved by the weathering out of the fossils.

Slide No. 58. Chert from Prairie Grove, Washington county, Arkansas.

This specimen is siliceous in composition and uneven in texture. It contains fossils, but not in such abundance as No. 57. The fossils have weathered out on the surface of the stone.

The section also is similar to No. 57. The groundmass is composed of very fine grains of silica clouded by a whitish dust; secondary quartz is common, apparently occupying former cavities. Surrounding the quartz and lining the cavities, chalcedony is commonly found in varying thickness. In this section the chalcedony is usually banded parallel to the side of the cavity, though it at the same time often takes mammillary forms; it also exists as in the specimen from South Hill, in irregular bunches. Both varieties are colored yellowish. Some of the colorless fine silica of the groundmass has a rude spherulitic form, showing a characteristic chalcedonic structure in polarized light.

The white dust which clouds the silica of the groundmass in these last two sections is not calcium carbonate, for no effervescence is obtained with strong hydrochloric acid. The occurrence of this white matter only with the silica of the groundmass, and not within the limits of the fossil forms, except in the hollows of crinoid stems and similar cavities, shows that it is not derived from the grinding material, but that it is the clayey material of the original sediment. It is important to note its occurrence, since it is undoubtedly the material which gives the opaque white color to many dense cherts as well as to the

white portions of mottled cherts. By its presence the translucent, watery appearance which these stones would have were the cryptocrystalline silica free from impurities as in novaculites, is changed. In the more porous cherts the presence of air cavities undoubtedly aids in producing a white color, just as they do in Ouachita stone and in milky quartz.

Slide No. 59. Siliceous limestone, locally known as "flint," from the base of the Lower carboniferous (Boone chert), Batesville, Arkansas.

Specimen, drab, sometimes mottled with gray; dense, with subconchoidal fracture. The section shows that calcite in irregular grains and masses makes up the greater part of the rock mass, and strong effervescence is given with hydrochloric acid. Cryptocrystalline silica fills the spaces between the calcite grains, and the whole is clouded by clayey material.

Slide No. 60. Chert from base of the Lower carboniferous (Boone chert), Batesville, Arkansas.

This specimen is mottled and streaked with brown, yellow and white; dense, with conchoidal fracture, and has the general appearance of flint. The groundmass resembles that of novaculites, but is finer grained; a considerable proportion of the silica has the spherulitic form and the fibrous structure of chalcedony. Rhombohedra of calcite are present, but are scarcer and smaller than in novaculite. Ferruginous and clayey material color the stone and render it opaque.

Slide No. 61. Chert from base of the Lower carboniferous (Boone chert), Batesville, Arkansas.

This specimen closely resembles No. 60, but contains less impurity; it is translucent in places and appears more like chalcedony. Under the microscope it shows more chalcedonic silica in proportion to the cryptocrystalline than the last. There are some thin quartz veins, and quartz is also developed within the bunches of chalcedonic silica. Small rhombohedral cavities are present and are often partly filled with limonite, thus indicating a probable origin from ferruginous calcite.

Slide No. 62. Spotted chert, from Scott county, Arkansas.

Specimen nearly black in color, with numerous white or gray circular, or sometimes irregular spots, generally less than an eighth of an inch in diameter, and giving it a pisolitic appearance. Small particles of pyrite are commonly distributed throughout the stone. Under the microscope the round spots are seen to be composed of very fine yellowish grains, probably calcite; with these are mingled as many equally fine silica grains. The matrix between the spots is silica, having the dense, compact appearance of secondary quartz. The quartz does not appear to come in direct contact with the calcite spots, but grades toward it by finer quartz grains into an amorphous mass which is black in polarized light. It seems probable that this stone is an oolitic limestone, the grains of which are being replaced by silica. It effervesces with cold dilute hydrochloric acid.

Slide No. 63. Greenish chert, from Scott county, Arkansas.

This specimen is composed of two varieties of stone, a lavender-colored, chalcedonic looking portion and a dark-green, more opaque part; the two intergrade, though the contact line is pretty sharp. The section was made from the dark-green portion. This part is a fine-grained, perfectly compact quartzite.

Slide No. 64. Flint from England.

This specimen is greenish gray, and is a typical flint. The grains of silica composing the groundmass are tightly interlocked and average less than .005 mm. in diameter. There are a few spots of fibrous chalcedony. Considerable clay and some iron is present. The only indications of organisms are two yellowish-brown spherical bodies with radiating spines which resemble radiolarian forms.

English cherts.—Many slides of English cherts and flints have been examined and described by Messrs. A. J. Jukes-Browne and W. Hill.* They show that much amorphous or opaline silica exists in a series of rocks which vary from a calcareous chalk to a siliceous chert, in the form of minute globules rarely exceeding .0005 of an inch or .0127 mm. in diameter and decreasing in size to considerably less than .0002 of an inch. These globules are soluble in caustic alkalies. Fibrous chalcedony is also common in the chert, and organic remains are distinguishable in all the sections. It is evident from the work of these observers and from similar investigations by Dr. G. J. Hinde that the English cherts differ considerably from many of the rocks called cherts in America. English chert has some 30 per cent or more of its silica in the soluble form of either chalcedony or opal, while in America rocks have been called cherts in which no chalcedonic or opal silica can be seen, though as a rule chalcedonic silica is present in fair amount. The sponge spicules too, which are so universally found in the English cherts, are only found in occasional beds in this country; the prevailing fossils in the American cherts are crinoids and mollusca, rather than sponges and foraminifera. So far as is known to the writer the globules of colloid silica described by Hinde, and by Jukes-Browne and Hill, have not been noticed in the American cherts of any horizon.* This does not necessarily imply a misuse of the term chert in this country, for, according to the weight of opinion among the English writers, chalcedonic silica and not opal is the important characteristic of cherts, so that judged by this standard the word chert is generally used in this country in its proper signification.

*Occurence of colloid silica in the lower chalk of Berkshire and Wiltshire, in the Quarterly Jour. Geol. Soc., Aug., '89.

Chert breccia.—A rock from the Menominee iron region which has apparently a very close resemblance to the brecciated novaculite or novaculite conglomerate, is described by Dr. Wichmann under the name of "Chert Breccia (Hornstone Breccia†)," as follows:

"Chert is always composed of a crystalline aggregation of small quartz grains, as may be seen in polarized light.

"This rock consists of irregular, angular fragments of greenish-gray chert. They appear colorless in a thin section, but microscopically observed, the fragments are furnished with

*Reference is here made only to cherts that are not Cretaceous; the Cretaceous cherts have not been examined.

†Geology of Wisconsin, Vol. III, p. 656.

many inclosures. Sharply defined rhombohedra are especially present in great numbers. These crystals possess a rough surface, and belong probably to calcite. They often contain a dust-like substance. The individuals are sometimes aggregated in clusters, which then represent star-like aggregations. The outlines of the fragments of hornstone are also surrounded by calcite, and the ends of these reach into the before named fragments.

"Fluid enclosures are abundant in some grains. Small, nearly colorless needles and scales occur everywhere, and green folia of chlorite are not unfrequent.

"The substance which cements the fragments of chert seems also to be a siliceous one. It becomes transparent in some parts of a thin section only, and here we recognize it as consisting of quartz, which is filled with numerous particles, and irregular grains of calcite. Besides this a dust-like substance is present, in consequence of which the cement is not pellucid. Some irregular folia of chlorite occur, and also a black opaque substance."

CHALCEDONY.

As a standard with which to compare the chalcedonic portions of various cherts two sections were made from specimens called chalcedony from the collection of Prof. N. S. Shaler of Harvard University.

Slide No. 65. The first of these specimens is a very dense stone, banded with alternate opaque, white, and translucent brown layers which have a roughly concentric arrangement and often exhibit the waxy lustre of chalcedony; the whole has the appearance of an organic form, possibly a stromatopore. The microscope shows the brownish layers to have a groundmass of very fine silica, the grains averaging less than .005 mm. in diameter. The white layers have a greatly preponderating amount of calcite in grains but little larger than those of the silica, which constitute the remainder of of these layers as well as the brownish ones. These calcite grains frequently form circles, ovals, and other shapes having an organic aspect, this organic appearance is increased by a

very even line which bounds the white bands on the concave side of the curve and by the rather irregular change to the translucent layer on the convex side. Strong effervescence was obtained with dilute hydrochloric acid. This examination shows no fibrous chalcedonic silica.

Slide No. 66. The second specimen consisted of mammillary bunches of fibrous silica on black limestone. The silica of the mammillary portion presents under the microscope a brush-like appearance with a radiating structure. The fibres are not continuous, but the appearance of continuity is given by grains of silica much elongated in a radial direction, and having the axis of greatest elasticity coinciding with the axis of elongation. The black limestone is full of fibrous silica also, forming complete and sometimes incomplete spherulites. These spherulites are of very much larger size than those noted in some cherts and siliceous shales, and are generally somewhat clouded by foreign matter. Between the pure chalcedony and the black limestone divisions of this section is a portion consisting of silica sometimes showing under a low power a fibrous structure, but more often only appearing as a mass of irregular grains. Under a high power, however, these grains are seen to have a fibrous structure also, but form only portions of small incomplete spherulites. Effervescence with dilute hydrochloric acid shows the presence of lime in the black part of the section. The coloring matter is probably carbon.

WHETSTONES.

Slide No. 67. Turkey oil-stone from Asia Minor.

Specimen bluish-gray in color, fine grained, with whitish lines and nodules. The surface is rough from the existence of cavities. Silica, in the form of grains about .02 mm. in diameter, composes the mass of the stone, and is mingled with calcite, clay, and some iron. The calcite has the rhombic form, in separate rhombohedra, in clusters, and in veins (the whitish lines). Some of the calcite has been dissolved from the veins, leaving cavities of irregular form but having rhombohedral angles; these form the cavities, which are visible to the unaided eye.

The sharpening qualities which this stone possesses are due to the grains of silica alone, since the cavities are irregularly distributed and are situated within (calcite?) which does not furnish sharp cutting edges as does the silica in the Ouachita stone. The grains of silica are not cemented together, but rub off with use and thus new abrading points are presented. It is to the advantage of this stone that it does not absorb much oil, and so does not "gum up" in consequence of the drying of the oil; then the materials of which it is composed grind up into powder and pass off without forming a cement.

Slide No. 68. Hindostan stone from French Licks, Indiana.

Specimen yellowish gray in color, homogeneous, and presenting the appearance of a very fine-grained sandstone. A few cavities exist between the grains. Small quartz grains .02 mm. in diameter constitute the greater part of the groundmass. The uniform size of the quartz grains is remarkable; there are no large grains of quartz, but some of the small ones are thick enough to give low polarization colors. Besides the quartz there is much iron and earthy material, and a little muscovite mica present. The earthy material and iron are in small masses about the size of the quartz fragments, and it is undoubtedly the large amount of these substances present which gives the stone its softness, though at the same time the iron acts as a cement to bind the grains of silica together.

Slide No. 69. Labrador oil-stone, from Labrador Lake, Courtland County, N. Y.

This stone is a fine-grained sandstone, of greenish-gray color. The grains of quartz vary from .08 to .01 mm. in diameter, and many give polarization colors of a high order. The silica is imbedded in a matrix of calcareous earth containing a large percentage of iron, and there are present also flakes of muscovite, sometimes bent between the grains of silica. The iron is limonite, unevenly distributed, which binds the particles of the stone together by its branching lines. The aggregation of the iron into these lines represents probably a secondary process; with the exception of this and some doubtful secondary quartz, the stone is an unaltered sediment. Considerable effervescence occurs when treated with dilute hydrochloric acid. The abrasive qualities are due entirely to the rough quartz grains.

Slide No. 70. Adamascobite stone from Pierce City, Missouri.

This is a yellowish-brown stone, very compact, but soft. It resembles the Hindostan stone, but it is finer grained and apparently contains much clay. The grains of silica are small, averaging .02 mm. in diameter. Muscovite is present in large amount, and the proportion of earthy material and iron is large. No effervescence is obtained with hydrochloric acid.

Slide No. 71. Sawing sands.

For comparison in size of grains between the various finer whetstones and coarser material the dimensions of sand grains were taken from the sand used for sawing whetstones at Manlius Station, New York. This is a reddish-brown river sand of rather fine grain. The quartz grains composing the sand vary from .35 mm. to .03 mm. in diameter, the average of thirty-three measurements giving .2 mm.

The sand used at the whetstone manufactory of George Chase, in New York city, is a coarse beach sand from Northport, Long Island, the grains of which have an average diameter of about a millimeter.

CHAPTER VIII.

THE CHEMISTRY OF THE NOVACULITES.

The chemical examination of the several members of the novaculite formation made by the Survey agree with the facts ascertained by the microscopic examination, while resemblances and differences which are not made apparent by the microscope are clearly brought out by the chemical analyses. Since some idea of the comparative values of the different whetstones may be obtained from their chemical analyses as well as from the microscopic examination, analyses gathered from various sources are presented in this chapter.

Quantitative analyses.—The analyses of the novaculites and associated rocks are presented in the table opposite. Where not otherwise stated the analysis was made by the Geological Survey of Arkansas, R. N. Brackett, analyst.

Attention is called to the following points in the analyses:

First.—These chemical analyses demonstrate the purely siliceous composition of the true novaculites, showing them to be as pure silica as crystalline quartz.

Second.—The Tertiary chert approaches the novaculites more closely in composition than does the quartzose sandstone.

Third,—The percentage of ferric oxide is very small in the novaculites, especially in the Ouachita stone.

Fourth.—The loss on ignition shows that there is but a small amount of volatile matter in the novaculites, and as this would include water in combination to form hydrous silica there can be little hydrous silica present in the purer rocks of the series.

Fifth.—There seems to be no difference in composition between the decomposed, altered, and unaltered cherts; and the determinations of soluble silica in the altered and unaltered cherts of southwest Missouri and Kansas show that the silica

Analyses of Arkansas Novaculites and Associated Rocks.

		Silica.	Alumina.	Iron.	Lime.	Magnesia.	Potash.	Soda.	Loss on Ignition.	Total.	Hygroscopic Moisture.	Number.
		SiO_2.	Al_2O_3	Fe_2O_3	CaO.	MgO.	K_2O.	Na_2O				
1	White novaculite, Hot Springs	99.45	26		.12	very slight trace.	.19	.54	.06	100 62	.002	1
2	Gray Arkansas stone, Rockport	99.47	.17	.12	.09	.05	.07	.15	.12	100 24	.07	2
3	Black Arkansas	99 36	13	.17	.14	.04	.11	.16	.09	100.20	.02	3
4	Red novaculite	99 51	.68	.60	.69	.17	.15	.26	..	102.09	.04	4
5	Flinty Shale from Bear	93.83	2.71	1.48	.17	.43	40	.26	73	100.01	.17	5
6	Tertiary chert from Rockport	97.38	.47	.41	.51	.13	.20	34	.95	100 39	.35	6
7	Fine Ouachita, Sutton's quarry No. 6	99 49	13	06	.04	.08	.16	10	.14	100 20	.12	7
8	Ouachita, Barnes' big quarry	99.06	.30	06	.09	.13	.13	.13	08	99.98	....	8
9	White Ouachita stone, Ten Mile quarry	99 12	.48	.02	.12	.06	.14	.24	22	100 40	09	9
10	Black Ouachita, Ten Mile quarry	99 27	.23	03	.08	.08	10	.11	.60	100 50	09	10
11	Mottled Ouachita	99.30	.19	.10	.07	.10	.12	.19	11	100.18	.09	11
12	Quartzose sandstone, Quarry mountain	96 44	1 74	.33	.17	.22	13	19	.90	100.12	.14	12
13	Clay, Barnes' big quarry	59 31	23 73	6 11	.31	.71	1 45	.93	8.33	100 88	3.09	13
14	Quartz, small, clear crystals, Clark county	99.16	0 37	.....	trace.	trace	none.	.32	.15	100 00	....	14
15	Quartz, massive, Montgomery county, Arkansas	99.46	0.27	.....	trace.	trace	none.	.19	.06	100 00	....	15
‡16	Quartz, massive	99.35	0.14	14	.05	.....	....	.07	22	99.97	....	16
*17	Chert, altered, Bellville, Mo	98.71	.43		.03	02			.50	99 69	....	17
*18	Chert, altered, Bellville, Mo	98 92	.48		.03	.02			42	99 87	....	18
*19	Chert, unaltered, Bellville, Mo	98.17	83		.05	01			.78	99 84	....	19
*20	Chert, slightly altered, Galena, Kan	98.60	.52		.10	trace	.....	.....	.40	99 62	....	20
*21	Chert, white altered, Galena, Kan	99.13	.16		trace.	.01	.....	.....	.20	99.50	....	21
*22	Chert, blue unaltered, Galena, Kan	99.23	.22		02	trace	.....	.....	.50	99.97	....	22
*23	Chert, gray unaltered, Joplin, Mo	99.46	.29		.04	trace	.....	.....	.34	100.13	....	23
†24	Chert, decomposed (powder), Independence county, Ark	99.21	....		....	.....	.....	.....	.28	99 49	10	24
‖25	Chert, decomposed (powder), Independence county, Ark	98 80	....		....	.....	.....	.....	33	99.13	.23	25

‡Quoted from Ueber den Monte Amiata in Tcscana und seine Gesteine. Stuttgart, 1887, Dr. J. Francis Williams

*Analyses by the United States Geological Survey, Prof. F. W. Clarke, chief chemist. The soluble silica was determined in Nos 17, 19, and 21, and the result for the respective specimens was 3.99, 4.52 and 3 35 per cent. With the permission of F. W. Clarke, chemist to the United States Geological Survey, the essential steps in the method of making these tests of solubility is given here: No. 17 was somewhat porous; 19 and 21 were compact, the last showing occasional cavities filled with quartz crystals. The specimens were finely powdered; the solution used was caustic potash made up of one part of solid caustic potash to three parts of water; one gram of the powdered material was heated in each case with fifty cubic centimeters of the solution for one hour on the water bath.

‖Qualitative analyses of these two rocks, (24, 25) showed the presence of a little iron and alumina, calcium and magnesia. The specimens were not tested for alkalies.

undergoes no appreciable chemical change while the rock is decomposing.*

Clays occur associated with the novaculites, and are found in the planes of bedding and also in thin layers or films along the joint planes. They are found particularly among the Ouachita stones. A chemical analysis of one clay was made to see whether any connection could be established between it and the stone of the same quarry. The object in making such a comparison is explained in Chapter XVIII, under "Clay Seams."

Comparison by tests for soluble silica.—Judging by the chemical analyses alone, any of the cherts mentioned might be classed as novaculites; yet there is a general difference in physical appearance between cherts and Arkansas novaculites. The lustre of chert appears either earthy or vitreous, that of the novaculite is dull-resinous or waxy; chert seems to have a smooth surface looking as though it were glazed when the specimen has a vitreous lustre, while that of novaculite appears minutely rough, so that it is natural for those unacquainted with the stone to try the grit. Thus the external characters seem to indicate an internal difference between the stones, and the following experiments on solubility tend to prove that there is a difference in the chemical conditions of the silica in the two.

The method of making the tests, unless otherwise specified, was as follows:

The caustic potash solution was made by dissolving 250 grams of stick caustic potash purified by alcohol in 500 cubic centimeters of distilled water. The solution had the specific gravity 1.297, equivalent to 30 per cent. of solid caustic potash (KOH).

*There is reason to believe, however, that No. 19 had undergone some change, though not enough to give it the physical appearance of an altered rock. The soluble silica of this specimen is somewhat greater than for the others, yet it is much smaller than it was found to be in cherts examined in the Arkansas Survey laboratory, and smaller than in the English cherty rocks from the chalk beds; thin sections of other cherts also show that soluble silica in the chalcedonic form makes up a large proportion of the rock mass; for these reasons, then, it seems doubtful whether No. 19 can be regarded as an entirely unaltered chert.

The potassium carbonate solution was made by dissolving 192 grams of chemically pure potassium carbonate in 500 cubic centimeters of distilled water. The solution had the specific gravity 1.274, equivalent to 27.5 per cent. of solid potassium carbonate (K_2CO_3).

Half a gram of the finely powdered material was heated with 20 cubic centimeters of the caustic potash or potassium carbonate solution in a covered porcelain casserole for six hours on a water bath at a boiling temperature. The solution in the casserole was then diluted with distilled water, and after the insoluble residue had settled, the clear supernatant liquid was decanted through a quantitative filter. The residue was washed several times with distilled water by decantation, and finally brought on to the filter and washed with distilled water until free from alkali. The filter and residue were dried in an air bath, ignited before the blast lamp in a weighed platinum crucible, allowed to cool in a desicator, and weighed. After deducting the weight of the filter ash from the weight found, the per cent. of insoluble material was calculated on the specimens dried before the blast lamp. The loss on ignition before the blast lamp of each specimen had been previously determined. The difference between the per cent. of insoluble material found and one hundred was regarded as the per cent of soluble silica.

These experiments upon the solubility of the silica in quartz crystals show that the silica of novaculite is in as stable a condition as that of quartz. Compared with novaculite and quartz two of the cherts tested show a considerably different constitution for the silica present, while No. 22 is almost all soluble silica, indicating that the substance is opal, as its physical appearance would denote.

In connection with the analysis by C. E. Wait, quoted in the table of analysis of whetstones below, the character of the silica is also determined. On boiling for three minutes in a 20 per cent solution of sodic hydrate 1.63 per cent of the mineral was dissolved; and thirty minutes boiling only led to the solution of 3.56 per cent. From this Mr. Wait concludes that the silica is cryptocrystalline rather than amorphous.

A comparison of the action of caustic potash and potassic carbonate solutions on novaculites, quartzites, quartz, chert, and opal.

CALCULATIONS ON MATERIAL DRIED BEFORE THE BLOWPIPE.

		Soluble in Caustic Potash.	Soluble in Potassic Carbonate.
1.	White Arkansas (No. 1 in table)	5.82	.44
2.	Gray Arkansas (No. 2 in table)	7.17	.62
3.	Black Arkansas (No. 3 in table)	2.70	1.14
4.	Red Arkansas (No. 4 in table)	5.00	.93
5.	Fine Ouachita (No. 7 in table)	4.49	.43
6.	White Ouachita (No. 9 in table)	5.11	.28
7.	Black Ouachita (No. 10 in table)	5.07	.54
8.	Mottled Ouachita (No. 11 in table)	3.25	.53
9.	Hard Ouachita	2.24	.51
10.	Quartzite (1)	3.17	.74
11.	Quartz crystals	6.28	1.47
12.	Quartz crystals (2)	2.59	.71
13.	Quartz boiled fifteen minutes with caustic potash (20 cc.)	4.07	
14.	Quartz boiled fifteen minutes with a mixture of caustic potash and potassic carbonate solutions (10 cc.)	2.15	
15.	Siliceous limestone locally called chert, from northern Arkansas—black	2.44	
16.	Siliceous limestone locally called chert, from northern Arkansas—gray	9.47	
17.	Siliceous limestone locally called chert, from northern Arkansas—gray	3.11	
18.	Lower Carboniferous chert (?) (4)	1.99	
19.	Lower Carboniferous chert (?) (5)	6.62	
20.	Silurian chert (6)	30.72	4.62
21.	Tertiary chert (No. 6 in table)	35.56	2.67
22.	Opal, geodized coral from Tampa, Fla	88.38	16.87

(1.) From north of Brodie's Creek, near Little Rock.

(2.) Clear and glassy chips from a single quartz crystal powdered to 150 mesh in fineness.

(3.) To obtain free silica about six to ten grams of each stone, finely powdered were treated with strong acetic acid and digested on a sand bath till the carbonate of lime (and magnesia, if present) was all decomposed. The material was then diluted with distilled water, the residue allowed to settle, the supernatant liquid decanted through a filter, and finally the residue was brought on to the filter and washed till free from acetic acid and acetates. The residue was dried in the air.

The remainder of the tests were made as in other instances; it is possible, however, that a little of the silica was rendered more soluble in caustic potash as a result of the treatment with acid.

(4.) From Batesville, Ark.

(5.) From Batesville, Ark.

(6.) From near Yellville, Ark.

(7.) This figure for soluble matter is rather high, owing to difficulty in filtering.

The siliceous rocks from the English chalk beds analyzed for A. J. Jukes-Browne, and W. Hill, show high percentages of soluble silica.*

ANALYSES OF ENGLISH CRETACEOUS CHERTS.

Siliceous matter insoluble in hydrochloric acid	33.6†
Silica soluble in hydrochloric acid	.4
Oxide of iron and alumina	.8
Carbonate of lime	63.4
Carbonate of magnesia	1.5
Trace of Alkalies and loss	.3
	100.0

Moisture	1.08
Combined water and traces of Organic matter	3.18
Colloid silica	19.08
Quartz and a little mica	11.23
Clay and glauconite	.47
Carbonate of lime and magnesia by difference	64.96
	100.00

Total matter insoluble in hydrochloric acid	35.17	Soluble in alkaline carbonate, 15 min. boiling	12.61
		Insoluble in same	22.56
			35.17

These analyses show that from 40 to 60 per cent. of the silica of the siliceous beds of the chalk formation is soluble or "colloid." The beds are called cherty in the accompanying subject matter, and the determinations made on their silica may be considered comparable with those of more massive cherts.

A consideration of all the cherty rocks here reported upon

*The occurrence of Colloid Silica in the Lower Chalk of Berkshire and Wiltshire, by A. J. Jukes-Brown and W. Hill; Quar. Jour. Geol. Soc., August, 1889.

†Of the 33.6 per cent. silica, 15 per cent. was dissolved by a boiling solution of sodium carbonate.

brings out the fact that the true cherts contain a large proportion of soluble silica, while another group of rocks, called cherts, are lacking in this form of silica. This suggests that a division of the cherty rocks into two groups might be made, but the data accumulated do not authorize one as yet.

Novaculite compared with hot spring deposits.—The Arkansas novaculite has been called geyserite by one writer.* For comparison some analyses of siliceous deposits from the Yellowstone Park are represented here:

ANALYSES OF NOVACULITE, GEYSERITE, AND SINTERS.

	Geyserite.	Algous Sinter.	Moss Sinter.	Typical Novaculite.
Silica	81.95	93.88	89.72	99.45
Alumina	6.49	1.73	1.02	.26
Ferric oxide	trace.	....	....	....
Soda	2.56	.28	....	.54
Potash	.65	.23	....	.19
Lime	.56	.25	2.01	.12
Magnesia	.15	.07	trace.	trace.
Sulphuric acid	.16	....	....	....
Chlorine	trace.	.18	....	....
Water	7.50	3.37	7.34	.06
	100.02	100.33	100.09	100.62

"Numerous analyses go to show that the sinters formed by algæ and mosses are generally purer than true geyserite."† True geyserite seems to differ considerably from novaculite, but the sinters bear a very close resemblance to it if the water of the hydrous silica of the sinters is driven off.

Novaculites compared with other whetstones.—On the page following a few analyses of whetstones are given. The list includes two of Arkansas novaculites. These analyses show that all other stones are very different from the Arkansas novaculite, even though called novaculite in the locality whence they came. The abrading substance in every case, except in that of the Belgian hone and some mica schists, is silica in the

*Ann. Rep. Geol. Surv. of Ark., Vol. I., 1888, p. 129.

†Formation of Siliceous Sinter by W. H. Weed, Am. Jour. Sci., May, 1889.

Analyses of Whetstones.

	White Novaculite, Ark §	Novaculite, Ark.‡	Novaculite, Irasburg, Vt.†	Novaculite, Marquette, Mich **	Turkey Stone.††	Bohemian Stone ††	Polishing Slate.††	Polishing Slate.††	Coticule.‡‡	(Coticule), Viel Salm.‖	Whetstone, Recht.‖	Whetstone, Steinach.‖
Silica	99.64	98 00	78.70	76.99	72.	79.0	83 5	66.5	.713	46.52	43.73	51 66
Alumina	.11	.80	12 80	13 92	3.33	1.0	4 0	7.0	.153	23.54	19.38	24 50
Ferric oxide	trace	trace	trace	.45	.....	4.0	.6	2.5	.093	1.05	2.42	14,50
Ferrous oxide	.....	.....	.....	77	.....	.....	.....		.....	.71	.....	.....
Manganous oxide	.....	.....	.....	trace	.....	.....	.....		.....	17·54	21.17	.....
Magnesia	.09	trace	traces	1.12		.....	.....	1 5	.....	1.13	.....	1.86
Lime	.....	trace	1.23	.32	13.33	1 0	8.5	1 25	.....	.80	.28	.67
Soda	.16	.50	5.57	.56	.....	.....	.....	.....	.....	.30	1.17	.64
Potash	trace	.60	.89	3.65	.....	.....	.....	.....	.....	2.69	3.51	2.28
Titanic oxide	.....	.....	.....	.....	.....	.....	.....	.....	.....	1.17	trace	.....
Phosphorous	.....	.....	.....	.....	.....	.....	.....		.....	.16	.....	.....
Phosphoric acid	.....	.....	.....	trace	.....	.....	.....	.....	.....	.....	.....	.....
Lithia	.....	.....	.....	trace		.....	.....	.....	.....	.....	.....	.....
Carbonic acid	.....	.....	.....	.....	10.33	.....	.....		.....	.....	.....	.....
Water	.....	.....	.....	2 35	.....	14.0	9.0	19.00	.033	* 3.52	2.40	4.56
Loss on ignition	.....	.10	.60	.....	.....	14.0	.....	.....	.....	.....	.....	.....
Total	100.00	100.00	99 79	100 13	98 99	99.0	105.6	97.75	.992	99 13	99 06	100 68

§ Amer Jour. Sci., Third Ser., Vol. VII, p 520, C. E. Wait.
‡ Second Geol. Reconnoissance of Arkansas, Owen, 1860, p. 24.
† Geology of Vermont, 1861, Vol. I.
** Bulletin No. 60 of the U. S. Geol. Surv., p, 151. Analysis by W. F. Hillebrand.
†† Tomlinson's Cyclopædia, 1854, Vol. II, Hone.

‡‡ Geologie, Introduction et Elements. Omalius D'Halloy, 1838 Analysis by Faraday.
‖ Chemische Geologie. Justus Roth. Berlin, 1887, Vol. VI, pp. 538, 589. The analysis of Veil Salm, Belgian stone is credited to Pufahl; the one from Recht, Belgium, to von der Marck; that of the whetstone from Steinach in Saxony to Guembel.
* Included in the water are CO_2, 2.04, S, .18 and organic substance, .02.

form of quartz, so the superiority of the Arkansas stone is noticeably connected with the abundance of silica. As before noted, however, silica alone is not sufficient to make a good whetstone; thus massive quartz and quartzites are of no use for abrasive stones, but with other conditions favorable the rock containing the largest proportion of silica will be the best whetstone. The microscopic garnets in the Belgian hone, having an average hardness equal to that of silica, would place this stone on a par with the Arkansas stone were it not for the fact that the rock is of such a soft composition that tool edges pressed upon it cut the stone. Since the Belgian stone is suitable only for razor hones, the Arkansas stones easily take the first place as whetstones from the greater abundance of silica in their composition.

CHAPTER IX.

THE ORIGIN OF THE NOVACULITES OF ARKANSAS.

Schoolcraft, the first geologist to examine the Arkansas novaculite, suggests no theory of its origin. He merely says that the honestone probably owes its good qualities to the presence of more silica and less alumina in its composition than is found in other novaculites.

Featherstonhaugh offers no theory of origin for novaculite, but his suggestive remarks seem to have furnished a basis for later theories. He says of the formations in the Hot Springs region of Arkansas: "Here I found the ferruginous hills of old red sandstone, sometimes consisting of solid masses of flint, at other times of a beautiful novaculite, and again of ferruginous sandstones. The curious gradations of this siliceous matter, in the forms of old red sandstone, flint, novaculite, hornstone and quartzose rocks, are surprising."*

Owen's theory.—The origin from sandstone implied by Featherstonhaugh was adopted by Owen, though no mention of Featherstonhaugh is made anywhere by him. Owen says of the novaculite: "Yet this snowy white chalcedonic novaculite was once a simple ordinary sandstone. From the state of an ordinary sandrock it has been altered or metamorphosed into this exquisitely fine material, not, as I conceive, by contact with fire or igneous rocks, but by the permeation of heated alkaline siliceous waters; perhaps somewhat hotter than the springs issuing at this moment from the Ridge, and somewhat more strongly impregnated with silica, potash, and soda. By the incessant and long-continued permeation of the sand rock with such waters, the particles of sand rock have been gradually changed from grains of quartzose sand to im-

*Geological report on the elevated region between the Missouri and Red rivers, by G. W. Featherstonhaugh, 1835.

palpable silica, and the greater part of the oxide of iron, manganese and other impurities, carried out in solution from the pores of the rock, leaving nearly chemically pure silica behind."*

Owen cites the chemical analysis already quoted in the chapter on chemistry† as a proof of this theory, since it shows such a high percentage of silica with so little impurity. In further proof he gives a description of the novaculite. Looking at the walls of novaculite in the Hot Springs gorge, he says that even a geologist would at first suppose that the rocks, standing apparently on edge, "had been shivered by internal and tremendous convulsions." An examination convinces him that the rocks, though somewhat tilted out of their original horizontal position, were intersected by a system of vertical joints which gave the appearance of stratification, and that during the metamorphosis of structure which the rocks have undergone the original stratigraphic partings have almost disappeared, or at least have become confused with the fine lines of cleavage.

The Crystal Mountains, more than twenty miles west of Hot Springs, are regarded by Owen as belonging to the same formation as that found at Hot Springs. He thinks that chemical action has been much less effective among them, and that the alkaline siliceous waters permeated chiefly along lines of stratification and joint planes producing the quartz crystals along these lines, while in novaculite the whole rock was permeated and altered.‡

Owen mentions novaculite elsewhere, but always appears to regard it as a metamorphosed sandstone.

Unfortunately Owen's reconnoissance was necessarily so hurried that he could not get a thorough idea of the country over which he traveled, or of the rocks with which he was dealing. Thus he mistook the stone forming the standing

*Second Geological Survey of Arkansas, 1860, p. 23.

†See p. 167.

‡Op. cit., p. 25.

rock* on Board Camp Creek, in Polk county, for a metamorphosed sandstone,† while in reality it is a novaculite, though it contains impurities which render it less translucent than usual. The Hannah Mountain, which he describes as composed of indurated sandstones, quartzites and novaculites, is almost exclusively of novaculite with some shales. It is evident that he did not see enough of the novaculite to realize that it formed a regular member in a geological series, and that it was not merely the product of local metamorphism. Had he traced out the geology of the Hot Springs district he would have found that the novaculites in the Hot Springs gorge instead of being only "tilted somewhat," had turned through an arc of 135° and more, so that they are completely overthrown. He would have noticed also that the line of demarkation between the novaculites and sandstones in the Hot Springs section is very sharp, though the sandstones are slightly altered. Furthermore, near the top of the novaculite strata in this section there is a bed of quartzose sandstone identical with those found higher up and showing no evidence of the chemical action, which, according to his theory, must have affected the beds on either side of it. Finally, the present Hot Springs issue from a sandstone which shows no signs of being changed to novaculite, though the extent of the spring deposits indicates that they have been long active in their present locations.

Besides these evidences found in the field against the idea of the formation of novaculite from sandstone by the action of hot waters, the microscopic examination of all the novaculites, and of the Ouachita stone in particular, tends to disprove the idea of great metamorphism. The conclusions drawn from the microscopic examinations are presented further on in this chapter.

Comstock's theories.—In collecting the data for this survey's report on gold and silver,‡ Dr. T. B. Comstock saw much of the novaculite area of Arkansas, and presented theories to

*See frontispiece.

†Op. cit., p. 34.

‡Vol. I, 1888, of the Annual Report of the Geological Survey of Arkansas.

account for its peculiarities which agree in part with Owen's view. His theories are presented in his accounts of the three localities of Hot Springs, Caddo Gap, and Magnet Cove, so a discussion of these three localities alone will be enough to understand his arguments.

In speaking of the novaculites near Hot Springs, he says: "The hard beds here are not simply quartz, but flinty rock, a product which would result from the alteration of quartz in place, by the action of highly heated water. Any other possible source of such material could not, by any means, have furnished deposits of the same character as these, which occupy a vast area in beds of great thickness occurring with extreme regularity. Owen took the same view, or a similar one, of the origin of these novaculites, as he termed them."*

There is, however, considerable difference between the views of Comstock and Owen; for while Owen attaches much weight to the change of condition of the silica by permeating waters, Comstock seems to ascribe more importance to the action of direct deposition of silica from waters carrying it in solution. Thus, concerning a locality high on Sugar Loaf mountain, north of Hot Springs, he says: "That the ancient springs were vigorous enough in some cases to eject the liquid is proven by the layered sinter (pealite) which forms the dome discovered in opening No, 4, upon the Glenpatrick lodes, and by similar evidences in other localities."† Again, in speaking of the rocks where Park avenue, Hot Springs passes over the Gulpher Creek divide, he says: "Just below the summit the road has been blasted out through a quartzite, which may, perhaps, have been deposited from subterranean hot water, drawing mineral supplies from the horizon of the hematite shale, which is presumbly beneath us at this point."‡

In the Caddo Gap region Dr. Comstock saw more evidence of the deposition of the silica from hot water than of alteration of the country rock. Here in the gap there is a "peculiar S-shaped twist in the rocks within the space of fifteen feet transversely which seems to have more than a local extent in the direction of the strike." These twists are reported as occurring elsewhere on the "Golden Wonder axis," which Dr. Comstock identified here at Caddo Gap, and "are believed to be relics of ancient hot springs with siliceous waters of a type now prevalent at the City of Hot Springs."

*Annual Report of the Geological Survey of Arkansas, Vol. I, 1888, pp. 48, 49.

†Op. cit., p. 48.

‡Op. cit., p. 44.

"The structure of the novaculite (geyserite) is nearly identical with that now forming in the Yellowstone Park, and it very closely resembles that which was observed north of Magnet Cove, in Garland county. The action of hot springs is clearly indicated here. In the Caddo Gap sintery layers are exposed for nearly half a mile."*

Of the Magnet Cove region Comstock says: "It is almost impossible to make out the structure, and in all the sections observed, the rocks are associated with anhydrous siliceous sinter and aluminous deposits."†

On the north side of the Cove, along the crest of the novaclite ridge there are some pits or basins which are known locally as "Spanish diggings." To account for these pits Dr. Comstock adopted the theory that they represented the bowls of hot springs. In support of this theory he presents the arguments that surrounding the bowls are rims of "pealite," and leading from them gulches which show the existence of former streams. The explanation that these pits were Indian flint quarries, Dr. Comstock rejected because he thought the material unsuitable for the uses of the Indians, and because he did not see any "archaic relics," or implements for "digging and shifting material" near them.‡

By "altered quartz" Comstock seems to mean the rock which Owen calls metamorphosed sandstones; and these have already been discussed.§ In favor of his theory of direct

*Op. cit. pp. 95 and 129.

†Op. cit., p. 81.

‡Op. cit., pp. 83 and 84.

§See p. 171.

deposition of the silica of novaculite from hot waters, Comstock presents six arguments:

First—The physical appearance of the novaculite which he calls "geyserite" and "pealite."

Second—Its layered structure.

Third—The occurrence with the rock of iron sinter.

Fourth—The existence of S-shaped twists in the layers of rock.

Fifth—The topography of the novaculites.

Sixth—The existence of the bowls of former Hot Springs.

In the explanation of what now seems to be the true theory of the novaculites, the arguments against Comstock's theory will be presented later, but the principal points of difference between his and the writer's views may be briefly stated here in reply to each of his arguments.

In reply to the *first* and *second* arguments, the resemblance of the novaculite to geyserite is certainly very marked, but the chemical analyses show that the greater portion of the novaculite is clearly a different rock.* The layered structure is a true bedding, for interstratified with the novaculites are shales and sandstones.

In reply to the *third* argument, the "iron sinter" has been found to belong to a well-defined bed in the novaculite series of rocks.

In reply to the *fourth* point, the S-shaped twists are nothing more than local crumples of the thiner strata in a much disturbed region.

The *fifth* argument is one on which Dr. Comstock frequently insists, and is particularly elaborated in describing parts of the Trap Mountain system. He finds in the similarity between the topography of the novaculite region of Arkansas and that of the Yellowstone Park a reason for believing that hot springs built up the ridges. The resemblance may be striking, and in reply it can only be said that there is nothing in the topography which cannot be accounted for by the ordinary processes of erosion.

*This volume, p. 166.

The *sixth* point will be considered here finally and at greater length: The so-called "Spanish diggings" near Magnet Cove are situated on the crest of a very narrow ridge of novaculite which rises sharply from the valley of Cove Creek to a height of five hundred feet or more above it. The "diggings" consist of round or oval-shaped hollows made in the ledges of the very crest of the ridge, varying from a few feet up to a hundred or more for the longer axis, by fifty feet in width. They are comparatively shallow, the largest being perhaps twenty-five feet deep. They extend along the top of one ridge for more than a mile, almost changing the top of the ridge from a rounded back to a hollow trough. Often but not always there are depressions in the rims of these hollows; no ravines of erosion leading from these depressions are to be seen in the steep mountain sides as would result if from each "gulch" there had been a constant stream of water.

That none of the rocks about the "diggings" are hot spring deposits is, however, evident, for the "Spanish diggings" pits are merely surrounded by walls of loose chips thrown out from the holes by those who made them; very commonly much of the material thrown out has fallen back again so that the quarries, for such they were, have now a symmetrical basin-like appearance. Secondly, the chips forming these rims are identical with the mass of mountain rock which lies in a stratified form associated with sandstones and shales; the stratification can be seen in and about the "Spanish diggings," though not very plainly.

It is not necessary to add any arguments to those given by Dr. Comstock to show that these hollows were not mines. The true explanation of their existence seems to be the one first offered by Featherstonhaugh in 1834, who saw similar pits near Hot Springs. He called them Indian flint quarries and noted the finding of Indian hammers about the quarries. Comstock rejected this theory because he did not find any "archaic relics" about the pits. This was either because the pits which he visited were well known to white men and the Indian hammers had been carried away, or because in the very limited time which he could spend at any place he did not happen to find them. The quartzite balls which were used for breaking or chipping the flints are commonly found, however, about the quarries. The difficulty of quarrying into solid ledges with stone hammers alone may be urged as an argument against the Indian-quarry theory to account for these pits. But it is evident from the signs of fire seen near Hot Springs on exposed ledge quarries that the rock was first shattered by means of fire and then quarried. It was natural that these fires should be built on the ridge tops, for the rocks are better exposed and fires more easily maintained there than on the steep mountain sides. Such quarries are very common throughout the novaculite area. To this class of Indian quarries belong most of the so-called " Spanish diggings " of the novaculite region.

Fortunately it is possible to give in support of the Indian-quarry theory the opinion of that eminent authority, Mr. W. H. Holmes, of the United States Bureau of Ethnology, who has visited the quarries on Indian Mountain near Hot Springs. Mr. Holmes, as is well known, has had a wide experience in Yellowstone Park and the other western regions of thermal springs, and unhesitatingly pronounces these pits Indian quarries. In corroboration of this theory Mr. Holmes collected both Indian hammers and rejected fragments of stone partly shaped for use as arrow heads and discarded on account of flaws, and for other reasons. The Indian Mountain quarries are not essentially different from the " Spanish diggings " northeast of Magnet Cove nor from other pits elsewhere in the novaculite area. The determination made by Mr. Holmes may therefore be regarded as finally deciding the origin of these well known pits or basins.

Branner's theory.—Dr. J. C. Branner, State Geologist, declares his disbelief in the theory that all the novaculites are metamorphosed sandstones, and suggests that the " compact varieties of novaculite usually known as 'Arkansas stone,' have been produced, not from sandstones or quartz, but by the metamorphism of chert. The reasons for this opinion, briefly stated, are:

" 1. The stratigraphic position of the novaculites of western central Arkansas, which is the same as that of the subcarboniferous chert or flint beds north of the Boston mountains.

" 2. The similarity of the gross structure of the two deposits.

" 3. The composition of the two rocks, the chert having its silica in an amorphous state, the metamorphism of which has produced the compact and very finely crystalline condition of the novaculite."*

It seems probable that the novaculites should be placed among the upper members of the Lower Silurian rocks, but as there are massive chert beds in the same geological horizon in northern Arkansas the first argument is still good. The writer has not seen the cherts in the northern part of the State, but understands that their resemblance to the novaculites in the massiveness of their beds and in the fractured appearance of the rock is very marked. The quantitative chemical analyses given in the preceding chapter also indicate that cherts and novaculites are practically identical in composition; the tests of solubility of the silica, however, indicate that there is some difference in the character of the silica in the two rocks. The microscopic examination of the two rocks further confirms the belief in a difference between them. However, the resemblance between them is so close that an origin of one from the other could not be questioned, were it not for the fact that they have apparently had different methods of origin. This leads us to a consideration of the origin of cherts.

Origin of chert.—But little special work has been done in the way of definitely determining the method of formation of the class of rocks known as flint, chert, hornstone, Lydian stone and jasper, so that most statements found concerning these rocks are theoretical. In Dana's mineralogy all are classed as cryptocrystalline varieties of quartz; flint, hornstone, and

*Ann. Rep. Geol. Survey of Arkansas for 1888, Vol. I, p. 49, foot-note.

basanite or Lydian stone are the special varieties most closely related. Of chert, Dana says: "Chert is a term often applied to hornstone, and to any impure flinty rock, including the jaspers." According to this definition chert may originate in many ways.

According to Von Cotta the name of hornfels (hornstone) is given in Germany to certain metamorphosed argillaceous rocks found adjoining igneous rocks to which they probably owe their metamorphism. "Flint is very similar to hornstone, but half amorphous."*

More work has been done in England on the subject of chert than elsewhere. The word is in England generally used as synonymous with flint, though it also includes siliceous limestones. Theories of chemical precipitation in different ways have been adopted.

In a review of previous work on this subject,† Dr. Bowerbank is credited with advocating a derivation of all the flints from the silica of sponges; the source of the silica he considered to have been the silica brought down in solution by rivers or furnished by springs. Prof. Ehrenberg suggests that the flints may be due to the chemical segregation of silex derived from the siliceous remains of Diatomaceæ, Polycystinæ, etc. Mr. Mantell thinks the phenomena presented by nodules, dikes, veins, etc., could be better accounted for by the supposition of heated waters holding silica in solution, derived from the "quartz of granitic and other plutonic rocks dissolved in the heated water and erupted into the basin of the chalk formation."

As Dr. Wallich points out, Sir Charles Lyell favored the idea that the flints were formed from the tests of diatoms.‡

Dr. Wallich's conclusions are that the Cretaceous flint is quite as much an organic product as the chalk itself, the silex

*Lithology, C. B. Von Cotta, Translation by P. H. Lawrence, 1878, p. 342.

†A contribution to the Physical History of the Cretaceous Flints, by Surgeon Major Wallich, M. D., Quarterly Journal of the Geological Society for 1880, pp. 68–92.

‡Elements of Geology, New York, 1866, pp. 321–322.

being derived from the sponges and from minute dead siliceous organisms continually sinking to the sea bottom and changing to a colloidal state thus forming layers of siliceous ooze.

Prestwich* refers to the suggestions "that the aggregations of silica present in chalk and other lime rocks are due to the replacement of amorphous carbonate of lime by silica as a pseudomorph, as in the instance of flint after polyzoan chalk, corals, oölite, etc," and to that of the silica of flints being pseudomorph after carbon.

Certain rocks found in England and on the continent contain a large proportion of silica in the form of an impalpable white powder of low specific gravity. This powder contains from 24 to 72 per cent of soluble silica which is regarded by Prestwich as a chemical precipitate either from siliceous river and spring waters, like those of Vichy and Aix-la-Chapelle, which were particularly abundant in Cretaceous times, the sea salts bringing about the precipitation, or there may have been adjacent continental tracts with drainage areas of much decomposed feldspathic rocks.†

Geikie‡ defines flint as consisting "of an intimate mixture of crystalline insoluble silica and of amorphous silica soluble in caustic potash." He considers that the silica was first abstracted from the sea water by living organisms, radiolaria and sponges, and then re-dissolved and re-deposited probably through the agency of decomposing organic matter.§

Geikie groups Lydian stone, with jasper and ferruginous quartz, seeming to regard these rocks as different from those of the flint group. Of the Lydian stone Geikie says: "It consists of an intimate mixture of silica with alumina, carbonaceous materials, and oxide of iron, and under the microscope shows minute quartz granules with dark amorphous matter. It occurs in thin layers or bands in the Silurian and later Palæo-

*Geology: Chemical, Physical and Stratigraphical, by Joseph Prestwich, 1888 Vol. II., p. 320.

†Op. cit., p. 324.

‡Text-book of Geology, London, 1885, p. 122.

§ Op. cit., pp. 456 and 457.

zoic formations interstratified with ordinary sandy and argillaceous strata. As these rocks have not been materially altered, the bands of Lydian stone may be of original formation, though the extent to which they are often veined with quartz shows that they have, in many cases, been permeated by siliceous water since their deposit."*

Professors A. J. Jukes-Browne and W. Hill† conceive that the silex is obtained from sea water by organic bodies, from which it passes into a colloid condition in the form of minute globules which show high percentages of soluble silica.‡ It is their opinion that the globules took their form while the whole mass was still in the condition of ooze or soft mud. Chalcedonic silica is present in considerable amount, and is regarded as a later product than the globular silica. In many of their conclusions these writers follow Dr. Hinde but they differ from him in the use of the word chert. Dr. Hinde holds that the silica of chert should be entirely chalcedonic while Messrs. Jukes-Browne and Hill regard a preponderance of chalcedony to be sufficient to denote a chert. The chalks and cherty rocks easily grade into flint when all the cavities are filled up and the calcareous matter is replaced by silica.

No special work seems to have been done in the United States upon the rocks of the chert group, yet they are well known and frequently mentioned. Owing perhaps to this lack of special work the distinctions between the rocks of this class have not been carefully kept in mind in this country, so that the names have been used in a broader sense.

The theory of chemical precipitation from sea water is accepted by Dr. C. A. White§ as accounting for the silica in chert.

In the region about Lake Superior in the States of Michigan, Wisconsin, and Minnesota there are extensive siliceous

*Op. cit., p. 122.

†Colloid Silica in the Lower Chalk of Berkshire and Wiltshire; Quar. Jour. Geol. Soc., August, 1889.

‡This volume, page 165.

§Geological Survey of Iowa, 1870, Vol. I, p. 223.

formations of different kinds, which have been treated at considerable length in various geological reports upon this region. In this region cherts are commonly associated with other siliceous formations which are allied to novaculites. These rocks were first described in detail in the Geology of Wisconsin,* where the following summary of the rocks of the Menominee iron region is given. "*Jaspers, cherts, hornstones* and *related siliceous schist,* gray, black, red, green, banded and brecciated, often ferruginous." The following varieties are considered:

"(*a*) Light to dark gray, banded, cherty, siliceous schists, having a somewhat deep-brown weather coating.

"(*b*) Lydian stone or black hornstone.

"(*c*) The banded, red, ferruginous, jaspery schists.

"(*d*) Brecciated and conglomeratic varieties, which appear to have originated from an internal fracturing and displacement of the quartzose layers in situ."

These rocks are described by Dr. Arthur Wichmann, and his nomenclature of the cherty rocks is based upon the conception that "chert is always composed of a crystalline aggregation of small quartz grains, as may be seen in polarized light," though this definition is not adhered to strictly. Thus† rocks denominated "banded jasper schist" have the provisional name of "red banded chert;" they contain "smoky gray laminæ of chalcedony," and are "associated with ferruginous slates, greenstones, and certain closely related gray and greenish banded cherty rocks, which prevail here in these more typical forms." In a "chert breccia" the groundmass of the original fragments consists of small grains of quartz, surrounding nuerous sharply-defined rhombohedra of calcite. Fluid enclosures are abundant in some fragments. Descriptions of the microscopic characters of "chert schist" and "siliceous schist"‡ show that these rocks resemble very closely the original fragments of the "chert breccia." Wichmann says that "the siliceous schists correspond to chert, only they contain more for-

*The Geology of Wisconsin, Vol. III, p. 510.

†Op. cit., p. 571.

‡Op. cit., pp. 615, 616.

eign substances, and therefore generally possess a dark gray or blackish color. * * * It would be advantageous to call quartzose schists, which are contaminated by other substances, siliceous schists."

Rocks similar to the cherty schists and jaspers of Wisconsin are described by Prof. R. D. Irving, who says: * "One of the most interesting points noted with reference to the Animikie series is the occurrence of a strongly marked continuous horizon of cherty and jaspery magnetitic schists and quartzites near the northern edge of the formation. The jaspery ingredients constantly recall the jaspery and cherty materials associated with the iron ores of the Marquette, Menominee and Penokee regions," and he suggests "that all these chert and jasper schists are original and not the result of a metamorphism upon ordinary and sedimentary deposits."

He says further of the cherty rocks: "At times these cherts are for a considerable thickness wholly composed of chalcedonic silica, but in other cases they contain fragments of quartz in smaller or greater quantities up to a predominating amount. * * * .These cherts, in part at least, seem to be of direct chemical origin."†

This opinion is reaffirmed and it is held that "certainly they (the cherts) are not the results of metamorphism of sedimentary material."‡

In a later article§ Prof. Irving expressed somewhat different views, giving the arguments in favor of chemical precipitation, and his reasons for rejecting this theory. His final conclusion is that since the "least altered forms of the ferruginous schists contain a considerable proportion of some carbonate—the amount of carbonate increasing inversely with the amount of disturbance and alteration—the idea of a possible formation of these rocks by chemical deposition approximately in their

*Preliminary paper on an investigation of the Archæan formations of the Northwestern States, Fifth Annual Report of the U. S. Geological Survey, 1883–4, p. 204.

†Op. cit., p. 228.

†Op. cit., p. 242.

§Origin of the Ferruginous Schists and Iron Ores of the Lake Superior Region: American Journal of Science, third series., Vol. XXXII, 1886, pp. 255–271.

present conditions gives place to views which include the idea of a replacement of some rock, originally dolomitic or calcitic, by siliceous and ferruginous substances."

Irving explains in a foot note that "the term 'chert' is used in this article to cover colorless, white or grayish hornstone like silica, which, under the microscope, is either wholly crystaline, or partly crystaline and partly chalcedonic, or even amorphous."

N. H. Winchell and H. V. Winchell described* siliceous rocks identical with those described by Irving. These writers advocate the theory of direct chemical precipitation from an acid or alkaline ocean, the silica and iron precipitated being derived from igneous rocks, the separation of the two being the result of gravity, and the stratified condition being caused by successive eruptions.

The arguments establishing the chemical precipitation of the silica of the "jaspilyte" as deduced by Dr. H. Hensoldt, from a microscopic examination of many specimens of the rock are as follows: "Under the microscope the section† of jaspilyte reveals a structure which might be termed 'cryptocrystaline,' but which differs completely from that of any ordinary massive or fragmental quartz rock, * * * and can only be accounted for by chemical precipitation from a saturated solution. Under a magnification of about sixty diameters the section presents the curious 'mottled' structure which characterizes certain siliceous deposits, such as the well-known novaculite of Hot Springs, Ark., which has never yet been observed in crystalized quartz."‡

Dr. Hensoldt presents two arguments to prove that the particles of silica in the jaspilytes are not sand-grains: First, their behavior in polarized light is not like that of ordinary quartz, but resembles that of chalcedony, jasper, agate, and the novaculite of Hot Springs. Second, no fluid cavities are seen in the silica of the jaspilytes, while, according to Hensoldt, they are

*Bulletin No. 6, of the Geological Survey of Minnesota, 1891.

†A typical rock section is selected for description.

‡Bulletin No. 6, Geological Survey of Minnesota, 1891, pp. 72 and 73.

always found in crystalized quartz, but are absent in agate, chalcedony, jasper and the novaculite mentioned above.*

To account for the hexagonal outlines which Dr. Hensoldt noted for the granules of silica in the jaspilyte he proposes the theory that the silica was precipitated in the form of globules, which by compression have taken a hexagonal form.

In other specimens Dr. Hensoldt observed that "in some instances the siliceous granules * * * presented the dense, compact appearance of most of the Hot Springs novaculites. In others the structure almost approached that of certain fine-grained sandstones, so clear and distinct are the component granules."†

Exceptions being taken to the statement of Dr. Hensoldt, regarding the identity of the jaspilyte with the novaculite of Hot Springs, a section of the above described typical jaspilyte (specimen 867) was submitted to Prof. C. R. Van Hise, who writes: "This I have closely examined, and find it in no way different from numerous other sections of jasper from the Lake Superior iron regions. I regard it as completely although finely crystalized quartz. It contains very numerous small liquid inclusions."

The solution of silica and the formation of chert is touched upon by Julien.‡ From the fact that the chert pebbles in some New Jersey sands of Tertiary and Cretaceous age have had their silica replaced by iron ochre, "while the crystalline and even chalcedonic varieties of quartz have been unaffected," he draws the conclusion that the humic and azo-humic acids act with peculiar efficiency, "for the solution of silica, in their *nascent condition*, on the partial separation of their oxidized base." Had the chert been absent from these gravels, Julien thinks that the acids would have carried their burdens of ferric oxide, which now cement the gravels, to a lower drainage level, or into sub-aerial basins. "These phenomena therefore seem

*Op. cit., pp. 73 and 74.

†Op. cit., p. 76.

‡On the Geological Action of the Humus Acids. By Alexis A. Julien; Proc. Am, Ass'n. Adv. Sci., Vol. XXVIII, 1879, pp. 311–410.

to indicate that the strongest solvents of amorphous or colloid silica in nature consist of a group of certain organic acids of humus, when separated from ferrous oxide by its higher oxidation."* Changes which have taken place in clays, the silification of fossils and wood, and the formation of concretions are also brought forward as arguments indicating the importance of these and other humus acids. The same, or similar organic acids, Julien argues, must be present in sea water, introduced by river waters, or formed by the decomposition of the organisms living in the sea.†

Julien attributes the genesis of amorphous or hyaline silica in nature to four agencies:

1. "*Separation by the life-force* out of solution in both fresh and marine waters, resulting in the growth of organic deposits, chiefly the diatomaceæ, radiolariæ, and polycystineæ. * * *

2. "*Deposit from solution in thermal waters.* * * *

3. "*Precipitation by acids of solutions of the silicates.* * * *

4. "*Deposit from solution in organic acids.* * * * The hyaline silica, due to this source, has assumed two forms: the one, *hydrated*, hyalite, as a kind of vein deposit, in crusts upon the walls of fissures; and the other, but in small part hydrated, as amorphous masses of flint, chert, etc.—within the body of limestone strata.‡

The microscopic examination of many thin sections of flint from France and England showed Julien that these rocks were very rarely without traces of organic forms. He continues: "We may also expect in time to determine the conditions which have differentiated the deposition of colloid silica in the Cretaceous beds as flint, and in other limestones as hornstone, chert, chalcedony, jasper, agate, etc. Numerous examinations of these last amorphous or cryptocrystalline forms of silica, in thin sections, by polarized light, show a more distinct granulation than that of flint, often fibro-radial, and with much

*Op. cit., pp. 345 and 346.

†Op. cit., p. 364.

‡Op. cit., pp. 392, 393.

stronger refractive energy. This indicates, in the condition of genesis—or at least of the last metaphorphism, a solvent and crystalline exertion which must naturally have accomplished the general obliteration of most of the more minute organic forms. Flint, hornstone, and amorphous chert, therefore seem to me to present the colloid form of silica necessarily deposited from a solvent of a colloid nature, such as humic and probably the azo-humic acids have been found to possess. Granular chert, jasper, etc., on the other hand, appear to be the crystalline forms of silica, probably in part deposited from solution in thermal waters, in the course of the metamorphism which has generally affected the pre-Cretaceous sediments in which they occur."* The supply of silica taken into solution and subsequently deposited as chert, etc., Julien considers was derived from the fragmental silica of the original sedimentary deposits.

Conclusion regarding cherts and allied rocks.—Without discussing the relative and quantitative values of these various theories here, it is sufficient to call attention to the fact that all the members of this group of cryptocrystalline rocks, except the Lydian stone of Von Cotta and Geikie, and some of the northwestern cherts of Irving, are considered to have had directly or indirectly an origin by chemical action; for the three exceptions the theory implied or directly stated is that of mechanical sedimentation. From the statements made regarding the chemical composition and microscopic characters of these various rocks by the authors cited, it seems to be possible to define more clearly some of the specific terms hitherto not definitely understood or at least not uniformly used. All rocks of this group have in common the general characteristics of a very siliceous composition with the silica in a very finely granular form. The special characteristic of *flint* seems to be that a considerable part of the silica is in the amorphous, soluble form of opal. *Flint* is a more purely siliceous rock than chert, and the name is perhaps more generally used in connection with the darker colored rocks of this group. For

*Op. cit., p. 398.

chert the weight of opinion seems to be in favor of a composition largely of chalcedonic silica; chert may contain lime even to a predominating amount. Rocks consisting of simple, crystalline quartz in very fine grains are sometimes called cherts but it may seem better to distinguish these rocks by a new name, chertite, following the suggestion given on page 166. There seems to be no chemical or microscopic distinction for *hornstone*, and this variety is distinguished from flint only by having a more splintery fracture. *Lydian stone* contains carbon, and always has a black color and fine gritty feeling; its simple sedimentary origin separates it from chert and flint. Enough concerning *jasper* has not been found in this connection to justify a definition of that rock, but it does not seem that it should be classed with flint and chert. The "jaspery" rocks or "jaspilytes" of the Lake Superior region seem to belong in part to the quartzites. They will be discussed elsewhere in this chapter.

Differences between novaculite and chert.—Defining chert according to the weight of opinion as a cryptocrystalline siliceous rock formed by chemical action and containing a large percentage of the silica in the chalcedonic form, it is now possible to state wherein the Arkansas novaculites differ from chert, and to present the theory of their origin. Chemical analyses tend to show that the novaculites of Arkansas have a purer siliceous compositon than cherts, though if the calcite had not been dissolved from the Ouachita stone it could not have been distinguished from chert. The tests of solubility of the silica show a decided difference between novaculite and chert. Microscopic examination shows that the soluble silica of chert is in the form of chalcedony, while novaculite is entirely without silica in this form. As a result, apparently, of this difference in the form of silica, novaculite has a fine gritty feeling while chert is more glassy. Owing also to the purer and more homogeneous composition of novaculite this stone is more translucent than chert. Novaculite is not a tough rock like chert and breaks more easily, though its conchoidal fracture is as perfect as that of any chert or flint.

Metamorphism of the novaculites.—Still, it might be possible that the Arkansas novaculites were metamorphosed cherts were it not that their microscopic examination disproved the idea of great metamorphism. The fine grains of silica composing the groundmass of the novaculites are not cemented, but seem to be merely jammed together, the tenacity of the stone being due to the interlocking of the irregular edges of the grains. In the Ouachita stone are perfect rhombohedral cavities about which the fine grains of silica are closely packed in a layer showing orderly arrangement;* outside this layer the granules have no orderly arrangement. In an early stage of the history of the rock the rhombohedral cavities undoubtedly contained crystals of calcite or dolomite; in fact, these crystals must have formed while the grains of silica were yet free to move about, that is, while the rock material was in a soft condition similar to that of mud or ooze on the sea bottom. That the silica particles were free to move is shown by the fact that those granules immediately surrounding the crystallizing calcite arranged themselves with their long axes perpendicular to the faces of the calcite crystals. Thus the calcite crystallized out in the original slime on the sea bottom, or in the still plastic beds below the slime; and it is noticeable that the calcium carbonate formed the tiny separate rhombohedra uniformly distributed through the rock, just as one would expect the fragmental carbonate to be distributed in an original sedimentary deposit, instead of collected together into concretions or into separate layers. The fact that the carbonate of lime did not gather into layers or concretions may indicate that the sedimentation was a rapid one.

The next change in these rocks of which we have evidence was the folding into the sharp plications which have been traced in the novaculite area.† During this folding the joint planes which so completely intersect the novaculites were developed. The existence of these furnishes the evidence that the novaculite rock was in a brittle condition before the folding, for had it been plastic it would not have been so completely fractured as it is. This gives evidence that after the carbonate had been crystallized the groundmass of silica became consolidated about the crystals and the siliceous mud hardened to a brittle rock.

*See p. 124.

†See sections on the Mt. Ida sheet of the accompanying map.

After the folding and elevation above sea level the percolating waters dissolved away the calcite leaving the present cavities. It can safely be said that this leaching process took place after the folding, because the porous Ouachita stones could scarcely have undergone the pressure to which these rocks were subjected and yet have retained the forms so perfectly preserved in them; then, too, the fact that the novaculite is found in the stream beds still containing the calcite undissolved, indicates that the leaching process is slower than erosion in these places; and it might be inferred from this that the leaching is carried on by percolating surface waters which do not accomplish much work below the level of the valley streams. If these considerations have any weight, then the leaching of these rocks, depending on the erosion in the valleys, has been accomplished in comparatively recent times.

Since the removal of the calcite a very few small cavities have been refilled with quartz; and some granular silica like that of the groundmass of the rocks has been either forced into some cavities or deposited there from solution so that the rhombic outline is often obscured. Except this formation of secondary silica, there is no evidence of recent change.

The general conclusions drawn from facts revealed by the microscope, together with those obtained by field work, are opposed to the idea that the present rock is a result of great metamorphism, and therefore opposed to an origin either from sandstone or from chert.

The summary of the history of the novaculite rocks, as shown by the microscopic examination, is as follows:

First, deposition in the form of sedimentary mud or ooze on the sea bottom.

Second, crystallization of the carbonate of lime in this deposit into rhombohedrons.

Third, consolidation of the siliceous part of the deposit into a hard, brittle rock.

Fourth, folding of rocks and elevation above sea level.

Fifth, erosion of the strata and the accompanying removal of the calcite crystals.

Sixth, the formation of a little secondary silica.

Novaculite a deep water deposit.—Since the novaculite does not show any great amount of metamorphism, it must be in nearly its original condition. This condition was clearly one of a sediment on the sea floor, for the rocks are stratified and associated with sandstones and shales. Moreover the formation was one deposited in deep water; many of the shales are highly ferruginous, such shales being considered an off shore deposit. There is one well defined novaculite bed which carries iron and manganese ores, besides other local deposits in other beds. Dr. Penrose says that these manganese ores "were very likely deposited in an open sea."*

Theories of chemical precipitation.—The material of the novaculites is in a very finely granular form, such as in chert and other deposits has been atttributed to chemical deposition. It has been said (see page 183) that the Hot Springs novaculites seem to be identical with the jaspilytes of Minnesota, and for the origin of the jaspilytes a theory of chemical precipitation is given.

The writer agrees with Prof. Van Hise regarding the composition of the jaspilytes. Of the jaspilytes the quartz grains are about .1 mm. in diameter; the grains contain minute fluid inclusions; and, judging from the description and plates of the bulletin previously quoted, and by examination of specimens obtained from Prof. Winchell by exchange, including the typical rock, No. 867,† described by Dr. Hensoldt, the rock seems clearly to be a quartzite. Fibrous chalcedonic silica is not anywhere mentioned in Dr. Hensoldt's description of the jaspilytes, and it is only this form and opal silica which are generally regarded as chemical precipitates. According to the

*Annual Report of the Geological Survey of Arkansas, Vol. I., 1890, p. 599.

†See page 149.

writer's examination (see page 150) specimen No. 1277, called in the bulletin a flint is practically identical with many of the siliceous shales of Arkansas, and contains some fibrous chalcedonic silica. Thus it approaches nearest to the novaculities. A third specimen, No. 907, which to the eye seems closely to resemble the novaculite, is apparently identical with the rock described by Irving as a carbonate replaced by silica. Hensoldt's description and plate of specimen 1565 seem to show that this rock is another specimen of the same variety.

The granules composing novaculite apparently contain fluid inclusions; and in size they are exceedingly small, averaging about .005 mm. in diameter. Thus the main difference between novaculite and the typical jaspilyte No. 867 is in the size of grains. If, however, the theory of chemical precipitation be chosen to account for the origin of all the jaspilytes the novaculites of Arkansas would not seem identical with them, and are not necessarily to be explained by the same theory of origin.

The close similarity in composition of the pure novaculites to quartz might be argued in favor of the theory of chemical precipitation, but the lithological association is sufficient to discredit this argument, even if the lack of crystalline form be disregarded. On the same ground of lithological association must be met the stronger argument drawn from the resemblance to silica powder produced in the laboratory. Then it may be argued too against the theory of chemical precipitation from sea water that the theory is too vague to be given credence when a more simple one can be presented.

The theory of precipitation through the agency of organic life, by sponges or foraminifera, does not seem to be of great value in this connection, for traces of organic life have been found in the novaculites in but one locality,* although there has apparently been little metamorphism. Still, the presence of a few fibrous spots of chalcedony in some of the impure rocks of the series may indicate a little work by the organic acids as described by Julien.

The sedimentary origin of novaculite.—The theory of simple

*See page 132.

sedimentation of fragmental material alone remains. It may be somewhat difficult to conceive of a constant supply of very fine fragmental silica, almost totally without other materials, in sufficient quantity to form beds several feet in thickness, with very thin layers of shale between, and making a formation from 500 to 600 feet in thickness, yet this seems to have been the manner in which these rocks were formed. After all, the conception is not so difficult when one considers that the fragmental silica of many of the slates and shales is as fine as that of novaculite, and as the percentage of silica in the sediments forming these rocks is increased the resulting rock approaches more and more closely the novaculite. Thus with the novaculites are associated very argillaceous shales, grading into siliceous shales and then into transparent novaculites. The almost absolute purity of the novaculites still causes doubt as to the possibility of this mode of origin; but many coarse sandstones are nearly as pure, (see analyses page 161) and if the novaculites can be considered as extensions of the sandstones toward the deep sea, where the finer fragments would settle, then we have at least a close approximation to the sediments forming the novaculites. That the same action which produces the angular fragments of quartz in sandstones must also afford a very large amount of exceedingly fine quartz is evident.

It is not at all incompatible with this theory to admit that chalcedonic silica found in many of the rocks of the series was precipitated chemically, perhaps through organic acids. It is noticeable that the amount of chalcedonic silica increases with the amount of iron and other impurities in the rocks.

This theory of simple mechanical sedimentation is the one adopted by Penrose* to account for the origin of some of the cherts of northern Arkansas. The reasons offered for this theory are the association with beds of shales, sandstones, and limestones and the commingling of the materials of these beds in the chert.

Influence of the salts on fine sediments in sea-water.—There

*Ann. Rep. of the Geol. Survey of Arkansas, Vol. I, 1890, p. 137.

is another consideration which it was thought might help in accounting for the purity of the novaculite deposits: The salts of sea-water, as is well known, hasten the deposition of fine clay sediments. It seemed possible that the influence on fine siliceous sediments might not be so great, so that the latter might settle in deeper water than the former, thus being the last of the fragmental sediments emptied by rivers into the ocean to settle. In this way very pure siliceous deposits might be formed. Some experiments tried in the laboratory of the survey to determine this fact by using salt water made after an analysis of sea-water, and distilled water with ground kaolin clay and ground novaculite powder, gave rather negative results. The powders were shaken thoroughly in the waters, and were then allowed to settle in separate glass tubes; the tubes were about twelve inches long, and an inch in diameter. In the salt water both powders settled in one night; the fresh water did not become clear for many days. To ascertain whether a weaker solution of the salt water might not show a difference between the two powders it was diluted to two-fifths its original strength. The water in both tubes was clear within a day. It became evident, however, that the tubes were too short and too small in diameter to give trustworthy results. The diameter should be large, because the powdered silica is white and does not show in water unless there is considerable of it, while the kaolin, having a deeper color is more easily apparent in the water.

Direction of the source of the sediments.—If the above experiments indicated anything, it was that the silica settled a little faster than the clay. This result would seem to be in accordance with the facts observed in the field. These facts are:

First, that overlying the novaculites of the southern part of the novaculite area are gray sandstones, and these are represented on the north side of the area chiefly by gray shales, indicating that the sediments were derived from the south.

Second, the novaculites on the south side of the novaculite area are pure in composition and massive, while on the north side they have largely the character of siliceous shales; so if the direction of origin of the sediments be the same, the massive novaculites represent a more rapidly settling portion of the sediments.

Coarse material in novaculite.—One fact brought out by the microscopic examination of the novaculites may seem somewhat damaging to the theory of their simple sedimentary origin, and that is that particles of considerably larger size than the grains of silica of the groundmass are pretty freely distributed through the rock. These are surely sedimentary, as some have the well-rounded outlines of small pebbles. Others have their outlines more or less jagged, as though decomposing to furnish more fine material for the ground mass. This action has apparently not been very great as the rounded outlines are still easily seen. But the presence of these larger particles does not seem entirely compatible with the extreme fineness of the great mass of the sediment, still, as there are grains of great difference in size in all sand stones, so there may be great difference here. The very fact that there are larger particles makes the resemblance to a sandstone even stronger perhaps than it otherwise would be.

Conclusions.—Since it is now shown that the rock composing what has been known as the novaculite formation of Arkansas differs from those rocks most nearly allied to it in physical characters and in origin, it is clear that this formation is entitled to a special name, and, as it has been already shown that the rock belongs to the novaculite of Linnæus, it preeminently deserves that name. The thickness and extent of the novaculite strata in Arkansas and Indian Territory should warrant a more general return to the use of the name in textbooks of lithology and mineralogy.

CHAPTER X.

Geography and Topography of the Novaculite Area.

Position—The western central part of Arkansas, with an extension westward into the Indian Territory, comprises the region in which the novaculite rocks are exposed. In Arkansas the formation is almost entirely confined between the parallels 34° 20′ N., and 34° 50′ N. The eastern limit is but a few miles southwest of Little Rock and near the meridian of of 92° 20′ W. The western limit of the great Arkansas area is near the meridian 94° 20′ W., about six miles west of the town of Dallas, in Polk county. The Indian Territory extension begins in Arkansas about ten miles east of the state line and runs about due west on either side of the parallel of 34° 20′ N. The western limit of this area is reported by Prof. R. T. Hill to be near the 100th meridian, in Indian Territory.*

The general trend of the formation is a little south of west. The novaculite area proper in Arkansas comprises about 2700 square miles, a region over twice the size of the State of Rhode Island. It includes large parts of Pulaski, Saline, Garland, Hot Spring, Montgomery and Polk counties, and touches Clark, Pike, and Howard counties.

Drainage.—The area is one in which many rivers have their sources, yet almost the entire drainage eventually finds its way into the Ouachita River, which empties into the Red River in Louisiana near the junction with the Mississippi. The main Ouachita River itself drains nearly the entire area, rising as it does on the north side of the western end of the novaculites, and receiving all the northern drainage for over sixty miles to the east, then crossing the area at its widest part diagonally in a southeast direction. A branch of the Ouachita, the Saline River, receives the waters of almost the entire part of the no-

*Geological Survey of Arkansas, Ann. Rep. for 1888, Vol. II, p. 10, foot note.

vaculite area east of the main Ouachita basin. The Caddo and Little Missouri Rivers, branches of the Ouachita on the west, drain most of the southwestern portion. The West Saline, Cossatot, and Mountain Fork, all branches of Little River, which is in turn a branch of the Red River, drain the remaining southwestern portion. A small portion at the extreme eastern end of the area belongs to the Arkansas River basin, the draining streams being the Little Maumelle River and Fourche Bayou.

The river basins on the north side of the area separate it in a measure from the mountainous country farther north and to the south there are no elevations of importance; thus, since the mountains of the novaculite area are isolated in position, and also, as we shall learn, isolated geologically, and more than that, are peculiar in rock formation and structure, it seems fitting that the system should have a name. The name of the chief river of the area, the Ouachita, suggests itself as most suitable for the mountain system also. The name Ouachita has already been used by Dr. Branner to apply to the more southern ranges of mountains,* and it is only necessary to extend its meaning to the whole system of which the southern ranges form but a part. Besides the novaculites, the Ouachita Mountains include those mountains of quartzose sandstone, part of which are now known as the Crystal Mountains, which lie within the topographical and structural limits of the novaculites; but the sandstone mountains lying north and west of these limits are not included in this system.

MOUNTAIN RANGES.

Northern Range.—This Ouachita mountain system may be conveniently divided into ranges. The longest but least prominent of these is the Northern novaculite range stretching from Little Rock to Board Camp post-office in Polk county. This range is composed generally of several parallel ridges, but sometimes is represented by a single ridge which may become so low as to be entirely without topographic importance. The ridges are usually not more than three or four hundred feet above the valleys, but occasionally reach an elevation of six hundred feet or more. The northern range starts at the east end from a single ridge rising near the junction of McHenry's Creek and Fourche Bayou in sections 28 and 33 of township 1 north, 13 west. The direction is at first northwest for about fifteen miles, the range having a width of three or four miles for the greater part of the distance, and is called the Fletcher Range. The direction then changes to west for another fifteen miles; thence the trend is steadily south of west; in this latter part of its course the range is seldom more than two miles wide, and often consists of a single, sometimes indistinct, ridge. The total length of the range is over one hundred miles. It contains no high peaks, and but few of the higher elevations have received names; these are Bald Mountain, Prilliman Ridge, Goosepond Mountain, and Muddy Mountain.

*Geological Survey of Arkansas, Annual Report for 1888, Vol. II, p. 10, foot note.

The Caddo Range—Uniting at the western end with this northern range is another series of ridges having a trend south of east to Caddo Gap; thence the same range changes its general direction to northeast becoming less prominent near the Ouachita River. This range consists in the main of parallel ridges forming a subordinate system two or three miles wide; but these ridges are much more prominent than those of the northern range, being five hundred to six hundred feet in height and rising in peaks which are about one thousand feet in elevation above the valleys.

Since the greater part of this range lies in the Caddo River drainage the name Caddo Mountains may be conveniently applied to it The range has a length of about sixty-five miles and contains some of the highest peaks among the novaculite mountains, including Blow-out Mountain, the Little Missouri Mountain, Fork Mountain, State House Mountain, Cogburn Mountain, the Fodder Stack south of Black Springs, the Gap Mountains at Caddo Gap, and the Three Sisters southeast of Plata post-office.

The Cossatot Range.—South of the western part of the Caddo Mountains and west of the Caddo River is a series of ranges which are conveniently grouped by themselves, and are separated from the Caddo Mountains topographically by the valleys of the South Fork of Caddo, part of the Little Missouri, Long Creek, Mine Creek, and the head-waters of the Cossatot River. The name Cossatot will be used here to include the whole of this small system, though this name has hitherto had only a local application to the mountains of the western end of the group. The name is appropriate because the part of the system already known as the Cossatot Mountains contains the highest peaks of the novaculite area, thus forming the grandest part of the system. The trend of this system is south of east and north of west; its length is about forty-five miles; in breadth it varies from a single ridge a quarter of a mile wide to a series of parallel ridges with a total width of six miles. Many of the mountains have received names; beginning with the west, are Ward's, Bald Eagle, McKinley, Shadow Rock, Buckeye, Rachel, West and East Hannah, Tall Peak, Porter, Brushy, Raspberry, Fodderstack, Musgrove, Blalock, Leader, Sugar Tree, Prior, Poll's Butte, Sulphur Spring, Fancy Hill, Line, Tweedle, and Pigeon Roost. All of these and others without names rise very sharply from 800 to 1000 feet above the valleys of the larger streams. The peak known as East Hannah is the highest mountain of the system and probably the highest in the novaculite area; a measurement with an aneroid barometer by Dr. Penrose of this Survey gave an elevation of 1000 feet above the Cossatot River at Rhode post-office; it is clearly higher than West Hannah and Bald Eagle Mountains toward the west, and higher also than those in its neighborhood toward the east. Prof. Owen, during his reconnaissance, ascended West Hannah Mountain, making the aneroid elevation 1000 feet. He reported that a level swept round from this peak indicated mountains to the east seventy-five or a hundred feet higher; this would give East Hannah an elevation of nearly 1100 feet. According to the maps made by the U. S. Geological Survey, the elevation of the country on the

north side of the Caddo Mountains, just north of the Cossatot Range, is about 1100 feet above sea level; thus the highest of these mountains are probably more than two thousand feet above sea level.

The Crystal Mountains.—Another range of mountains deserving separate mention is the one lying north of the eastern end of the Caddo range, known locally as the Crystal Mountains, from the abundance of rock crystal found in veins in the quartzose sandstones of which the mountains are composed. The range is continued northeastward through Bear Mountain to Mill, Blakely, and Cedar Mountains east of the Ouachita River. All these belong to the same formation, are characterized by the development of quartz, and should all be included in the Crystal Mountain system. The general trend of this system is north of east, and its length is about sixty miles. That part of the range south of Silver City is sometimes known as the Silver Leaf Mountains, but this name is not so generally known nor for a general name so applicable as Crystal Mountains. As with the novaculite mountains, the range is composed of parallel ridges sometimes having a breadth of three or four miles. These mountains are very rough and are as high as the novaculites, but are not as a rule so steep. The highest mountains of this range are in the northern part of township 3 S., 24 W. The peaks here appear to be higher than the high novaculite peaks called the Three Sisters, lying south, and it is possible that they may approach the elevation above sea level of the higher peaks of the Cossatot range.

The Zigzags.—East of the Ouachita River rises a continuation of the Caddo range, and through a system of northeast and southwest zigzagging ridges, trends in an east-southeast direction. This range has a length of twenty-five with a breadth of six or eight miles; for it Dr. Branner suggests the very appropriate name of the Zigzags.* A striking feature of this range is the general trend of the ridges which is almost at

*The name Ozark has been locally applied to these mountains by a few persons; but the use of this name is inappropriate and confusing, the true Ozark Mountains being in Missouri and North Arkansas.

right angles to that of the system. The ridges are sharp and commonly 500 to 600 feet in height. There are some prominent peaks and ridges which have names: Near Hot Springs are West Mountain, Hot Springs or Observatory Mountain, North also called Quarry Mountain, Sugar Loaf and Indian. Other prominent mountains of the range are Cutter's, Bald, Teager, and Basin.

The Trap Mountains.—South and west of the Ouachita River, southwest of the Zigzags, but connected with them through low ridges at the eastern end is the last division of the Ouachita system, called the Trap Mountains. This range trends almost east and west, with a length of thirty-five miles, and a maximum breadth of about four miles. The ridges are not as a rule much over three or four hundred feet in height, still there are many sharp peaks which approach seven and eight hundred feet. Few names have been given to individual mountains, as they are not very well known; Jack, Bare, and Panther Mountains are among the most prominent elevations.

The Indian Territory system.—About ten miles southwest of the western end of the Ouachita Mountain system begins a new one which extends westward into the Indian Territory where it attains its greatest development. In Arkansas it consists of but three east and west ridges of moderate elevation having a total length of eleven miles. The mountains become much higher, however, in the Territory, the system widens out, and extends as far west as the eye can see.

BASINS.

The various mountain ranges of the Ouachita system divide the novaculite area into very distinct natural basins. There are two basin areas separated from each other geologically and topographically. First, there is the great northern one between the Northern range and the Caddo Mountains and the Zigzags on the south, in which the rocks underlie the novaculites. Second, there is the one between the Caddo Mountains, the Zigzags and the Trap Mountains, with perhaps also the valley of the south fork of the Caddo lying between

the Cossatot and Caddo Mountains; in this basin the rocks overlie the novaculites. Owing to the differences in character between the overlying and underlying rocks, there is a noticeable difference in the vegetation of these two basins.

The great northern basin.—The great northern basin is divided into three parts by the east and west ends of the Crystal Mountain range. The eastern basin is drained by the Saline River and its branches; the central one by the Ouachita, together with the South Fork. The western one is drained chiefly by the Caddo, but also in part by small tributaries of the Ouachita. The country within these basin limits is generally undulating, often rough, with sharp ravines and ridges a hundred feet or more in height; along the streams are level bottoms usually proportionate to the size of the streams. The soil of these basins is generally fertile; the hard woods mainly form the forest, though pines occur plentifully where the underlying rocks are sandstones. The bottoms along the larger streams have very rich and practically inexhaustible soils.

The Mazarn basin.—The Mazarn is the second basin, two of its principal streams having this name and being confined to its limits. The Ouachita River flows across the eastern end of the basin and receives the waters of the Mazarn creeks from the west and its many smaller streams from the north and east, so it is the most important stream of the basin. The Caddo drains the western end of this basin. The country within the Mazarn basin is rougher than in the three divisions of the northern basin, owing to the presence of more massive rocks, which have resisted erosion more effectually than the softer strata of the other basins, and form considerable ridges.

Projecting above the sandstones in the western part of this basin stands a sharp, solitary ridge of novaculite called Pigeon Roost Mountain. It is not connected naturally with any of the previously-mentioned mountain ranges, so will be considered separately as a topographic feature of the Mazarn basin. It is about five miles long and has a crescent shape. It has several peaks, the highest of which is nearly 900 feet above the valley. Along the north side of the mountain the overlying sandstones form a considerable ridge, which continues to the east beyond the end of Pigeon Roost, on the south side of Big Mazarn Creek. This ridge is the most prominent topographic feature of the basin,east of Pigeon Roost, and is known as Mazarn Ridge.

There is less land suitable for cultivation in this basin, though, as in the other basins, level tracts are found along the streams. The rocks of this region are chiefly sandstones, so the soil is not very productive as a rule; the timber is chiefly pine.

The relations of topography and geology.—The novaculite area as a whole is characterized by swiftly moving streams in a broken country from which rise the sharp narrow ridges forming the mountain ranges. The courses of the streams depend very much upon the geologic structure and have adapted themselves to the present mountain ranges. Thus the general direction of the streams is east or west with the trend of the rocks, and north or south across them, but where the general trend of the rock formations changes direction, as it does notably in the Mazarn basin, the directions of the streams also change. The rapidity with which the streams flow would seem to indicate a recent elevation above sea level, and numerous proofs of this supposition are found in the region. The elevation does not seem to have been uniform, however, for while the general level at the eastern end of the area is about 400 feet above sea level, at the western end about Dallas, it is over a thousand feet; while at the intermediate points of Hot Springs and Mount Ida, it is 600 and 700 feet, respectively. At all these places submergence in comparatively recent times is indicated by the extensive deposits of coarse gravel and clay in level terraces or plains.

The mountain ridges of the area have remarkably level crests, and the elevation above the valleys depending upon the thickness and attitude of the formation, remains closely about 600 feet when the novaculite formation is present in its full strength of 500 to 600 feet in thickness. The continous ridges are seldom more than 500 feet high except in the western part of the Cossatot range, but from the ridges rise sharp peaks which reach a much higher elevation.

CHAPTER XI.

GENERAL GEOLOGY OF THE NOVACULITE AREA.

Literature.—Not much was known concerning the general geologic structure of western-central Arkansas until the present geological survey was begun. Featherstonhaugh in 1835 traversed the country from Little Rock to Hot Springs, but his observations were of a very general nature. He regarded the rocks as belonging to the old red sandstone of Devonian age.

Owen's reconnoisance.—Owen crossed this area in several directions while making his survey in 1858 and 1859, and was able to draw somewhat better conclusions; still his work was far too limited to make accurate determinations in such a complicated area. He regarded the various formations from the southern limits of the coal fields to the Cretaceous of southwestern Arkansas as all belonging to the millstone grit. The thickness of these rocks indicated by the steep and very constant dip was considered to be enormous, rivalling the great sandstone formation of Scotland* and called by Owen "the great and leading formation of Arkansas." He admitted that this assignment of these rocks to a particular geological age was merely provisional, as fossils were very rarely found and the strata of the southern region were thought merely to correspond to the Sub-carboniferous beds farther north where fossils were found and the geological horizons determined. What have since been determined to be entirely distinct formations, or at least, distinct parts of the same general group, Owen included in the millstone grit. Thus the novaculites of Hot Spring and Polk counties are called metamorphosed sandstones; while these together with all the mountains of Polk county, both sandstones and novaculites,† also the sandstones of Montgomery

*Second Geological Reconnoissance of Arkansas, 1860, p. 33.

†Loc. cit., pp. 29, 33, 95.

county forming the Crystal Mountains, which he regards as a portion less metamorphosed than the novaculite mountains,* and the "slates" of Saline county were included in the millstone grit series.† Of the formations at the above localities only the sandstone mountains of Polk county belong to the Lower Carboniferous, the other mountains falling in the Lower Silurian area.

Owen remarked the great folding of the strata all through the region of western-central Arkansas, but did not understand the size of the folds nor realize the extreme contortion which the strata of the region have undergone. He presents no diagramatic sections, but one gathers the idea that had he done so he would have indicated huge folds involving a thickness of several miles.

Comstock's report.—In his investigation of the gold and silver mines of this region, Dr. T. B. Comstock spent a few months, and collected data for a more extended report‡ on this area than had previously been given. His work, however, necessarily lacked the connected details which alone could solve the structure of the region, so that the maps published by Dr. Comstock are diagrammatic representations based upon some of the salient features of the structure, rather than true geologic maps. Thus Dr. Comstock caught the northeast and southwest trend so strongly accented about the Mazarn basin and in the western part of the north side of the great northern anticline, but exaggerated the importance of this general trend when he made all the axes of his folds parallel with it. The cause of this was perhaps that Dr. Comstock's work led him more into the region of the northeast and southwest trend, while little was seen of the Cossatot and Caddo Mountains where the trend holds steadily north of west. That the region is one of folds is also expressed by Comstock's maps, though his work was not detailed enough to recognize the closeness with which these folds were everywhere jammed

*Loc. cit., p. 98.

†Loc., cit., p. 107.

‡Geol. Survey of Arkansas, Ann. Report for 1888, Vol. I.

together, nor to see that the folds were frequently interrupted and overlapping. That the folds of this region were overlapping and not continuous was the opinion expressed by the State Geologist, Dr. Branner, in his introduction to the report in question.* That the axes of the folds changed frequently in direction was also remarked by Dr. Branner, but this fact is not brought out by the maps of Dr. Comstock. Another objectionable feature in the plan of structure as proposed by Dr. Comstock is the great northwest and southeast fault thought by him to exist just northeast of Hot Springs. Numerous anticlinal† and monoclinal ridges have now been traced across this fault line and none are broken or show any sudden changes in the character of the rocks.

No direct evidence concerning the age of the rocks in western central Arkansas was reported by Dr. Comstock.

THE PRESENT WORK.

The field work of the present report was undertaken with a view to ascertaining the distribution of the Arkansas novaculites.

The formation has proved to be widely extended and the leading one of the area which it occupies. Thus its study in detail has revealed the bolder structural features of the region and has outlined the less prominent ones so that the latter can be worked out easily.

Formations.—From the existence of graptolites in the shales both overlying and underlying the novaculite formation it has been ascertained that these rocks belong to the upper part of the Lower Silurian. Overlying these rocks conformably are shales, over which are massive beds of sandstone slightly quartzose, almost barren of fossils. The few fossils found are probably of Lower Carboniferous age. Another reason for placing these sandstones in the Lower Carboniferous group is based upon investigations made in Northern Arkansas, where

*Loc. cit., p. XXX.

†For explanation of the terms anticline, syncline, and monocline, see chapter XV, near the end of the chapter.

the line of junction has been accurately determined and where Lower Carboniferous rocks rest directly and conformably upon Lower Silurian rocks, with a small thickness of possible Devonian rocks between them. The equivalent of these supposed Devonian strata has not been noticed in the novaculite area. Just where the line between the Lower Silurian novaculites and the Lower Carboniferous sandstones should be drawn has not yet been determined. This report deals chiefly with the Lower Silurian rocks, though the Lower Carboniferous strata are involved with them and so command some consideration also. The strata below the novaculites are shales, limestones, massive quartzose sandstones, cherty blue limestones, with gray, black and yellow shales at the bottom, aggregating about 1300 feet. The novaculites include rocks about 1200 feet in thickness, and above them are sandstones and shales, including some strata of Lower Carboniferous age, aggregating 1200 to 1500 feet. The Barren Coal Measures, according to Branner, are at least three miles thick north of Little Rock between Big Rock and the top of Petit Jean Mountain, and the Coal Measures add another mile to form a total thickness of four miles of the strata known to have covered this area.

Besides these old formations, Tertiary and Pleistocene gravels and other deposits cover considerable portions of the valley regions. The coarse gravel deposits are most conspicuous, seeming to have been the latest of all and reaching higher elevations than either the sands or clays.

The geological history of the area.—A partial idea of the geological history of the novaculite area has been given in the chapter on the origin of the novaculite, but the points there demonstrated will be mentioned here for the sake of completeness. The sequence of events in this history seems to have been as follows: A deposition of very fine fragmental material on the deep sea floor to form the Silurian strata, included in the upper part of which are two groups where graptolites abound. At the end of the Lower Silurian deposition, through the periods known as Upper Silurian and Devonian, there was an almost total cessation of the deposition of sediments. There seem to be two possible explanations for this fact: First, there may have been a depression of the sea bottom which left this area so far from shore that no thick sediments were accumulated over it, and this was followed by an elevation in Lower Carboniferous times renewing sedimentation in perfectly conformable beds; the second explanation is that while Upper Silurian and Devonian beds were being deposited elsewhere, the same period was occupied by a deposition in the Arkansas area characterized by Lower Silurian organisms. This continued until a decided change of conditions in Lower Carboniferous times renders necessary a change in the nomenclature of the beds in consequence of the change in the character of the fossils.

True Coal Measure strata covered the novaculite area also, for they are found in Texas in a latitude considerably south of 34° 30′, while the trend of the formations is nearly east and west through this part of Arkansas and through Indian Territory. The south members of the coal strata of Northern Arkansas have been worn completely away and are now buried beneath the Cretaceous and Tertiary deposits which cover southern Arkansas.

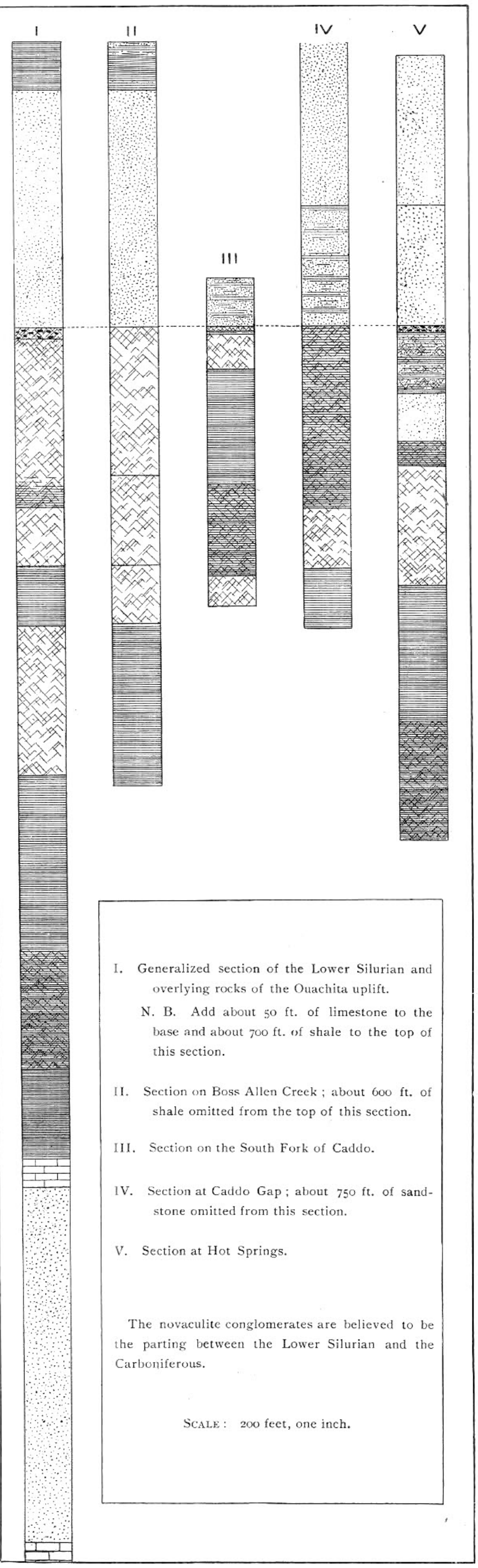
Following the formation of the Coal Measures, and probably synchronous with the Appalachian uplift came the elevation of Arkansas above sea level. The time following this post-Carboniferous elevation of Arkansas has been one of erosion, though we have evidence of some periods of accumulation as well as denudation. The three periods of accumulation were the Cretaceous, Tertiary, and Pleistocene, during which there were partial and perhaps complete submergences of the area.

Fundamental stratigraphy.—Before considering the details of this general period of denudation, the geology of the region under discussion will be described.

The region as a whole is an anticlinal uplift, having a width of from fifteen to twenty-five miles, and extending in a direction a little south of west and north of east. The eastern nose of the anticline has been worn away and covered over with Tertiary deposits. Its easternmost outcrop is in township

1 N., 13 W., section 28, southeast quarter of the southeast quarter, just west of the Benton road on the south side of McHenry's Creek. The rocks have here a dip northeast and represent the north side of the anticline. The most eastern exposure of the south side of the anticline is in township 3 S., 16 W., section 9, southwest quarter, north of the Military road on Ten Mile Creek, a distance of about forty miles southwest of the outcrop on the north side.

Nomenclature of structural forms.—The type of structure prevailing in the novaculite area is a folded one, though some faults produced by the crushing of the folds have been noticed. A characteristic of the Arkansas folds has been that the strata have not remained parallel during the folding, but different groups of beds have formed separate folds varying in magnitude with the thickness of the strata involved. The groups of beds remain constant throughout the area, so that plications of a certain magnitude are also constant. Three sets of folds have a sufficient size to influence the physiography of the country, and these are distinguished in this report by different terms. The first of these involved the entire thickness of the strata, from the top of the Carboniferous to the lowest rocks seen in the area, a thickness of perhaps four miles or more. These folds are called great anticlines or anticlinal uplifts and have special names; they define the present mountain ranges. The names are the Ouachita anticline, Trap Mountain anticline, Cossatot anticline and Choctaw anticline. The second set involves a thickness of less than 4000 feet of strata which are sharply crushed into folds. These folds form the present mountain ridges and peaks. The third set comprises less than 1000 feet of strata, seldom more than a few hundred feet, and are called wrinkles. They influence the minor topographic features, forming the smaller elevations and controlling the minor portions of stream courses. The softer rocks are the ones affected by the wrinkles, and they belong essentially to the valley structure. The novaculites are comprised in the second set, so that it is of the folds that this report chiefly treats.



I. Generalized section of the Lower Silurian and overlying rocks of the Ouachita uplift.

N. B. Add about 50 ft. of limestone to the base and about 700 ft. of shale to the top of this section.

II. Section on Boss Allen Creek; about 600 ft. of shale omitted from the top of this section.

III. Section on the South Fork of Caddo.

IV. Section at Caddo Gap; about 750 ft. of sandstone omitted from this section.

V. Section at Hot Springs.

The novaculite conglomerates are believed to be the parting between the Lower Silurian and the Carboniferous.

SCALE: 200 feet, one inch.

The columnar sections.—A generalized columnar section of the rocks of the novaculite area is given on plate V. The entire thickness represented by the column is involved in the great anticlines. The group of strata of which the novaculites are the central portion forms the folds. The strata between the massive novaculites and the sandstones at the bottom of the column, also comprised in the folds, are those forming the wrinkles. The massive sandstones at the base of the column are bent into plications of equal magnitude with the folds, and this term is applied to the flexures of the Crystal Mountains.

Natural divisions of the general uplift.—The anticlinal uplift which should be considered as extending into the Indian Territory is depressed in two places in Arkansas, giving synclines within the anticline. The more important one, as concerns this report, is the Mazarn basin, already described to some extent in the previous chapter, which almost cuts the novaculite area in two. The Mazarn syncline takes the general trend south of west of the anticline. It lies in the back of the anticline, as it were, separating the smaller anticlinal region of the Trap Mountains from the great anticline north of the basin; its western extension up the valley of the South Fork of Caddo may be considered to extend completely through to the valley of Mountain Fork of Little River, setting off the Cossatot system from the northern anticline. The separation of the Trap Mountains is practically complete, since the ridges which seem to connect it with the Zigzags are very insignificant. Thus this syncline practically divides the anticlinal uplift into two anticlines for a distance of about ninety miles. The smaller southern anticline is divided into two by the depression in the northern part of township 5 S., 23 W., which separates the Trap and Cossatot Mountains. The other syncline extends northwest and southeast, at the western end of the Cossatot Mountain system, separating it from the Indian Territory system by a distance of about five miles in the narrowest part. This is merely a depression in the uplift and does not destroy its continuity, for the rocks of this syncline have no great thickness so that as compared with the thickness of strata that has

The columnar sections.—A generalized columnar section of the rocks of the novaculite area is given on plate V. The entire thickness represented by the column is involved in the great anticlines. The group of strata of which the novaculites are the central portion forms the folds. The strata between the massive novaculites and the sandstones at the bottom of the column, also comprised in the folds, are those forming the wrinkles. The massive sandstones at the base of the column are bent into plications of equal magnitude with the folds, and this term is applied to the flexures of the Crystal Mountains.

Natural divisions of the general uplift.—The anticlinal uplift which should be considered as extending into the Indian Territory is depressed in two places in Arkansas, giving synclines within the anticline. The more important one, as concerns this report, is the Mazarn basin, already described to some extent in the previous chapter, which almost cuts the novaculite area in two. The Mazarn syncline takes the general trend south of west of the anticline. It lies in the back of the anticline, as it were, separating the smaller anticlinal region of the Trap Mountains from the great anticline north of the basin; its western extension up the valley of the South Fork of Caddo may be considered to extend completely through to the valley of Mountain Fork of Little River, setting off the Cossatot system from the northern anticline. The separation of the Trap Mountains is practically complete, since the ridges which seem to connect it with the Zigzags are very insignificant. Thus this syncline practically divides the anticlinal uplift into two anticlines for a distance of about ninety miles. The smaller southern anticline is divided into two by the depression in the northern part of township 5 S., 23 W., which separates the Trap and Cossatot Mountains. The other syncline extends northwest and southeast, at the western end of the Cossatot Mountain system, separating it from the Indian Territory system by a distance of about five miles in the narrowest part. This is merely a depression in the uplift and does not destroy its continuity, for the rocks of this syncline have no great thickness so that as compared with the thickness of strata that has been eroded, the covering of the novaculites in this depression is but thin.

Thus we have in the novaculite region of Arkansas three complete anticlinal regions and the beginning of a fourth. The two smaller anticlines lying on the south side of the uplift were not elevated so high as the north side, and consequently have not been so much worn away. The Ouachita anticline was elevated much higher and formed the main feature of the Ouachita uplift. It extends from near the Arkansas River south of Little Rock to a point eight miles east of the Indian Territory line, a distance of 120 miles. The average width of the great anticline is nearly fifteen miles, but the Mazarn basin reduces it in the middle to about eleven miles. The top of this anticline has been entirely worn away and within its well defined limits the underlying rocks form a topography different from that outside the enclosing walls.

The structure of the anticlines.—These anticlinal regions are not at all simple anticlines with two uniformly parallel sides, and ending in noses gently plunging below the overlying strata; but consist of a multitude of anticlinal and synclinal folds rising abruptly through the overlying rocks and often crushed together in much confusion. To understand how the mountains of the novaculite area gained their present forms, it must be borne in mind that all were once below the level of the land surface and at that time the streams were at work eroding away the Carboniferous and Lower Carboniferous strata which buried the novaculites. These overlying rocks must have been folded conformably with the novaculites, and the streams which were eroding them must have adapted themselves well to these folds, for this is the case now in those regions where the overlying rocks have not been entirely removed. Then as the streams wore down to the hard novaculites they naturally sought the synclinal valleys where the rocks were softer. As these valleys were worn out and the novaculite ridges stood up more prominently, they became subject to the attacks of small streams eating back from the larger ones in the valleys. It was only a question of time for the small branches to cut entirely through the novaculites, and this once accomplished, the soft underlying rocks were rapidly eroded, the streams again adapting themselves to the strike of the rocks, though this time within hard novaculite walls. With the continued elevation of the area and the consequent sinking of the streams, the novaculite walls themselves became undermined and the breach widened. The borders of the anticline must always be preserved, however, and though the higher parts of the uplift, including many smaller folds, may have been removed by erosion, the limits of the anticline were simply extended, and in the extended boundary the traces of the consumed folds can be found in anticlinoses and synclinal spoons.

All the above stages are represented in the novaculite area. We have in the Mazarn basin, streams running in the direction of the strike in the Lower Carboniferous rocks beneath which the novaculites are still buried. In the eastern part of the Trap Mountain region we have the low folds of the novaculite which are just appearing above the surface, and among which the streams follow the synclines. The central part of the Trap Mountain region, where the elevation was greater, exhibits the stage of small breached anticlines. The Cossatot range shows this stage also at the two ends of the system, but the centre, which was elevated higher, has been so extensively cut away that the breach is now twenty miles long and two and a half miles wide in its widest part. This small basin is known locally as Greasy Cove. Within this breach are several isolated mountains capped by novaculite, showing synclinal structure and lying in synclinal axes of the basin's rim, thus proving conclusively the crumpled condition of the strata that have been removed. The northern anticline shows the last stage of erosion. There the elevation was so great and erosion so effective that the breach has lengthened out to over one hundred miles and in one place is eighteen miles wide. Within its limits isolated synclines near the boundaries and sharp folds of the underlying rocks supplement the evidence furnished by the very numerous

folds found in the Caddo range and in the Zigzags that the eroded portion of this anticline was also greatly crumpled.

The diagram of axes.—The axes of the great anticlines and folds are represented diagrammatically in plate VI. The continuous lines represent anticlines, the dotted ones, synclines. The relative sizes of the lines show the relative magnitude of the folds. The novaculites alone are represented in this plate, and as many of the folds about the great anticlines exist only in part, the lines representing them end bluntly.

Attention is called to the branching of folds and to the many changes in the directions of axes.*

General geologic relations of the area.—Mr. Winslow has expressed the opinion† that the folding of the strata in the region of the Coal Measures lying north of the novaculite area was synchronous with that of the Appalachians. His arguments are, first, that "no Triassic or Jurassic rocks are found overlying these Carboniferous beds conformably; and, second, Cretaceous beds rest unconformably upon and in contact with the upturned edges of the Paleozoic beds along their southern border, the Cretaceous beds showing little or no evidence of disturbance, which latter fact demonstrates also that the folding, or at least such portion of the folding as was widespread in its effects, antedated that period." Thus the folding was pre-Mesozoic. The similarity between the structure of the Arkansas area and that of the Carboniferous area in Pennsylvania, Mr. Winslow states, "is not a mere accident, but is due to a trans-Mississippian extension of the same cause."

The work in the novaculite area corroborates this view by increasing the number of facts showing the similarity between the two parts of the Appalachian system, and by bringing out other relations. *First*, the geologic section in the novaculite area comprises rocks which are well toward the bottom of the

*A detailed discussion of the abnormal directions of axes in the eastern-central part of the area is given in chapter XVI, under the heading "folds between Blocher and Brazils post-offices.

†The Geotectonic and Physiographic Geology of Western Arkansas, Bulletin of the Geol. Soc. of America, Vol. II, p, 23, Arthur Winslow.

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*Geological Survey of Arkansas, Annual Report for 18

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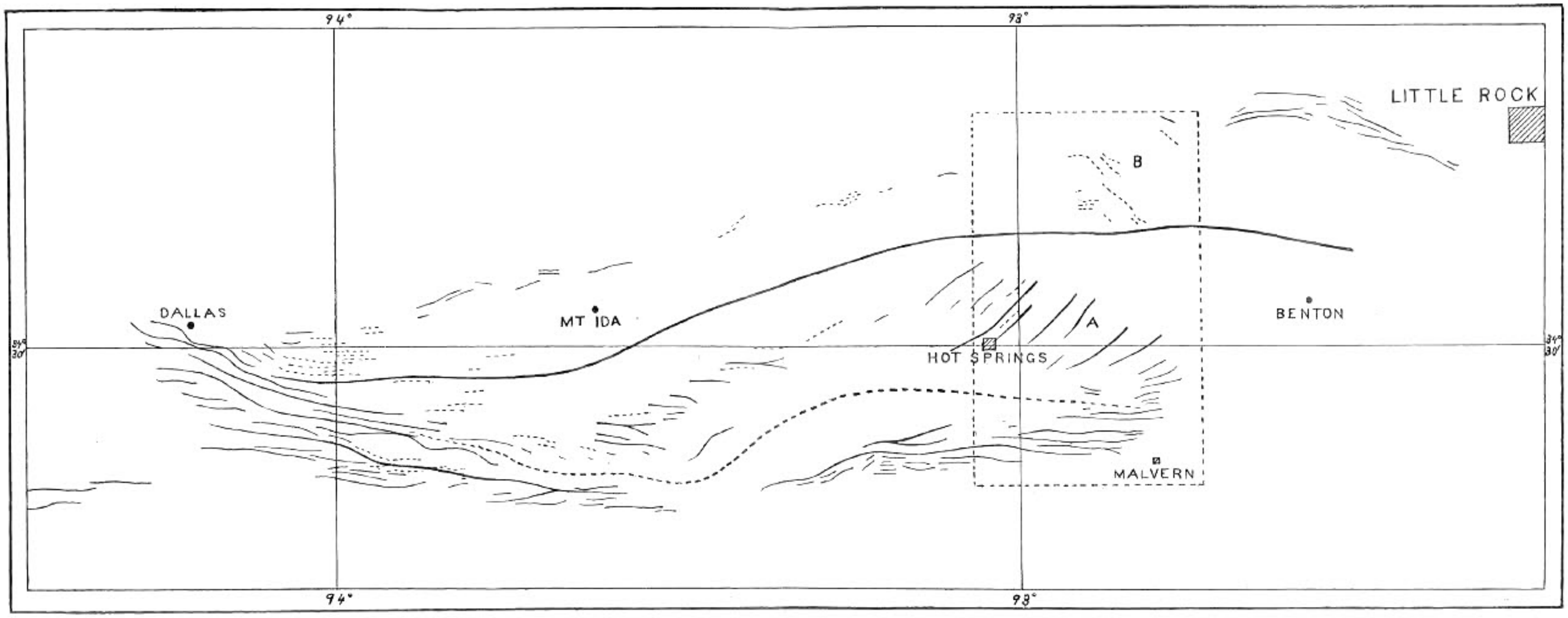
Lower Silurian series. No unconformity has been found, so the complete section involved in the Arkansas folds is more nearly identical with that of the main system. *Second*, in the novaculite area still better than in the Carboniferous region

GEOLOGICAL SURVEY OF ARKANSAS, VOL. III., 1890. PLATE IV.



DIAGRAMMATIC REPRESENTATION OF THE AXES OF FOLDS IN THE OUACHITA UPLIFT.

Solid lines represent anticlines, dotted lines synclines. The strength of the line indicates the comparative size of the fold. Scale 13 1-3 miles to the inch.

long exposed at the beginning of Cretaceous time; so we

*Geological Survey of Arkansas, Annual Report for 1888, Vol. II., p. 123.

folds found in the Caddo range and in the Zigzags that the eroded portion of this anticline was also greatly crumpled.

The diagram of axes.—The axes of the great anticlines and folds are represented diagrammatically in plate VI. The con- tinuous lines

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†The Geotectonic and Physiographic Geology of Western Arkansas, Bulletin of the Geol. Soc. of America, Vol. II, p, 23, Arthur Winslow.

Lower Silurian series. No unconformity has been found, so the complete section involved in the Arkansas folds is more nearly identical with that of the main system. *Second*, in the novaculite area still better than in the Carboniferous region lying north of it, the resemblance to the Pennsylvania structure is shown. Here the parallel anticlinal ridges overlapping at the ends are the common forms of simple structure, and these, when eroded, give a Z structure and topography. *Third*, the direction of the origin of pressure is identical, the folds being very closely appressed on the south side and becoming flattened to the north, a pressure acting from south to north thus being indicated. *Fourth*, the source of the sediments was relatively the same, the existence of sandstones beds overlying the novaculites on the south side of the uplift with shale beds occupying the corresponding position on the north side, indicate that the land whence these sediments were derived lay to the south, just as in the case of the Appalachians it lay to the east. *Fifth*, the axis of the uplift strikes toward the disturbed Paleozoic region between Mississippi and Tennessee, which region has been regarded as a southwestern termination of the Appalachian system. The Ouachita uplift, however, is regarded by the State Geologist as only an outlier and not as having formed the barrier between the ocean to the south and the enclosed Mississippi basin on the north. This barrier he thinks was an uplift farther south, between Arkansas and Louisiana, and extending south of west into Texas, perhaps farther, its folds having been eroded away and covered by Cretaceous and later deposits. The Cretaceous contact line is about twenty miles south of the novaculites, and runs east and west parallel with the mountain system. The position of this contact line on Lower Carboniferous rocks indicates that the Carboniferous of this region and a great part of the Lower Carboniferous had been eroded away before the beginning of Cretaceous times.

At Burnet, in Texas, the Cretaceous lies upon Silurian* From this fact it may be inferred that the novaculites had been long exposed at the beginning of Cretaceous time; so we

*Geological Survey of Arkansas, Annual Report for 1888, Vol. II., p. 123.

have evidence that by far the greater part of the erosion of the Ouachita uplift was accomplished before the beginning of the Cretaceous period.

The record since Cretaceous times shows numerous oscillations of the whole area, but it is evident that the Ouachita Mountains were above sea level through all this later time.

There is Pleistocene on the top of Grindstone Ridge north of Arkadelphia at an elevation of 600 feet above sea level. The gravels about Hot Springs at the same level, those of Mount Ida in Montgomery county at 700 feet, and those of Dallas in Polk county at 1100 feet are probably all referable to the same epoch. Thus we see that this (Pleistocene) subsidence was considerably greater than the preceding and that the recent uplift has not been a uniform one. During the Pleistocene subsidence the mountains of the Ouachita system must have been islands in the sea; the traces of the shore line, however, where seen at all, are indistinct, and denote that the line was not long permanent at one level. The Tertiary depression was also sufficient to bring the shore line up to the border of the novaculites at their eastern end. The submergences of these two periods can only be regarded as temporary invasions which have had but little influence in the novaculite area except in changing the courses of some streams to a very slight extent.

RIVERS.

The general system—With this understanding of the geology of the Ouachita uplift, it is possible to make some explanation of the courses of the rivers of this area. The uplift as a whole extended to the 100th meridian, has had a marked influence on the river systems since it gives an east and west course to the streams west of the Mississippi and north of the Gulf of Mexico. The natural tendency of the streams of this part of the United States is to flow southeast or south, in order to adjust themselves to the post-Cretaceous uplifts which have been greater to the northwest. The existence of the pre-Cretaceous elevation interferes with this tendency and its result is seen in

the general east and west course of the Arkansas River from the head of the Canadian Fork to Little Rock.

Drainage of the Arkansas portion of the uplift.—The Silurian region of Arkansas shows the evidence of both very old and of comparatively new streams. Since the evidence is that this area has been as a rule above sea level since Carboniferous times, the present rivers should represent the streams which flowed in the synclines of the originally elevated region; or in the terms which have been applied to rivers with reference to their origin, these rivers should be the survivors of the "consequent" rivers of the area. The present system has been a long established one, so the rivers may be considered as "adjusted"* to the geological structure of the area.

For rivers that have, as it were, selected their courses, following the geological structure and depending upon it as closely as the rivers of this area must have done, they present several strange features, although as a rule the adjustment to geological structure is almost perfect. The exceptions are the Ouachita, the Little Missouri and the Cossatot. The Ouachita breaks across the hard novaculite formation in two places when it seems possible that this work might have been avoided. In the same way the Little Missouri River has cut through twelve thicknesses of the novaculite, some of which might have been avoided. The Cossatot, also, has apparently been doing needless work of this character.

There seems to be four possible explanations of these phenomena. *First*, the original consequent streams may have had north and south directions as well as east and west ones, and the streams may have maintained their directions across the already folded strata. *Second*, the mountains may have been growing while the rivers were wearing down, and the rivers cut through them as fast as they rose. *Third*, the rivers may not have been original consequent streams, but streams that have gradually eaten their way back into the mountains from consequent streams or from the ancient shore lines. *Fourth*, they may represent stream courses rearranged on a post-Car-

*Rivers of Northern New Jersey, by W. M. Davis, p. 4.

boniferous base leveled plain or temporary sedimentary cover. There is no positive evidence that the conditions necessary for the second supposition have influenced the present streams; the peculiarities in drainage which might be explained by this supposition seem better referred to a modification of the first. Streams of the third class are very common throughout the area.

In considering the history of these rivers it must be borne in mind that where novaculites are now exposed a thickness of three miles of strata has been removed, not allowing for any increase of this thickness by the folding which left the beds in a position nearly vertical as a rule. It is not supposed that all this folding was accomplished before erosion began; it is probable that erosion along the line of the present novaculite area increased the weakness along the axis of the uplift, thereby causing a continuation of the folding process along the line. Thus the folding of the area was probably synchronous with and, to a certain extent, dependent upon the denudation. It is highly probable, however, that the novaculites were nearly, if not quite, in their present contorted shape before the streams which were at work wearing away the land surface of that time, had cut down to their level.*

The history of the Ouachita River.—It would seem hardly possible to trace an original consequent stream in an area which has been so enormously eroded as that of the novaculites, yet it appears very probable that the course of the Ouachita through the Mazarn basin represents such a case. That basin must have been an early structural depression; and though the novaculites are exposed at its eastern end where the river has its outlet, they have not been long exposed and their comparatively gentle folds, which would tend to decrease In the overlying strata, indicate that a minimum thickness of rocks was cut through at this place.

That part of the Ouachita River now north of the Mazarn basin was probably derived by the backward extension of the headwaters. The conditions for such a backward extension at

*See Chapter XIII, heading, "relation of folding to denudation."

this point were favorable. In the first place, the Ouachita anticline at this point, was not so sharply jammed into folds as it was both to the east and west, so that the streams had less work to do. Secondly, the novaculite formation was weak at this place, consisting chiefly of siliceous shales.

The extension of the headwaters beyond the break in the novaculites offers some interesting features. The novaculite formation being weak on the north side the streams easily cut through it in several places; but the massive Carboniferous sandstones striking east and west hindered a rapid northward extension of the streams. The one, however, which cut back in the direction of the present Ouachita found itself on a broad monocline of soft shales between the novaculites and Lower Carboniferous sandstones; the work of carving out a valley here was easy and as a result we have the long valley of the Ouachita from Dallas to Muddy Mountain. One branch within the breach, the South Fork, easily eroded away the shales underlying the novaculites; but it did not gain territory as fast as the main Ouachita by the backward extension of headwaters in consequence of sinking between the massive Crystal Mountain sandstones and the most massive novaculites of the northern monocline.

Thus the Ouachita River as seen in the novaculite area is in its lower part a "consequent" stream, and in its upper a "subsequent adjusted" stream. There is a marked difference between the two parts, the lower or older part having a comparatively straight course while the newer portion is very crooked. The straightness of the older portion is largely dependent on the greater prevalence of massive formations in this basin, with the trend of which the river flows or across which it cuts squarely. The meanderings of the upper part of the river are not due to the fact that the stream is near its base level, for the current is generally swift; it must be attributed to the extremely contorted condition and to the local variations in the character of the strata through which it flows.*

*The softer members of the novaculite series of rocks, while conforming in a general way with the more massive formations, are very much crumpled in themselves.

The Little Missouri River.—There seem to be two possible explanations for the peculiarities of the Little Missouri River. One is that the present stream represents an older one having its origin in the northern anticline. This old stream had a larger drainage area than the present one, and was able to cut through the novaculites of the Cossatot range when its channel reached them in its down-sinking, by virtue of its larger volume of water. That the work was too great even for the larger stream, is shown by the fact that the headwaters of the Caddo now drain the district which formerly contained the source of the Little Missouri. The evidence of the former extension of the Little Missouri consists in a now useless gap in the northernmost ridge of the Caddo range, in township 3 south, 27 west, section 33, southwest quarter. In the little synclinal valley south of this gap a small stream still flows south to join Crooked Creek, belonging to the Little Missouri drainage, but the headwaters of Polk Creek, a branch of the Caddo, are gaining ground on this small stream, and it is a question of comparatively short geological time when this stream valley will be drained the other way. It is probable that the South Fork of the Caddo has also taken some of the former drainage territory of the Little Missouri.

Long Creek, and its branch, Straight Creek, have courses which seem to indicate the same settling down of old streams from a higher elevation upon more resisting geological formations, as in the case of the main Little Missouri, of which Long Creek is a branch. Instead of following the easily eroded, straight, synclinal troughs, these streams have cut across strong novaculite anticlines. That these anticlines were cut across by superimposed streams, and not by backward cutting of headwaters, is indicated by the present position of the divides. The smaller streams in the structural synclines are gaining upon the larger ones, and now the divides in these synclines are much lower than the tops of the mountains through which these streams have carved their way.

The Cossatot River.—The Cossatot furnishes another example of a stream which has lost some of its drainage area. The Dallas and Center Point road passes through a wide high gap in the Little Missouri mountain, in township 3 south, 29 west, section 19. This gap is not due to a depression in the anticlinal structure, for it is too sharply defined, and the dips show clearly that the novaculites have been eroded away. There are only the smallest kind of wet-weather streams now draining either way from the divide which is crossed in going through the gap. The stream which formerly flowed through this gap was apparently a large one, and probably drained at least a part of the Dallas plain now drained by the Ouachita.

The present Cossatot River gives even stronger evidence of superimposition than the Little Missouri and its branches. In the first place, the break through the McKinley Mountain anticline in township 3 S., 29 W., section 32, southwest quarter, has the character of a breach made by the sinking of a stream on the structure for it occurs in a depression in the anticline such as a stream of this kind would naturally find, whereas a stream which works its way backwards successfully in the novaculite area, is noticeably one which finds the strata overthrown, locally jammed, or otherwise weakened. There seems to have been no particular weakness here.

The McKinley mountain break, however, is not so suggestive as the one through the Hannah Mountain in 4 south, 30 west, section 12. This mountain is the boldest in the whole novaculite system, and the peak on the west side of the river gorge measures 1000 feet above the river. On looking at the map, one sees that a pretty broad extent of the overlying rocks situated north of the mountain must have offered a good opportunity for the escape of these river waters by making a detour of only four miles to the west; the tendency to avoid the novaculite anticlines in this manner is seen in the course of the Cossatot in relation to the ridges both north and south of the Hannah Mountain.

The fact that the river cuts this very massive mountain when the course round it would have been so much easier, is a strong argument for the theory of superimposition. Furthermore, the work done by this river in cutting through the novaculites is better realized when it is considered that on the top of the Hannah Mountain the dip of the strata is about vertical, indicating a former extension upwards of the novaculites to a greater elevation. It is clear that the cutting on the Hannah Mountain novaculites began before the river had found the depression in the McKinley Mountain.

The theory of an old base level.—These remarkable exceptions to the general rule of perfect adaptation of drainage to the structure might perhaps be explained more easily by the hypothesis that these streams settled down from a post-Carboniferous base level or a cover of sediments, rather than from the simple post-Carboniferous consequent drainage. A readjustment of streams on such a base level or cover would make the Hannah Mountain gorge much more possible than simple uninterrupted erosion, as it allows less time for the streams working in the natural structural channels to overcome the advantage possessed by a stream having a larger volume of water though doing more work. The supposed level surface was above the tops of the present mountains, but could not have been far above them. It is not possible to prove such a broad level surface, but there are some evidences which seem to favor the idea. The highest mountain in Arkansas, as far as known, is a peak of the Magazine Mountain in Logan county, 2850 feet above sea level according to the observations of the U. S. Geological Survey. This peak stands up from a broad mountain top having an elevation of 2500 feet. On Rich Mountain in Polk county is a peak standing at 2700 feet on a mountain top, which is often broad, 2500 feet in elevation. This 2500 foot level is reached by a few other mountains and seems to be the only high elevation which shows any constancy. This level, however, is not frequently enough found to give by itself any strong argument for a former base level at the mountain elevation. Many mountains approach this elevation, among them are the peaks of the Cossatot, Caddo, and Crystal Mountain ranges. The ridges connecting the peaks have remarkably level backs, which may well have descended from a higher level surface; though much of this character is undoubtedly due to the structure of the ridges. The generally lower elevations of the mountains toward the east and south may be explained by differences in post-Cretaceous elevations. While the evidence of irregular mountain peaks falling within general levels of several hundred feet of each other may not argue very strongly for a former base level, yet it would be remarkable if they showed any uniformity had the area been one highly elevated at first and afterwards subject to a steady uninterrupted denudation, It would be remarkable also if in such steady erosion no large stream found its way through the depression between the Cossatot Mountains and the Indian Territory system.

South of the mountains of the novaculite area is an east-west trough-like depression, commonly several miles wide, which is bounded on the south side by level topped ridges of Lower Carboniferous sandstones a few hundred feet in elevation. Still further south the ridge tops become broader and the valleys shallower. The appearance of an upland plain becomes more marked as the elevation decreases southward and less opportunity is given for deep stream erosion. The southward sloping plain of Paleozoic rocks sinks below the Cretaceous or Tertiary strata, and none of these old rocks are seen again south of the contact line projecting through the later sediments. This gives evidence that the Paleozoic strata of this region had been worn down to a pretty level surface before the Cretaceous strata were deposited. Thus we have altogether good evidence of a former base level plain which is naturally less distinct toward the north where subsequent elevation and denudation have been greater.

We might suppose that the southward courses of the Little Missouri and Cossatot Rivers were given by the post-Cretaceous tilting of this base level plain, but we have other evidence that leads to an easier conception. The Cretaceous strata dip gently south; they have, according to Hill,* a thickness of "many thousand feet" and the lowest members are the ones bordering the Paleozoic rocks. Thus it would seem entirely

*Ann. Rep. Geological Survey of Arkansas, 1888, Vol. II., p. 186.

probable that Cretaceous strata formerly covered the base level plain described above; and it is easy to see that if the level surface of sediments was raised above sea-level, southward courses would be given the new streams, and these courses would become more strongly fixed on the underlying rocks than under any other conditions.

If the validity of the above evidence is admitted then we have in Arkansas a sequence of events in accordance with those demonstrated for Pennsylvania and northern New Jersey by Davis.*

This evidence of an old base level plain and Cretaceous cover on which a new drainage system came into existence after the elevation above sea-level is perhaps not conclusive, yet there is nothing in the supposition which conflicts with the facts of the present drainage, and by it the very arbitrary courses of the Cossatot and Little Missouri Rivers can best be explained.

The Caddo and Saline Rivers.—Besides the rivers discussed above, the Caddo and Saline rivers are worthy of mention in their relations to the main features of the geological structure. The Caddo has a basin above Caddo Gap, which must have resembled the present Little Missouri basin; but the stream was successful in cutting through the many folds and since then has extended its basin rapidly in the soft underlying rocks. Below the Gap it follows the natural depression in the Lower Carboniferous rocks.

The Saline has a history similar to that of the Caddo, but, having less massive rocks to erode, has been more successful. The rocks on the south side were so completely worn down that the later deposits have been at a sufficiently high level to cover them; while the head waters have succeeded in crossing the northern side of the anticline, and even in reaching for a considerable distance into the territory beyond. The basin of the Saline is the largest of the breached anticlinal basins and contains less rough land.

Subordinate drainage.—The smaller streams of the novaculite area show a very perfect dependence upon geological structure. The valleys are synclinal as a rule; the anticlines when breached are generally drained by two streams which unite and flow through a gorge in the side, and it is noticeable that this gorge has been cut at a point of weakness in the structure—commonly an overthrow of the strata. The detailed relationships between drainage and structure are described in considering the geology of the different divisions of the area. As a whole, the streams of the novaculite area form an exceedingly interesting study, since in the same area they occur in relation to both great and small geologic features; and the variation in the character of the formations, from massive rocks of great endurance to soft shales much contorted and easily eroded, has caused the dependence of streams upon structure to become very marked in the topography of the region.

*Rivers of Pennsylvania, and Rivers of Northern New Jersey, by W. M. Davis.

CHAPTER XII.

Detailed Geology of the Novaculite Area.

Since the various mountain ranges of the region under discussion represent different stages in the denudation of an irregularly elevated and folded series of rocks, it may be well to describe these divisions in the order of simplicity of the drainage, which means also in the order of the simplicity of the structure.

THE TRAP MOUNTAIN SYSTEM.

The newest mountains of the novaculite system, that is to say, those most recently exposed in the progress of denudation, are the Trap Mountains. These mountains are also of the least topographic importance; their elevations above the valleys are less, and those above sea level probably lower than the elevations of the other ranges, except the northern one. The central part of the range, however, abounds in high sharp peaks. It is exceedingly interesting geologically, for it now exhibits the general topographic features which formerly characterized those divisions of the uplift in which erosion has now gone much further. Thus we can see what was the character of their original drainage, and how the streams first cut into the novaculite folds.

This range has been previously described as lying on the west side of the Ouachita River, but more exactly, it should include also, on the east side of the river above Rockport, the prolongations of some of the west side ridges. The most prominent of these eastern ridges is the one ending about a mile east of Butterfield station on the Hot Springs Railroad. This ridge is crossed by the railway just east of Butterfield, and it continues westward on the south side of the railroad track. It is cut by the Ouachita River in 3 S., 17 W., section 32, southwest quarter, and continues west of the river for some

miles as a well-defined ridge. It is the most northern of the ridges of the Trap Mountains, and also extends farthest east. The other ridges on the east side of the river are lower, and extend further to the west as they succeed each other toward the south.

The novaculites of the eastern end of the Trap Mountain range are the lowest exposures in the area, being not over 250 feet above sea level along the river, and the tops of the ridges are less than 500 feet in elevation. When it is considered that the railway station at Hot Springs is 600 feet above sea level, and that the Dallas plain is over 1000 feet, the relation of these ridges to the rest of the area in point of newness is better understood; for other things being equal the greater erosion is indicated by the lower elevation. In structure these new ridges are anticlines running parallel to each other for a greater or less distance, then disappearing below the overlying rocks toward the west, or beneath the Tertiary or the Pleistocene drift to the east. The Ouachita River is now cutting through six of these anticlines in escaping from the Mazarn basin.

The northeastern folds.—The two northern anticlines of the Trap Mountain system are sharply jammed, the dips are nearly vertical, the ledges form bold cliffs on either side of the river, making picturesque gorges, and the ridge tops are about 250 feet above the river level. The northernmost ridge is seven miles long, rising from an alluvial valley in township 3 S., 17 W., section 35, northeast quarter, extending south of west to the river gorge, then due west, ending in township 3 S., 18 W, section 34, southeast quarter. A little over a mile west of the Ouachita River gorge, there is another cut in the ridge made by a small stream which drains a portion of the synclinal valley between the two northern ridges, and flows northward into the Ouachita. This small stream must be a relic of an older one, for new streams, manifestly owing their existence to the process of backward headwater erosion are not found in this region of low ridges, except in the very early stage of ravines. Then, too, the natural drainage of this syncline would have been east into the river had there not been some pre-existing stream to divert the drainage elsewhere. The gorge is pretty deeply cut also, for a stream that has a drainage basin scarcely half a mile wide and a length of about two miles.

The ridge south of this northernmost one has a length of eight and a half miles, extending east and west, just a little south of the township lines between townships 3 and 4 S., 17 and 18 W. The eastern end disappears beneath the drift a short distance east of the Hot Springs Railroad track in the western corners of sections 35 and 2, of townships 3 and 4 S., 17 W. There is a southward bend in this anticline in sections 5 and 6 of 4 S., 17 W., but on the western side of section 6, the ridge is again just south of the township line and continues due west to township 4 S., 18 W., section 5, northeast quarter. With the exception of the Ouachita river gorge this anticline is unbroken.

These two northern anticlines occupy an intermediate position between the Zigzags and the rest of the Trap Mountains, the valleys on either side being a little wider than that between the two ridges. They resemble each other much in general characters; the tops of the eastern ends of both are considerably eroded and are now nearly flat. The dips at the eastern ends are rather low, being from 45° to 60°, but the ridges are more sharply jammed to the west, so that the dips are nearly vertical and even overthrown. The sandstones which overlie the novaculites and are found at the base of the ridges show the anticlinal structure, and also, by their dips, indicate that the erosion of novaculite from the tops of the ridges has not been so great as one might think from the vertical dip of the strata. The greater crushing of these anticlines at their western ends is manifested by the very steep slopes of the anticlinal noses, the rise from the general level being abrupt.

Deductions from the relations of Tertiary deposits to the novaculites.—The Tertiary deposits of this vicinity are interesting in their relations to the history of the Ouachita River. The old Tertiary shore line was about on the present level of 425 feet above the sea, but Tertiary deposits are found on the Ouachita River at 250 feet, and the valleys between the ridges contain similar deposits. This indicates that the present topography was well defined before the Tertiary submergence. Furthermore, the Ouachita River gorges must also have been cut in pre-Tertiary times. As there is no evidence of much erosion since the Tertiary, the fact that there are now two synclinal valleys in which the divides are lower than the tops of these two northern novaculite ridges through which the river cuts, shows that this cutting must have begun before there were lower divides elsewhere, and hence before the Tertiary. The two valleys mentioned are those north and south of the two ridges described above. It is of course possible that these valleys might have been filled with Tertiary material forcing the river over the novaculite ridges, thus making the gorges post-Tertiary; but there is no way of accounting for the removal of the barriers, since the divides in each valley are simple ones shedding water either way, and located with reference to the river far up the valleys as simple erosion divides naturally would be. The valley on the south side in particular is broad and the divide between its draining streams, Bayou de Chute and the east branch of Cooper's Creek, is a low flat one. It would not be a great undertaking to divert the Ouachita through this valley; indeed it seems strange that the river did not take this course after either the Tertiary or Pleistocene submergences. In this way the facts observed in this small area support the theory of the history of the Ouachita River presented in the last chapter, that in its lower course the stream cut its channel in a structural depression.

South of the valley last mentioned, which is nearly a mile wide, the Ouachita has cut through other novaculite ridges, but they are lower and the anticlines are not so sharply jammed, the dips being 45° and less. These are not merely the crests of ridges which show steeper dips below for the ridges are so close together that the synclinal hollows cannot be far below the surface. In township 4 S., 17 W., sections 8 and 9, there are three anticlines within a distance of three-quarters of a mile;

and half a mile below, at Rockport, is the south dip of another anticline:—the north dipping ledges are covered by recent deposits of waterworn material. Only one of these anticlinal ridges, the most northern, really forms any considerable feature of the landscape, though it is possible, even probable, that some of the other anticlines may connect with the marked ridges which rise above the drift two miles west of the river. In figure 2 is shown the complete section across the six folds described above.

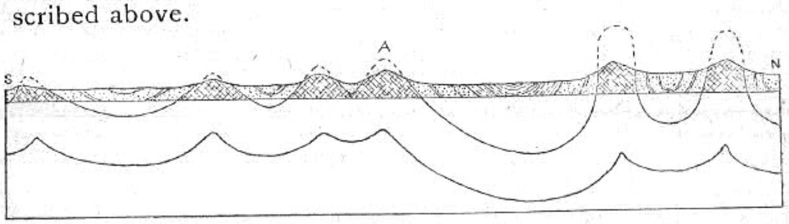


Figure 2. Section across the east end of the Trap Mountains.

The Cooper's Creek anticline.—The anticlinal ridge lettered A in figure 2 offers an illustration of the first effects of erosion on an elevated and expanded anticline. The anticline is eleven miles long, rising just east of the Ouachita and running almost due west on the section line between the two upper rows of sections of townships 4 S., 17, 18, and 19 W., ending in the center of section 10 of 19 west. For about five miles its eastern end has a pretty level back, but further west it becomes more uneven and higher; in township 4 S., 18 W., section 9, northwest quarter, the ridge divides into two, one arm continuing due west, the other to the north of west. The southern arm is presently cut through by a small north flowing stream along which graptolite bearing shales are found, and continuing beyond is incised by several sharp ravines which extend back southward to a higher and broader novaculite mass with which this novaculite arm is joined by high north and south divides between the ravines. The trend of this south arm is west; a small stream cuts through it in section 7, the northeast quarter; this is the main branch of Cooper's Creek. This south arm continues west and joins again with the north arm in township 4 S., 19 W., section 12, northeast

quarter. The northern arm is cut by Cooper's Creek in a single gorge in township 4 S., 18 W., section 6, southeast quarter, in the upper part of which the novaculites dip south at an angle of 55°, while farther down the dip becomes lower until finally the sandstones which overlie the novaculites have a dip of 20°.

The two arms which thus separate and come together again represent the sides of the anticlinal ridge which was here forced up higher and at the same time widened out. These circumstances of elevation and widening made this place an early point of attack for eroding agencies. The normal dips for the anticlines should be north on the north side and south on the south side, but we have the north dip overthrown to a south one, and overthrown so much that the structure of the anticline was greatly weakened. A stream has found its way to this weakest point, cut back through it, eroded out the soft shales between the novaculite walls, and has since been cutting through the southern wall. We have here an example of a breached anticline in which the erosion has progressed beyond the stages of a simple breach. In figure 3 the structure of the anticline is shown in its relation to the folds of the Rockport Mountain. The novaculites at A, A, and B form the higher elevations. Within the large anticline, defined by the

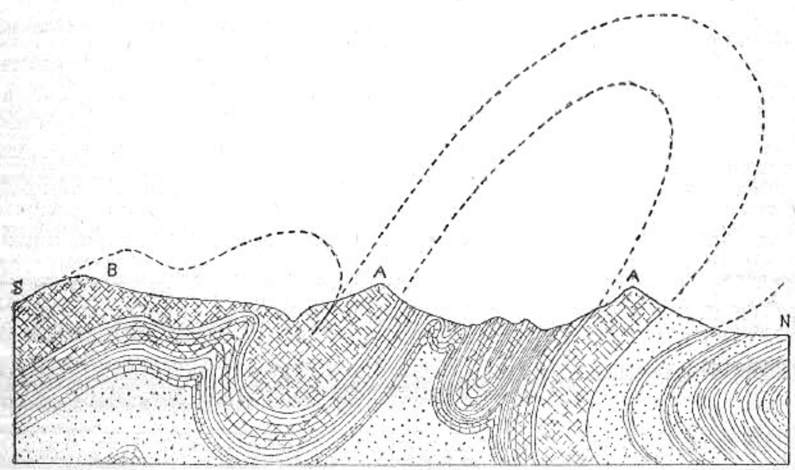


Figure 3. Cooper's Creek and Rockport Mountain section.

ridges at A, A, are several small folds formed by the underlying, less massive siliceous shales and other strata. These flexures belong to the class denominated wrinkles in this report.

The two arms of the anticline unite at the west end of the breach in a high ridge. The direction of this ridge is south of west for a mile and a half, in which distance the elevation of the ridge decreases and the structure becomes that of a simple anticline with north and south dips. A small stream draining a high synclinal valley has cut a considerable gap in the ridge in township 4 S., 19 W., section 11, west half. A mile west of the gap the ridge comes to an abrupt ending, with the overlying sandstones forming the western nose. This last division of the ridge is known as East Mountain.

North of the Cooper's Creek anticline, west of the basin, and distant about quarter of a mile, there is an isolated parallel ridge nearly as high as the Cooper's Creek ridge, having a length of about three-quarters of a mile.

Rockport Mountain.—The anticline cut by the Ouachita just south of the Cooper's Creek anticline is concealed by the gravels just west of the river and apparently has no representative further west. In the same way the next one south becomes lost; still, either it or the Rockport anticline probably connects with the ridge which rises above the gravels in township 4 S., 17 W., section 8, southwest quarter. This last ridge has a south of west direction for a little over a mile, in which distance it is twice cut by streams. It acquires little topographic importance until it rises on the west side of the second stream. Its direction is then north of west, the greater part of the ridge lying on the north side of the south line of the second row of sections in range 4 south. This ridge becomes broad and flat-topped, rising gradually to the west. It is the backbone ridge of the eastern end of the Trap Mountains, and is known towards its eastern end as the Rockport Mountain. It is this ridge which backs up the south arm of the anticline breached by Cooper's Creek, and in which the headwaters of this creek have cut many sharp ravines. The structure of the ridge is not easily discerned along its more

eastern extent, as there are no stream cuttings, but the breadth of the ridge suggests that it is something more than a simple anticline. A section obtained in township 4 S., 18 W., section 7, southwest quarter, in deep ravines on opposite sides of the ridge show a well defined double anticlinal structure, with the north dips overthrown to 83° and 84° south, the true south dips being about 60°. Thus we have here two closely jammed anticlines forming the southward continuation of the section represented in figure 3.

This double anticlinal ridge continues to broaden to the west. As it does so the spring branches open little strike valleys in the syncline between the folds until finally the northern anticline is completely set off and ends in an anticlinal nose in the high divide in township 4 S., 19 W., southwest quarter. The southern anticline continues as a high narrow ridge for two miles, then gradually falls off till it reaches a sharp ending in township 4 S., 19 W., section 9, southwest quarter. The total length of this Rockport Mountain is eleven miles.

Another east and west ridge belonging to this group of parallel ridges rises in township 4 S., 17 W., section 18, southwest quarter; its strike is a little north of west, and its elevation is about the same as that of the other ridges; in fact, all these ridges are so near the same level that from one of them only the next one on either side can be distinguished. Near the west line of section 18 a small south flowing stream has cut across the ridge making a very picturesque gorge. The strata here are vertical; and a single massive bed twelve feet in thickness stands out from the ledges on either side of the gorge in smooth cliffs forty feet in height and separated only by a narrow cut which shows the work of the stream. The stream has eroded a considerable valley above the gorge; and since the erosion of the valley depended on the downcutting of the stream it is evident that these cliffs have been standing for a long time. This is one of the best examples to be seen in the whole area of the resistance of the novaculite to weathering, only the Standing Rock, shown in the frontispiece, being more remarkable. Half a mile west of this gorge the headwaters of this stream, rising on the south side of the ridge, cut a ravine across the novaculites.

The total length of the ridge is seven miles, including at its western end two miles of ridge composed of the overlying sandstones which have not been removed from the novaculites, The eastern end of the ridge is too sharply jammed to show the structure well, but a cut through the sandstones at the western end, in township 4 S., 18 W., section 18, eastern half, shows an anticline with moderate dips.

Fourche à Loup Mountain.—The eastern ends of these various anticlines withdraw to the west as they succeed each other to the south. Thus the next ridge south, which forms the south ridge of the range for some miles, rises two miles west of the eastern nose of the ridge next north of it. This is the sixth large ridge and the ninth anticline of the Trap Mountains. It begins in township 4 S., 18 W., section 14, southwest quarter; its direction is north of west for about half its length, then south of west, practically continuing through the centre of the range to the very western end; it is interrupted, however, in several places, and the gap in township 4 S., 20 W., section 19, northeast quarter, seems to set off the eastern extent as one anticline having a length of sixteen miles. The northern branch of Blakley Creek cuts this anticline about a mile from its eastern end. The ridge stands sharply above the general level of the country south of it and has a very even crest. The elevation increases slightly toward the west; it is interrupted by a gorge, however, in township 4 S., 19 W., section 13, southwest quarter, near the west line of the section. The dips of the strata on the south side of the gorge are south 84°, and on the north side they are north 60°. The eastern Hot Springs-Arkadelphia road passes through this gorge, in which Morrison's Spring is situated. The water of this spring is pleasant-tasting and chalybeate, and is said to possess valuable medicinal properties.

The stream flowing from this gorge is entirely out of proportion to the size of the cut, indicating clearly that a much

larger stream formerly flowed through this opening. We have already seen several other instances where the drainage has not yet become adjusted to the structure.

West of the Morrison's Spring gorge the ridge increases in elevation more rapidly, and broadens at the same time. About the middle of section 16 it divides into two, and in half a mile or more both arms are cut by the east fork of Fourche à Loup Creek, up the valley of which passes the "middle" Hot Springs-Arkadelphia road. In its manner of cutting across and breaching this anticline there is a strong resemblance between this creek and Cooper's Creek, though there is no overthrow of the structure here, the dip of the massive novaculite beds of the north arm being north 78°, and that of the south arm south 74°. The less massive beds overlying the novaculites show irregularities in structure, however, for on the south side the dip decreases within 200 yards to 20° S., and on the north side it swings through the vertical to an overthrown dip southward. The graptolites were not found in the shales exposed in the breach of this anticline, but a more careful search would probably reveal them.

The two arms of the ridge rise rapidly on the west side of the creek, and unite in a peak on the west line of section 17; the novaculites on the north side here dip north 80°, and on the south side they dip south 44°. West of the peak in section 18, the anticline is breached again, forming two ridges. The stream which has accomplished this work has not cut back through the south ridge, so this breach is a simple one. Where the stream cuts its gorge in the northern ridge the dip of the novaculites is overthrown to south at an angle of 74°; the south ridge shows a dip of 65° to the south. The change of the dip on the north side from 80° north to 74° south, within a distance of half a mile is noticeable, as well as the changes from 74° to 44° and back again to 65°, all south, within a mile's distance along the south monocline. In the latter case some allowance should be made for the fact that the 74° dip was several hundred feet lower than the 44° one, a difference in elevation often showing a decided change in the angle of dip, since the higher levels approach nearer the crest of the anticline. The 44° dip is also somewhat higher than the 65° one, but the differences in elevation are not sufficient to account for the whole difference in dip. The rapidity with which the dips change and the non-parallel character indicated by them for the two sides of the anticline are marked features of novaculite structure, and probably indicate local differences in the massiveness of the novaculite beds since the novaculites seem to have controlled the folding.

A line of instrumental levels run by Dr. Branner, from Arkadelphia to Hot Springs, along the west line of township 19 west, gave an elevation of 640 feet above the Ouachita River for the northern ridge of the Fourche à Loup Mountain, and of 620 feet for the southern one, or for the higher one 950 feet above sea level. Many peaks and some ridges of the system are considerably higher than this, and even these two were not measured at their highest points.

The ridge continues south of west and the overthrow of the north monocline continues for two miles. In township 4 S., 20 W., section 14, southeast quarter, another stream which has breached the anticline has cut a gorge part of the way down through the north ridge at a point where there seems to have been a twist in the beds. Thus on the east side of the cut the dip appears to be 70° south, while on the west side it is vertical. Down the stream to the north the overlying sandstones and shales give an overthrown dip of 55° to the south. This sudden change of dip may indicate an actual break in the strata at this point consisting of a horizontal movement with a vertical north and south fracture.

Another small break in the north ridge occurs in section 15, southwest quarter. The rocks in this vicinity are much crushed and show dips in various directions. West of this cut the two arms of the anticline join into one ridge. This ridge falls off at first, but presently recovers and is prominent as far as the valley in which flow the headwaters of Fourche à Loup Creek. The cut made by this stream is a narrow one, and ledges on the west side continue the fold which has already been traced

for a distance of sixteen miles; but only the upper strata of the novaculites here appear above the surface, so that the ridge is low here, and as the fold becomes involved in a crushed mass with several others farther west, it seems well to consider the original anticline as ending at the stream valley, in section 19, northeast quarter, at the western Hot Springs-Arkadelphia road.

Jack Mountain.—South of the central portion of anticline No. 9, and nearly a mile away, is the last of the long east-west simple anticlines, known locally as Jack Mountain. It rises in township 4 S., 19 W., section 24, western part, has a direction a little north of west, and ends in township 4 S., 20 W., section 24, western half, having a length of six miles. At both ends the ridge rises sharply from the valley, maintains an even and unbroken crest throughout its length, and is the highest ridge in this eastern group of the Trap Mountains. The eastern end of the ridge shows the anticlinal structure, but at the western end it is not clearly shown, the north dip being overthrown to a south one.

Between the western end of Jack Mountain and the south ridge of anticline No. 9, on the line between sections 13 and 24, there is a short novaculite ridge considerably lower than the ridges north and south of it. The dips of the strata indicate a very sharp anticlinal fold.

The synclinal valleys of this eastern division of the Trap Mountain anticlines have some features in common. Their streams are not very rapid ones until the lower part of the valley is reached; they are impeded to a considerable extent by gravel deposits. The divides in these valleys are generally low, and the tillable land is in narrow strips, but it is fairly fertile, and is fast being occupied by settlers.

The black thin beds of novaculite overlying the massive beds are exposed in a small stream valley in township 4 S., 18 W., section 26, southwest quarter. This stream is in the crest of a low anticline, so it may be inferred that another fold lies just below the surface here. To the west sandstone ridges rise in a line with this axis, but nowhere were the novaculites seen exposed.

The middle division of the Trap Mountains.—The structure of the middle part of the trap mountain uplift is much more complicated than the eastern division. The anticlines are shorter, more sharply folded, and more closely crowded together; in addition, there is a change from a general east and west trend to a northeast and southwest one, which has involved a considerable bending of the axes.

This division of the system may be said to begin with the anticline which rises on the south side of the western end of Jack Mountain. A stream flowing south has cut through this anticline in township 4 S., 20 W., south half, and down the gorge thus made the middle Hot Springs-Arkadelphia road passes. West of the gorge the ridge rises high and widens. A south flowing stream has breached the widened part, and cut back a short distance north of the northern arm, separating from it a sharp ridge about half a mile long which is jammed closely to it. This ridge is in about the middle of section 22. The only dip observed on this short ridge was a south one, but it must be an anticline in structure. The northern arm of the anticline continues due west; the novaculites composing it, however, are less massive and the ridge becomes low in consequence. It probably joins with the south arm in the western part of section 21, but the usual peak at the junction is wanting. The ridge continues westward to the west side of section 20, showing both south and north dips. A branch flows west and northwest between this ridge and the mountain next south of it, cutting across the ridge in the southwest corner of the section. The western nose of this anticlinal ridge appears to be jammed against the mountain on its south side, so that the stream valley in its upper part lies in a syncline from which it escapes by cutting across the anticline, leaving the anticlinal nose of the north ridge attached to the side of the greater anticline on the south. The length of this anticline is five and a half miles.

In township 4 S, 20 W., section 26, northern half, is an isolated ridge striking east and west with a length of about a mile. Its western end is in section 27. Its structure has not been determined by actual dips, but it is safe to say that it is a sharply appressed anticline.

Saddle Mountain.—About a quarter of a mile northwest of the western end of this ridge and south of the longer anticline described above is a low, narrow, anticlinal ridge. This ridge rises gradually to the west; it has been sharply jammed and shows on the north side a dip of 44° to the south, while on the south the dip is 56° in the same direction, thus the anticline is overthrown and opened out at the top like the Cooper's Creek anticline. In the northeast quarter of section 28 this ridge unites with another which rises just south in a very sharp anticlinal nose. These combined anticlines form a broad high ridge, the highest yet described among the Trap Mountains; it is known as Saddle Mountain, and its elevation must be nearly 800 feet above the valley. About a mile west of the junction of the two anticlines there is a considerable depression in the summit of the ridge; it is this depression which forms the hollow of the saddle. The cause of the depression is found on going south down the mountain side; a ravine extends nearly to the top of the mountain. In the hollow of the mountain on its south side the dip is north 50°; this dip represents the north side of the southern anticline. In the ravine below, the underlying shales show a dip north 75°. Below the shales there are more novaculites, vertical and forming the south side of the anticline. Below the novaculites in the ravine are overlying shales and sandstones, at first vertical, but further down the stream changing more and more to a low south dip. It is clear that the folds at this point spread out too much at the top, thus forming a weak place which has been attacked by the stream, and the result has been a hollow in the crest of the ridge.

In the western part of section 29 the two anticlines of Saddle Mountain separate, forming two much lower ridges. Big Hill Creek cuts across these ridges in section 30, in the northeast quarter. The southern one shows a south dip of 81°; between the two are shales and sandstones resembling those which overlie the novaculites; the north ridge shows a north dip of 35°. The more northern ridge is weaker than the other, and is twice cut by small branches. Near its western end the dips indicate an anticlinal structure. The southern ridge remains unbroken. Both end in township 4 S., 21 W., section 26, northeast quarter, the northern one having a length of five miles.

One ridge south of the western end of these anticlines is found in townships 4 S., 20 and 21 W., in section 30, southwest quarter, extending west to section 26, southeast quarter. This is a simple anticline, giving north dips of 65° near its western end on the north side, and south dips of 50° on the south side.

North of the Saddle Mountain anticlines is a confused mass of novaculite ridges in which the strata have been so closely appressed and the whole eroded in such a peculiar manner that it would require much detailed study to determine the structure with precision. The most that can be done here is to indicate how the ridges run and to propose tentative explanations for their structure.

The Round Mountain anticline.—In township 4 S., 20 W., middle of section 20, a broad ridge rises abruptly from the overlying rocks. It would naturally be inferred that the structure was anticlinal, yet the dips found not far from the eastern end are 20° S. on the north side, and on the south side 74° N. It is possible that this is an exaggerated case of the spreading of anticlines at the top; it is also possible that a system of joint planes was mistaken for stratification. The fact that the ridge soon divides into two, as though breached, favors the first supposition. The stream rising in the breach flows northward, and is one of the sources of Fourche à Loup Creek. The north arm has a south dip of 45° on the west side of the breach, thus seeming to indicate a continuation of the overthrow. The arm on the south side of the breach is not cut down in any place, but has been irregularly eroded so that it forms a crooked divide. It is very likely that the irregular

erosion depended upon actual twists in the structure, as the rocks are massive. The dip taken more than a mile west from the first was also north, this time 35°. The note book record, however, indicates that at the place under discussion the topography shows that the north dip represents the north side of an anticlinal nose, which is broken down, but whose south side and western end are represented by a ridge and peak in township 4 S., 21 W., section 24, near the south line. If this is the case, then the south side of the doubtful anticline is pressed closely upon the north side of this broken anticlinal nose. However this may be, the two arms of the breached anticline come together in the southeast quarter of section 24 in a high, broadly rounded peak called Round Mountain. It is probable that two thicknesses of novaculite are jammed into the south arm above discussed, as the ridge representing the south side of the new anticline has a south dip of 66°.

Round Mountain and the western end of another ridge distant not more than a quarter of a mile north are jammed together. This northern ridge has a somewhat broken crest, is nowhere of high elevation, and trends north of east, then east to the western end of the long anticline previously called No. 9; so it, too, is anticlinal. It is about a mile and a half in length.

North of this ridge and less than half a mile away is another, generally higher ridge, also trending north of east and south of west. The dip shown is generally south, but near its eastern end on the north side the dip is north, hence, like the others, it is an anticline. It starts in township 4 S., 21 W., section 17, southwest quarter, and in 4 S., 21 W., section 24, northwest corner, it joins with another ridge coming from the northeast. This northeast and southwest ridge shows a northwest dip near the junction, but it is probably an anticline since it rises from the overlying rocks in the southeast quarter of section 13, township 21 W. A curious feature about this short northeast ridge is that it supports at its northern end a peak which has a longer axis running east and west, while the rocks dip due south; as will be noticed on the map, the trend of the whole western end of the Trap Mountain system is northeast-southwest, while that of the eastern ridges is due east and west. It seems probable that these two sets of folds were not formed at the same time. The ridge in question indicates that the east and west ridges were formed first, since the peak, which has a marked east and west elongation, is uplifted on the northeast and southwest fold. The peculiar relation of this peak to the ridge might also be regarded as one of the accidents of the general crushing in this part of the Trap Mountains. More detailed work would be necessary to decide this point.

From the union of this northeast and southwest ridge with the one coming from the north of east, there results a high ridge, having a direction intermediate between the two and with a south dip. This ridge ends in the middle of the northeast quarter of section 23, but a novaculite divide at a lower level extends north of west and joins another short east-west peak lying near the north line of section 23 on the half mile line. The strike of the rocks on this divide is N. 60° W., dip from vertical to 69° to the southwest; this fold is, therefore, almost at right angles with the general trend of the system. The peak to which it leads shows a strike of N. 50° E., dip on the north side vertical and on the south side, southeast. The larger topographic axis of this peak does not coincide with the strike of the rocks, though this does not signify much as the peak is a mere rounded knob.

Panther Knob.—A novaculite divide runs north of west from this knob to the eastern end of a still higher mountain known as Panther Knob—probably the second highest point in the Trap Mountains. The direction of the ridge is nearly northeast and southwest; the northeastern end rises very abruptly; the highest point is about in the northeast corner of section 22. The dips are rather irregular, especially at the northeast end, but show a general south or southeast tendency on both sides of the ridge, the parallelism and comparative lowness of the dips (the angles are from 45° to 60°), indicate an original anticline that was closely jammed and considerably overthrown. In following the ridge southwest the elevation decreases rapidly. This decrease seems to have been caused by the work of two spring branches directly opposite each other on either side of the ridge, for beyond the hollow the ridge rises sharply, though not as high as before. The anticline gradually sinks to the west, becoming narrower as it falls away. In the southeast quarter of section 20, the novaculites disappear beneath the overlying rocks where the "Valley road" passes over the divide. The maximum length of this system of ridges is about six miles.

The Bare Mountain anticline.—North of this confused group of anticlines lies the western part of an important group of peaks and ridges, the greater part of which lies to the northeast on the north side of the Fourche à Loup Creek. These mountains, taken as a whole, illustrate the next stage beyond that of the simple breached anticline already several times described. Two broad, high anticlines uniting through a plunging synclinal fold have been breached and eroded so that the anticlinal valleys are united and the novaculite walls, remaining entire, give a zigzag mountain topography. It is easiest to describe the structure beginning at the northeast extremity where the largest anticline rises up in a peak called Bare Mountain. This mountain has its origin in township 4 S., 20 W., middle of section 1. Its course is due southwest, and it rises steadily with a slope of about 10° for over a mile. The anticline is a very broad one, and has been, in consequence, more enduring than the ordinary sharply jammed folds; the top of Bare Mountain is, therefore, the highest point among the Trap Mountains. The dips of the strata taken in a section across the peak are southeast at an angle of 60° on the south side of the mountain, and on the north side they are north at an angle of 65°.

The anticline has been breached from the west so that from the north and south sides of the peak narrow ridges continue in the general direction of strike. These ridges are high and remarkably straight, with even crests for a distance of over two miles. The north ridge is then interrupted by a gorge near the center of section 8, through which the stream draining the breached area flows northward. The ridge changes its southwest course to west in the southern part of section 7, near the half mile line. The dip all along the ridge west of the gorge is overthrown, and probably the gorge itself is along the line of greatest overthrow. About on the west line of township 20 W., the north and south sides of the Bare Mountain anticline meet again in a complicated jam of peaks and ridges.

Meanwhile the south ridge has undergone many changes. The straight ridge from Bare Mountain runs into a very sharp, high synclinal ridge in the extreme north central part of section 17, forming the north side of the syncline. The western end of the synclinal spoon is abrupt; the rocks are much crushed, but easterly dips of 35° at the top and 10° below are visible. The syncline is prolonged by a knob of underlying sandstones. The western end of the syncline is in the northeast quarter of section 18. From the south side of this syncline the novaculite ridge runs nearly east for a little over a mile, the dip remaining nearly vertical, slightly inclining to south. In the northeast quarter of section 16 it forms the north side of another long, high, anticlinal nose. This nose ends in the southwest quarter of section 11, and is as long as Bare Mountain but not so broad. A section across the mountain in the north central part of section 15, gave dips of 50° north on the north side, on the south side near the top of 30° to the southeast, and at the bottom of 53° to the southeast. Where the south side of this nose becomes a separate ridge in the northeast quarter of section 16, the dip is east of south at an angle of 45°. A small stream which has been breaching this anticline in the northern part of section 16 cuts southward through the ridge about in the center of the section. On the west side of the cut the ridge continues south of west in a straight course. A depression in the ridge in the southeast quarter of section 18, is traversed by the trail leading from the western Hot Springs-Arkadelphia road to the Amity-Hot Springs road. West of this gap the dip remains south, here about 83°, and the direction of the ridge changes to north of west; the rocks of this portion of the ridge are not very massive, so the ridge is low and narrow. In the western central part of section 18, a stream flowing northeast breaks through the ridge. Across the stream it rises again with a southwest dip of 75°, and runs into the south side of a high peak, which connects on the north side with the northern arm of Bare Mountain. Thus the limits of the double anticlinal breach are defined.

The mass of ridges and peaks extending west from the junction of the two arms must be regarded as anticlinal, but the structure is in itself much confused, and erosion has greatly increased the confusion, so that much detailed work would be necessary to determine the structure with precision. So far as the observations of the writer go the following explanations can be offered. The northern arm of Bare Mountain, which suddenly comes to an end in township 4 S., 21 W., section 12, southeast corner, with an overthrown south dip of 71°, seems formerly to have extended further southwest, to the peak in the northwest quarter of section 13, which in turn has an abrupt eastern ending with a south dip of 65°. The western end of this last peak has the appearance of a sharp anticlinal nose with a north dip of 75°. The high peaks between the two sides of the anticline as they come together toward the west, represents the syncline between the two large eastern anticlines, and corresponding with the high, sharp, anticlinal peak described in connection with the south arm.

The general structure of the mountains in sections 14 and 15 must be anticlinal, but the crushing has been very irregular and has resulted in numerous humps and hollows since erosion on simple anticlines does not give such topography as is found here. It is possible that the suggestion offered in another place, namely, that the folds were formed at different times, may apply to this locality, but there is no marked correspondence in the direction of axes as in the other case. Within a distance along these ridges of less than two miles there are three ridge-like peaks. The first has an east-west axis corresponding with the strike of the rocks; the second one has a northwest-southeast axis though the strata strike nearly east and west; and the third trends northeast and southwest apparently across the strike of the rocks. It seemed evident in the field, however, that the western end of the first and the southeast end of the second axis were once structurally connected but have been separated by erosion; the third is evidently the broad anticlinal end of this anticlinal jam, and has an actual change in the direction of its axis, the nose being in the southeast quarter of section 15 near the south line of the section. The dips all about this nose are exceedingly steep being from 70° to 80.° The Lightfoot Springs are situated on the west side of this last peak and appear to issue from an eroded anticlinal nose; but it is clear that the anticlinal structure seen at this point is due to a bulging out of the side of the anticline with its change of axis, so that the real nose and the western end of this group of the Trap Mountain ridges is as stated above. The greatest length of this complete anticlinal uplift is eight miles.

The western end of the Trap Mountain system.—The remaining Trap Mountain ridges are simple overlapping or interrupted anticlines, sometimes slightly breached, and becoming lower, as a rule, toward the southwest. These ridges may be said to begin west of Round Mountain which fills the east central part of section 24 of township 24 west, and are separated from it by a small basin-like valley which probably represents a synclinal depression. Round Mountain is the central divide of the region; from it flows northeast Fourche à Loup Creek, southeast and south flows Big Hill Creek, and west and south Valley Creek, while north of the mountains on the north side starts Henderson's Creek, a branch of Little Mazarn Creek.

The last group of ridges is connected with Round Mountain and the Saddle Mountain group of ridges by a northwest and southeast novaculite divide which, since it connects with an anticline, seems to be an anticline with the axis bent. If this is correct the bend in the axis is remarkably sharp, being nearly a right angle. The bend is in section 23 north part of the southeast quarter, and at this point a ravine has almost

separated the two ridges. On the west side of the ravine the anticline strikes southwest. A small stream cuts it in two half a mile from the bend, and west of the cut the ridge is nearly a mile in length. The ridge is a sharp one and its western termination is abrupt.

A parallel ridge less than half of a mile northwest of the last one mentioned is a higher and broader one. It starts in section 23, central part of the northeast quarter. The structure there is not clear, the crushing has evidently been great and erosion has rendered it still more obscure. In height the ridge nearly equals the Panther Knob which lies to the northwest, and maintains its elevation well toward the southwest, though broadening meanwhile. The anticlinal structure becomes clear in the southwestern part of section 26, though both dips are nearly vertical. In the northeast corner of section 28 and the southeast corner of 21, Valley Creek, flowing south, cuts a gorge through the ridge and has separated the two sides of the anticline by short strike valleys. On the west side of the creek the trend of the ridge changes to west, thus the stream chose the bend of the anticline as the easiest place to break it down; the dips in the gorge also show the reasons for the cutting at this point, for the dip on the north side is overthrown to south 55° while on the south side is 70° toward the south. A mile and a quarter west the ridge abruptly ends and the novaculites disappear below the sandstones with dips nearly vertical and parallel in strike.

South of the western end of the above ridge and distant about a quarter of a mile another sharp northeast-southwest ridge rises abruptly, extends in a straight course uninterrupted for two miles and sinks rather gradually in the northeast corner of the southwest quarter of section 31. Only south dips were observed but the structure must be anticlinal.

Two knobs rise above the general level of the sandstones in the northeast quarter of section 29 and the southeast quarter of section 20. These knobs give no evidence of structure save a doubtful south dip on the former and a north dip of sandstone at the east end of the latter; they evidently represent, however, anticlinal bulges of the underlying novaculite.

Nearly in an axial line with these knobs novaculite ridges soon appear in the southwest. Of these the northern one is the more prominent. It rises in the northwest quarter of section 29 (4 S., 21 W.), and strikes in a southwest direction. The Point Cedar road passes through a depression in this ridge in the south part of the northeast quarter of section 30; the dip here, south 30°, is probably the north dip overthrown. At this place a small stream has cut back a ravine and caused the depression in the ridge, of which the highest point is just west of this gap. The dip at the gap is south, the angle 70°. From here westward the ridge gradually becomes lower. In the middle of the southwest quarter of section 30 a road crosses the ridge through a hollow, and not far west is a north dip of 35°. About on the west line of this township (4 S., 21 W.), the novaculites of this ridge disappear, but the overlying sandstones show the dips of an anticlinal nose. The axis of this fold is indicated, however, by a low ridge of sandstones which continues with two breaks, through which wagon roads pass, to the middle of the northeast quarter of section 35, township 4 S., 22 W. Here the novaculites appear again as a sharp ridge increasing in height westward. The anticlinal dips are found in several places, but the prevalence of south dips indicates that the fold is frequently overthrown. In the southwest quarter of section 33 the fold spreads out more broadly and a stream has cut back into the ridge making a small breach. There seems to have been a peculiar twist in the fold at this place, for east of the breach the north dips on both sides of the ridge indicate a north overthrow, while a short distance west of the breach the corresponding dips are south showing here a south overthrow. The ridge falls off slightly toward the west and ends with a rather sharp plunge; the north side of the nose has apparently been eroded away, thus the axis of the ridge crosses the strike of the rocks in a direction south of west. The end lies in township 5 S., 22 W., section 5, north part of the northwest quarter. The length of this anticlinal fold is about seven miles.

The southern of the two axial ridges mentioned at the beginning of the preceding paragraph is only about a mile long, and is not a prominent topographic feature. The anticlinal structure is apparent at the southwest end.

South of this ridge, in the northern part of section 31 of 4 S., 21 W., are two lower and narrower ridges, each having the same northeast and southwest strike. The more southern one shows no outcrops, but the northern one is cut by the stream which flows southward through the west part of section 31, and shows an anticlinal form. What is apparently the very axis of the anticline is exposed on the east side of the stream; here the strata form an inverted V with a dip of 80° on either side. From the middle part of the V the rocks have been removed leaving a small cave. At the apex of the V the strata appear to have broken squarely without bending. This ridge ends about a quarter of a mile southwest of the Point Cedar road.

Just north of the west end of this last ridge another one rises with a steep slope in which the vertical strata strike north 60° east. Following southwest along the top of the ridge both north and south dips are found. A small stream cuts the ridge in the southeast corner of section 35, township 4 S., 22 W. The ridge continues on the west side of the stream, but gradually dies out. The end is about on the township line in the extreme south central part of the southwest quarter of section 35. Some low sandstone ridges indicate a continuation of the folding along this general axis, until in township 5 S., 22 W., section 5, northeast quarter, the novaculites come to the surface for the last time as part of the Trap Mountain range. The ridge is a low one and the beds are not sufficiently uplifted to bring the massive strata to the surface and so show its anticlinal structure. Like many parts of the other Trap Mountain ridges all that is seen at the surface are angular fragments and blocks of the thin upper beds of the novaculite series. The novaculites disappear at Elm post-office in township 5 S., 22 W., section 6, the northern part of the southeast quarter.

Conclusions regarding the Trap Mountain system.—As a whole, the Trap Mountain range consists of novaculite anticlines, no less than thirty in number, varying from a quarter o a mile to sixteen miles in length. The manner in which these anticlines seem to burst up through the overlying rocks is the constantly surprising feature of their occurrence; the anticlinal noses often lack the expected symmetry of radiating dips, and show only steep dips parallel with the anticlinal axis. The division of the range into two groups of ridges, one east-west set and the other northeast-southwest, is also noteworthy. It would seem probable at first that these separate divisions were formed by different pressures at different times, and this has been suggested in the previous description in connection with some pertinent evidence of such action. But the way in which the east and west anticlines succeed each other and form a system extending steadily south of west, and in particular the way in which the west end of anticline No. 9 seems to conform to the trend of the ridges north of Fourche à Loup Creek, seems to indicate that the same pressure caused both sets of folds. It is evident that the general directions of pressure in the novaculite area were north and south, so the northeast and southwest folds may represent a local shearing action in the general crushing. The two apparently conflicting suggestions made above concerning the relative dates of the folding of the two divisions of the system may be reconciled by the supposition that the folding was one continuous process in the latter part of which the northeast-southwest tendency was developed.

The large number of very steep folds in the Trap Mountains necessarily involved the actual movement of strata for several miles. The question naturally arises, in what direction was the movement? The very common occurrence of overthrown folds with south dips indicates, according to the generally accepted notion in regard to overthrown folds, that the movement was from the south. The existence in considerable numbers, however, of north dipping overthrown anticlines seems to necessitate a pressure from the north as well; but in

the consideration of the Cossatot anticline it is shown that this is not essential.

Novaculite at Amity.

Nearly in the general axial line of the western part of the Trap Mountains, but six miles distant, in a southwest direction, a knob of novaculite is reported by Dr. Penrose and Mr. Geo. H. Ashley of this Survey, projecting through the overlying rocks. It is situated in township 5 S., 23 W., section 34, northwest corner, just north of Amity post-office. Its height is scarcely more than a hundred feet, yet owing to its isolated position it is very prominent. This locality lies beyond the limits of the maps accompanying this report.

Several other outcrops have been noticed by Mr. Ashley in his study of the Paleozoic area lying south of the Trap Mountains. These novaculite exposures all occur along anticlinal axes.

CHAPTER XIII.

Detailed Geology of the Novaculite Area.—*Continued.*

THE COSSATOT MOUNTAIN SYSTEM.

Another anticlinal area complete in itself is the system of mountains grouped together under the name of the Cossatot range. These mountains stand at a higher elevation above sea level that the Trap Mountains, their folds have also been lifted higher, and erosion has therefore left a more complicated structure than that of the Trap Mountains. The system forms a natural continuation of the Trap Mountain system, but between the two there is a depression of the anticlinal folds, so that the overlying strata are the ones now exposed. By this depression the Cossatot and Trap Mountain novaculite systems are separated about seven miles.

The Eastern Ridges.

According to Mr. J. Perrin Smith of this Survey, who traced the southern line of the Cossatot system, its easternmost exposure of novaculite is at Mitchell's Ford on the Caddo, township 5 S., 24 W., section 13, northeast corner. The rocks at this place dip south, 20° east at an angle of 70°. On the east side of the river there is only a low outcrop, but on the west side the novaculite forms a prominent ridge between two and three hundred feet in height. The northern side of the ridge has apparently been eroded away at Mitchell's Ford, for on following the ridge west to the Rock Creek gap a north dip of 80° is found showing the structure to be anticlinal. West of Rock Creek the ridge becomes lower, the novaculites barely coming to the surface and the direction, which east of the creek was south of west, now changes to north of west. The ridge is a solitary one for a few miles, but as it is only about a hundred feet in height it does not form a prominent topographic feature.

The anticlinal structure is clearly shown in the gap in section 8, northeast quarter of the southeast quarter, west of W. D. Ward's house. West of this gap the direction again changes to a little south of west. A low gap in section 7, southeast quarter of southeast quarter, is traversed by the Chany Trace road. About half a mile west of this gap, and just over the west line of 24 W., the ridge ends, its length being about six miles.

Brooks Mountain—Four additional anticlines rise on the north side of the above ridge within a distance of two miles. The nearest of these rises as a low nose in the east central part of section 7, followed by a gap through which the Chany Trace road passes. The ridge is higher on the west side of the gap, and in township 25 W. it is known as Brooks Mountain. Brooks Mountain reaches an elevation of about 400 feet, but falls off to about 150 feet in township 25 W., section 11, middle of the section. Another rise to 400 feet follows, with another depression at Brook's Gap in the central part of section 10, through which passes the Fort Smith road. The ridge does not again reach its former height and comes to an abrupt ending in a nose overthrown to the south near the centre of section 9; its total length is four miles.

A quarter of a mile north of the eastern end of Brook's Mountain another ridge starts in a gently rising anticlinal nose. Its general trend is west, the structure is anticlinal, and the maximum elevation about 400 feet. It comes to an end in township 5 S., 25 W., the northeast quarter of section 11, with a total length of two miles.

The Rundle's Creek anticline.—The third ridge, known as Markham Mountain, rises on the west side of the Caddo River, in township 5 S, 24 W, section 4, east central part; its direction and elevation are the same as the last mentioned. In township 5 S., 25 W., section 1, southeast quarter, it separates into two ridges—another instance of a breached anticline. The two sides of the anticline are not very regular, however; the northern arm runs west until cut by Rundle's Creek in section 3, the northeast quarter of the southeast quarter. The dip here is north from 50° to 70°. West of this gorge it strikes northwest for two miles, then swings around to the southwest over two miles more, when it joins the south arm in Pennywinkle Mountain, in township 5 S., 26 W., section 12, north half. The south arm has an irregular structure and has been strangely eroded, so that its ridges seem disconnected. In township 5 S., 25 W., section 2, southern part, it is twice cut by small streams originating in the breach of the anticline just north. These, with other small branches unite to form the east fork of Rundle's Creek and cut north across the same novaculite ridge in the southwest corner of section 2. Other smaller branches of Rundle's Creek have incised this arm, but the general course is west, with south dips, the end being in Pennywinkle Mountain. This anticline is between nine and ten miles in length. It is noticeable that where Rundle's Creek cuts through the north side of the anticline in section 3, the dip of the rocks is the normal north dip, so the weakness of this particular place was due to the bending of the rocks, involved in the sharp change in the direction of the strike.

The fourth anticlinal ridge of 5 S., 24 W., rises on the north line of this township in the northwest quarter of section 5, and the southwest quarter of section 32, of 4 S., 24 W. It continues due west along the township line about to the adjoining corners of townships 4 and 5 S., 24 and 25 W.; the direction then becomes south of west, and the ridge terminates on the east side of Rundle's Creek in a jam with the north arm of the anticline just described. At this point is a peak called North Mountain; it has an elevation of about 500 feet.

High Top Mountain.—Between the western end of Brook's Mountain and the south side of the Rundle's Creek anticline, in township 5 S., 25 W., section 9, north central part an anticlinal ridge rises. Within less than a mile from its eastern end, this anticline is cut across and breached by Little Self Creek in such a way that on the east side of the creek its structure becomes confused with that of the south arm of the Rundle's Creek anticline. The north ridge of this High Top anticline is distinctly separated from the south side of Pennywinkle Mountain by a synclinal valley. All three ridges have an elevation of about 400 feet above the valley, and the peaks into which they run are about 700 feet high. The highest point of Pennywinkle Mountain is in 5 S., 26 W., section 1, southwest quarter of the southeast quarter; and the highest point of High Top in the same township, section 12, southwest quarter of northeast quarter. The south side of the High Top anticline has been cut by a stream in township 5 S., 26 W., section 12, southeast of the northeast quarter.

To the west, the High Top and Pennywinkle anticlines are jammed together into one mountain, and Self Creek cuts across this ridge about on the west line of section 12. A section made down this gorge by Mr. Smith shows that the double anticlinal structure exists, though the north dip of the northern anticline is wanting, having been worn away or otherwise obscured. Farther west, however, the two anticlines merge into one, and the ridge falls away rapidly to a low depression in the west central part of section 10, where the overlying sandstones almost cover the novaculites. West of this depression the novaculites rise again, however, to an elevation of about 300 feet in the middle of section 9; then there is a gradual decline with a sharp ending in the west central part of section 8 at Little Blocher Creek. The anticlinal fold is continued for a mile on the west side of the creek by a much lower ridge of the overlying rocks through which the upper novaculite beds appear in places. The length of the High Top anticline is eight miles.

Warm Spring Mountain.—On the west side of Self Creek the southern ridge of the mountain has the name of Warm Spring Mountain from a spring at its eastern end. This spring is said by Dr Sutton, a resident of this neighborhood, to have a temperatnre of 87° Fahrenheit. Mr. Smith says that the warm water of this spring flows from a fissure parallel to the bedding of the rocks which are stratigraphically at the top of the novaculites. This water flows then from rocks having a stratigraphic position corresponding closely with those from which the hot springs of Garland county flow, the latter coming from the sandstones just overlying the novaculites. The water of the warm spring is impregnated with iron and ferruginous deposits are plentiful round about. It is located in township 5 S., 26 W., section 12, northwest quarter of the southwest quarter, on the west side of Self Creek about 100 feet up the mountain side.

The Cossatot Anticline.

One more novaculite fold originates in the eastern end of system, and it is this one which, widened and breached, with numerous dependent anticlines and synclines, form the great mass of the Cossatot Mountains. The eastern nose of this great anticline is jammed together with the north side of the Rundle's Creek anticline in the extreme northern part of section 5 of 5 S., 25 W., and forms a ridge-like peak nearly 800 feet above the valley, the highest at the eastern end of the system. From the south side of this peak at either end the Rundle's Creek ridge comes off at a much lower level than the top of the peak; and the east end of the anticlinal nose is marked by a projecting knob from which the elevation drops off rapidly as the Rundle's Creek ridge bears away to the southeast.

Tweedle Mountain.—From the western end of the peak two ridges start west; thus the breach begins almost at the very eastern end of the anticline. The northern ridge, or northern monocline as it will be called, runs due west on the township line between 4 and 5 S., range 25 W. From its south side rises a peak known as Tweedle Mountain, near the adjoining corners of townships 4 and 5 S., 25 and 26 W., which is nearly as high as the nose of the anticline a mile to the east. The low dip of the novaculite strata on top of Tweedle Mountain shows that it is a part of the old anticlinal arch the rest of which has been worn away. The direction of the monocline changes to a little north of west from the west end of Tweedle Mountain, but turns again west in about a mile. In township 4 S., 26 W., section 34, southeast quarter, the ridge ends.

Pigeon Roost and Line Mountains.—The southern monocline of the anticline just mentioned is cut almost at its beginning

by the headwaters of Self Creek in township 5 S., 25 W., section 6, northeast quarter, the stream flowing from the breach of the anticline. The direction of the south monocline is here nearly southwest; the dip is reversed to the north. A mile and a half away another branch of Self Creek flows south across the monocline. West of this cut the monocline forms the south side of an anticlinal ridge, Pigeon Roost Mountain, of which the western end disappears beneath the sandstones in township 5 S., 26 W., section 3, south central part. From the north side of this anticline the monocline becomes a separate ridge in the same township, section 1, southwest quarter. From this point it swings around through north till it again strikes due west on the line between townships 4 and 5 S., 26 W.. The valley between Pigeon Roost Mountain and this one on the north, known as Line Mountain, is thus a syncline spooning out to the east. The curve made by the ridge is a fine example of the synclinal curves so common in the novaculite area. Where the south monocline turns west into Line Mountain it approaches the northern monocline of the Cossatot anticline very closely. Only a short high divide separates the two sides of the Cossatot anticline at this point.

The south monocline.—The two sides of the anticline do not come close together again until they finally meet in the Hannah Mountain anticline nearly twenty miles from this point. Hence, for the sake of clearness, the south side will be traced completely through before considering the other.

The south monocline in Line Mountain runs due west, with a very even-backed ridge just north of the crest of which runs the township line between townships 4 and 5 S. A high gap in the ridge in the northwestern corner of section 4 probably indicates an old stream course; through it passes the mail trail from Langley to Fancy Hill. In township 4 S., 26 W., section 32, southwest quarter, the monocline forms the south side of a high peak, from which extends in a direction south of west an anticlinal ridge having a length of about two miles. This ridge is cut by Blocher Creek in township 5 S., 27 W., section 1, north central part. At this cut it is but the arch of a low anticline which disappears about a mile and a half to the west. A quarter of a mile north of this cut the creek has also cut a gorge through a high ridge which shows a south dip of 47° to 54°. The Black Springs road passes through these gaps. This northern ridge runs into the north side of the high peak last mentioned and is the continuation of the south monocline which, in the high peak, has been doubled into an anticline followed by a syncline. In this case the anticline and syncline are more closely jammed together than in the case of Pigeon Roost and Line Mountains yet here also the synclinal fold is prolonged in a valley.

Poll's Butte and Raven Mountain.—West of the Blocher Creek gorge the monocline continues as a sharp ridge between 400 and 500 feet in elevation, due west along the township line for a mile and a half. Then it again forms the south member of another peak known as Poll's Butte. As in the preceding case this is another combination of anticline and syncline, the syncline being on the north side and having a continuation of the monocline for the north side of the spoon. The anticlinal nose in this case is long and high and bears the name of Raven Mountain. It has a course south of west for some miles and in this distance rises to a height of 700 feet, and is never below 500. In township 5 S., 27 W., section 6, southeast quarter of the northeast quarter, it is cut by the Little Missouri River, where a fine gorge is formed. The dips are north 55° and south 75°. The continuation of Raven Mountain on the west side of the river is called Big Tom Mountain. In this mountain the axis swings gradually through west to a direction north of west. Small streams have cut back into this ridge, especially on the north side. The general elevation is about 500 feet, but after crossing the line into township 4 S., 28 W., the height is not more than 300 feet. Where the Saline River cuts through it in section 31, southeast quarter, the height is still less and west of the river the novaculites soon disappear below the sandstones. The entire length of the ridge is ten miles.

Little Musgrove and Fodderstack Mountains.—Poll's Butte

is formed entirely by a synclinal curve; the north and east slopes of the mountain are steep and bare and the geological structure is easily discernible at a distance of several miles. The peak must approach 800 feet in height above the valley. From its north side the monocline continues in a direction a little south of west. The Little Missouri River has cut a gorge through the monocline in township 4 S., 37 W., section 32, southwest quarter, where the dip is 50° south. West of the gorge the ridge bears the name of the Little Musgrove Mountain. Near the west line of section 31 a small stream has cut a gap, separating the Little Musgrove from the Fodderstack Mountain. In this gap the strata show reversal to a north dip. The reversed dip increases on approaching the Fodderstack, and is as low as 60° on the lower part of the south side of the mountain. Ascending the mountain underlying shales are crossed, and above them forming the top of the mountain are the novaculites dipping north at an angle of 36°. Here, then, we have an anticline considerably overthrown toward the south. Fodderstack Mountain is between 800 and 900 feet in height; it forms the eastern end of an anticline from which the north arm passes through another syncline to continue again the south monocline. West of Fodderstack peak the anticline becomes considerably lower; the ridge is known as Prairie Mountain. The overthrow of the anticline continues for more than a mile, then the south dip on the south side is regained. The ridge is high for the greater part of its length, but falls off to the west very gradually. The overlying sandstones cover the novaculites on the east side of the Saline River in section 31, northeast quarter. The length of this anticline is five miles.

The monocline coming from the north side of Fodderstack and connected with it, doubles in a sharp synclinal curve forming another high peak just north of Fodderstack; it is a distinct synclinal peak just as the main Fodderstack is an anticlinal peak. East of this peak, and lying in the direction of the axis of the syncline, half a mile away is an east and west ridge-like peak capped with novaculite. It is undoubtedly a portion of the old synclinal trough continued from the above mentioned synclinal peak. It is a little less than a mile long and ends west of the Little Missouri River.

Little Raspberry, Blalock, and Prior Mountains.—From the Fodderstack syncline the south monocline takes a north of west direction, gradually approaching a ridge which lies on the north side of the monocline. In township 4 S., 28 W., between sections 26 and 35 the two are joined by a high divide of the underlying shales, thus showing that they form an anticline. A small branch of the east fork of the Saline River has cut this anticlinal nose, making a considerable breach in it a mile west of the divide. The west end of the nose is in section 28, the southwest quarter. The north dip of this anticline is in the north ridge; the direction of this ridge is south of east and it leads to a sharply rounded peak known as Little Raspberry. The synclinal structure of this peak is clearly visible from the neighboring mountains. Forming a continuation of the axis of this syncline to the east are Blalock and Prior Mountains. A branch of Blalock Creek has separated Blalock Mountain over half a mile from the Little Raspberry, and the Little Missouri River has cut a gorge separating Blalock and Prior by a much smaller distance. The last mountains have novaculite caps which as seen from the gorge show a gentle synclinal structure. The identity of these mountains with the Little Raspberry axis is unmistakable. Blalock is a little more than a mile and Prior two miles in length; both reach an elevation above the valley of 800 or 900 feet.

Brushy Mountain.—We should expect to find the south monocline extending west from the Little Raspberry syncline, but a branch of Blalock Creek has cut it away at this point. It appears, however, as a high ridge in the southwest quarter of section 25, striking nearly west. This ridge approaches an elevation of 900 feet above the level of the stream. A high divide of the overlying sandstones connects it with the next ridge south in the central part of section 27. The dip is reversed to 79° north. The novaculites of this ridge seem to run directly into the south side of a high peak, Brushy Mountain, in the north central part of section 28. There is the appearance of a separate anticlinal nose for the southern side of Brushy Mountain, though in reality the diagonal cutting of a small stream across the novaculites of the south monocline with the overlying sandstones, produces the semblance of an anticline.

The east and west ridges between Fodderstack and Brushy Mountains increase in elevation toward the north and culminate in the Brushy Mountain ridge which is about 1000 feet high at its highest point. The ridges are closely jammed together and the dips are very steep; they are often overthrown.

Tall Peak Mountain.—Brushy Mountain slopes steadily away to the west and where cut by the head waters of the Saline River in the southeast corner of section 19 is but a low ridge. Its continuation on the west side of the river rises higher as it joins the south side of Tall Peak Mountain; but it soon separates and shortly ends in township 4 S., 29 W., section 24, southeast quarter. To the east the ridge continues to be high for more than two miles when it ends abruptly. This eastern end of the ridge is a syncline originating where the south monocline comes out from the north side of Brushy Mountain in the northeast quarter of section 28.

The direction of the monocline from this point changes through northwest to nearly west, until in the west central part of section 20 it becomes the south side of the Tall Peak anticline. The road from New Moon to Rhode, coming up the Saline River valley, crosses the monocline in the east central part of section 20. The direction of Tall Peak anticline is south of west for nearly a mile, when the axis bends to a westerly course and later to north of west. The Tall Peak rises in the southwest quarter of section 19, where this anticline is reenforced by the prolongation of Brushy Mountain. Its elevation is about 1000 feet. The ridge itself as it continues to the west maintains an elevation between 700 and 800 feet and bears the names of Raspberry and Porter at its east and west ends respectively. The ridge continues to be high well towards its end, and its crest is a sharply plunging one.

It disappears on the east side of the Cossatot River in township 4 S., 30 W., section 14, southeast quarter. The total length of this anticline is about nine miles.

On the south side of Tall Peak ridge and jammed closely to it throughout the greater part of its length is another ridge nearly as high as Tall Peak itself. This ridge is an independent anticline, rising on the west side of the Saline River in township 4 S., 28 W., section 30, northeast quarter. Its direction is steadily north of west until on approaching the end it turns due west. In its entire length of twelve miles it is many times transected by the small streams rising on the south slope of Tall Peak Mountain, and in these cuts in township 29 west, the structure is seen to be an anticline reversed southward, the dip of the novaculites on the south side being north at an angle of 70°. In township 30 W. the ridge becomes low and it disappears in section 21, the northwest quarter.

Hannah Mountain anticline.—The south monocline forms a high synclinal peak as it comes from the north side of the Tall Peak ridge in township 28 W., section 20, northwest quarter. From this syncline the strike of the monocline is nearly northwest, and it steadily decreases in height. A small stream flowing southwest has cut a gorge through the ridge in township 29 W., section 13, southwest corner. The ridge is a high one on the west side of the gorge, and in the west central part of the section a high divide of the underlying shales connects it with a high peak just north. This high peak is an elevation of the north monoclinal ridge of the Cossatot anticline, and the connection of the two ridges by the high shale divide resembles the connection at the eastern end of the great anticline beginning just west of Tweedle Mountain. It cannot be considered, however, that the anticline is yet closed. The south monocline is again cut in section 15, northeast quarter, and the anticline is breached for about two miles. Just west of this cut the two monoclines unite, forming a closed anticline in East Hannah Mountain, the highest peak of the novaculite area.

A profile section across East Hannah Mountain, just west of the high peak and including the next mountain ridge on the north side, is introduced here (fig. 4) to show the character of the folds and their reference to topography more clearly than can be seen in the sections shown on the Mt. Ida sheet of the accompanying map. This section was made by Dr. R. A. F. Penrose, Jr., to illustrate the position of the manganese bed in the novaculite series, and to explain its repetition on bot sides of the ridges. Since the manganese bed is constant throughout the novaculite area, it is very useful in determining structure. Thus the section shown has a general application to anticlinal ridges.

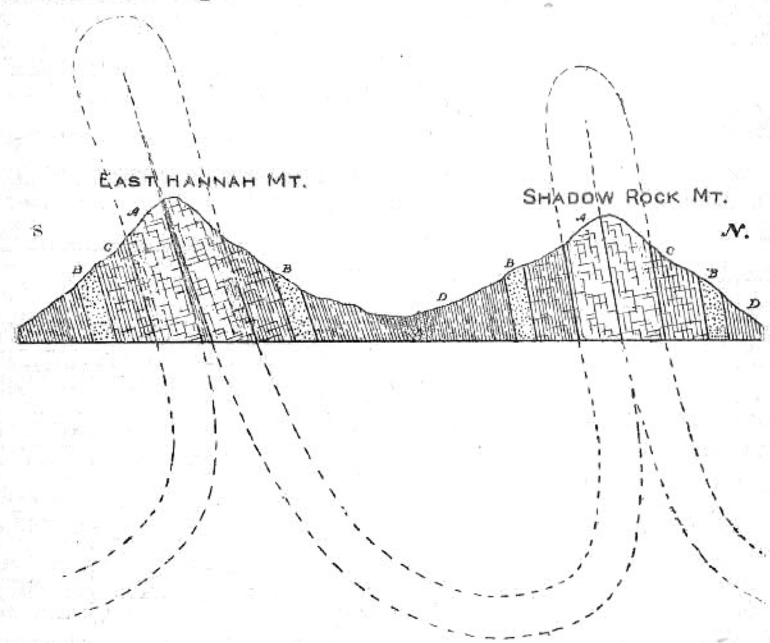


Figure 4. Section through East Hannah and Shadow Rock Mountains.

The Hannah Mountain anticline has the south dip of the novaculites reversed to 60°–70° north. The ridge is high and also broad when not breached, though two branches of Straight Creek on the north side have cut considerable valleys in the soft shales lying between the novaculite walls. On the west side of the Cossatot River the anticline supports West

Hannah peak, a mountain somewhat lower than the East Hannah. A depression follows, succeeded by another peak lower than the West Hannah and known as Rachel Mountain. This is situated in township 4 S., 30 W., the middle of section 10. The decline of the ridge toward the west is gradual from Rachel Mountain, and the direction changes to north of west. Before reaching Brushy Fork in section 5 the sandstones cover the novaculites. The anticlinal nose from East Hannah Mountain to Brushy Fork is between eight and nine miles long.

The north monocline.—From the north side of East Hannah Mountain the ridge marking the northern side of the Cossatot anticline extends away toward the east. The direction is at first south of east through the high peak already mentioned as being situated in township 4 S., 29 W., section 13, northwest quarter. A mile or more farther east and following a slight depression, is another somewhat lower peak connected by a high divide with the Shadow Rock Mountain ridge just north of it. This divide does not represent a syncline, however, but merely owes its existence to the peculiarities of erosion on two ridges closely jammed together, the strata of the northern one being overthrown. The usual syncline connecting the parallel ridges lies a mile farther east in township 4 S., 28 W., section 17, southwest quarter, and is separated from the last peak by a gorge cut by small streams. A synclinal ridge extends half a mile southeastward from the curve and ends abruptly as most of the synclines do.

Shadow Rock Mountain.—The north side of this syncline forms the south side of the Shadow Rock anticline. This mountain throughout its extent across township 4 S., 29 W., is a fine example of an anticlinal ridge, having an evenly elevated straight back, very steep slopes, with projecting ledges forming the crest. The dips are either vertical or reversed to north; the western termination in 4 S., 30 W., section 1, southeast corner, is a sharp one. The entire length of the anticline is eight miles. The structure of this ridge is shown in figure 4.

Leader Mountain.—The north side of Shadow Rock anticline, which has here become the north monocline, only extends a mile and half before it is interrupted by a gorge through which a stream flows southward. East of the gorge a synclinal mountain trending southeast and called Leader Mountain, is the remnant of an old synclinal trough, the rest of which has been cut away, leaving Leader Mountain in a position similar to that of Prior and Blalock Mountains, though unlike these mountains, Leader is one continuous ridge; besides, it does not show clearly the synclinal structure, the dips being vertical. In township 4 S., 27 W., between sections 19 and 30, near the west line the direction of the mountain changes to east-west. The east end of the mountain consists of a knob on the east side of the Little Missouri River in section 28, northeast corner. At the western end of the Leader Mountain syncline, the north side of the syncline is folded into an anticlinal ridge extending a little more than two miles north of west. As the north side of this anticline at the east end is partially cut by a gorge just as it becomes separated as the north monocline, Leader Mountain is left as an isolated ridge composed of a syncline at one end and an anticline at the other, the whole being nine miles long.

Briar Creek Mountain.—The gorge just mentioned as isolating Leader Mountain on the north side, is in 4 S., 28 W., section 15, southwest quarter. From its east side the north monocline continues in a south of east direction in Briar Creek Mountain. The crest of this ridge is pretty even and the ridge is high, though Leader Mountain is perhaps higher still. The dip in this western part of the ridge is overthrown to south 80°, and the strike of the ridge changes often, depending in a measure, on the changes of the dip. In township 4 S., 27 W., section 21, northwest quarter, it swings sharply to a southeast direction. The Little Missouri River cuts through the ridge in the southeast quarter of the same section. At this cut the dip on the west side is steep to the southwest; on the east side the dip appears to be north from 60° to 70°, the outcrops on this side, however, are considerably obscured, and the fact that farther east, the dip varies between 40° and 62°

south, renders this observation doubtful. It is entirely possible, however, that the dip on the east side is north, and that there was a local fault that has afforded a line of weakness for the attack of the stream. The sharp change in the direction of the ridge to east on the east side of the river, shows at least a sharp bend.

Sulphur Spring Mountain.—The continuation of Briar Creek Mountain, east of the Little Missouri is much lower and more uneven in elevation than it is west of the river. This may be owing partly to the great overthrow which this part of the monocline has undergone, and partly to local changes in the character of the beds, which here seem to be less massive. In township 4 S., 26 W., section 30, western part, a small stream has cut north through the ridge. The drainage belongs to the South Fork of the Caddo. A mile east of this cut is the first eastward plunging anticlinal nose of the north monocline. This is a very sharply sloping nose and is overthrown southward. There is no anticlinal ridge, as in the case of the westward plunging anticlines, for the monocline immediately turns in a syncline. The anticlinal nose and synclinal spoon are closely jammed together, and form the high peak called Sulphur Spring Mountain, named from a chalybeate spring on its southeast side. Westward from this mountain extends a high, but irregular ridge of the underlying rocks. This ridge sinks in the western part of section 30, but rises again in 4 S., 27 W., sections 25 and 26, where there are two ridges separated by a hollow. The dips of the rocks in these ridges or peaks are steep and their structure is not apparent, but it can safely be inferred that they are relics of an old synclinal trough.

From the syncline making the south side of Sulphur Spring Mountain, the monocline is immediately folded in another very sharply plunging anticlinal nose. The syncline following does not make a deep curve, so that the last nose does not appear prominently on the map. Indeed, these last two folds are scarcely more than flexures in the vertical monocline, since their axes are in a nearly vertical position instead of the more nearly horizontal one which these folds have normally. A

short distance south from these flexures the monocline continues on its general east course, and comes to an end in township 4 S., 26 W., section 33, northeast quarter. Between this point and the west end of the north monocline as it comes from Tweedle mountain, is an area about a mile wide, across which there are no topographic prominences to aid in the interpretation of the structure. The dip of the rocks in the ridge on the east side of this gap has already been stated to be an overthrow to 40° south; in the ridge on the west side it is almost east, which corresponds to a north dip, from 30° to 60°. There was evidently then, a twisting and jamming of the strata here, which resulted in a weak place, and the streams have taken advantage of this weakness and eroded away the the novaculites, leaving only low ridges.

The folds of the Cossatot anticline.—The completely closed Cossatot anticline thus traced through its many small synclinal and anticlinal folds presents as a whole some interesting features. The most striking one is the existence of ten long anticlinal ridges reaching west at the west end of the area with only three short anticlinal noses at the eastern end to correspond. Had the folds been continuous we should have expected an equal number at each end; as it is, it is clear that either several of the western folds became united in the now eroded part of the anticline, or else that the eastern folds were formed at an elevation higher than the present mountain tops. It is probable that both causes existed, that toward the western end anticlines united as they do in the Trap Mountains, thus reducing the number of folds, while the evidence of high folds at the eastern end is possibly indicated by the frequent changes in the direction of the north monocline.

Underthrown folds.—Less apparent but much stranger features are the generally reversed dips of the two monoclines, which thus give the section across the anticlinal area the fan-like form. This case is different from the one in which a single anticline is involved and the structure can be explained as the natural bulging at the apex of a fold made by the pressure producing the overthrow for here both dips are reversed. It is not possible that opposite overthrowing pressures could have acted in such a very short distance; it is not probable that there were two opposite pressures squeezing the anticline at the bottom; pressure from one direction is sufficient to explain the condition of affairs if it is supposed that it acted at a low elevation on the side from which it came, underthrowing the strata on this side, then on the farther side acting at a relatively higher elevation overthrowing the second dip.

With this explanation all the phenomena of folding in the novaculite area can be explained by the pressure and movement from the south supposed to have been active in the case of the Trap Mountains. The numerous anticlines among the Trap Mountains and elsewhere which have the normal south dip reversed to north are explained as underthrows, and do not necessitate the existence of an overthrowing force from another direction.*

Direction of the crushing movement.—It may be asked why the idea of a movement from the south rather than from the north has been adopted, if reversed dips are common in both directions. No positive evidence of movement in either direction has been found in the novaculite area, but the folds decrease in sharpness to the north, so that in some places even south of the Arkansas River the strata are horizontal, while to the south the beds continue to be highly contorted. This pressure from the south corresponds with the southeast to northwest movement in the Appalachian folds with which the folds of this area are correlated.

Relation of folding to denudation.—The following deductions are made from the existence of both north and south reversed dips in the same small area. On the assumption that the movement was from the south, the reversion of south dips to north ones represents a relatively lower movement in the earth's crust than the simple overthrowing of the north dips to the south ones. The hypothetical projection of sections made in

*The character of the folds in the Cossatot area and their relations to one another are illustrated in the sections laid upon the Mount Ida sheet of the map accompanying this volume.

the area indicates that the vertical distance between these two planes of movement varies from two thousand to five thousand feet or more. It is not intended to convey the idea that these are two actual planes of separate movement, but merely that at different relative elevations in the mass crushed the horizontal movement differed in amount. That is to say, at various places there were points where the movement was retarded; if the point of resistance was relatively low down in the folding mass the result was an overthrow; if relatively high, an underthrow. We can thus assume that the south dips reversed to north were caused by resistance at the top of the fold. Such resistance involves the presence of massive overlying strata also involved in the folding and less easily moved than the lower parts of the novaculite folds. It seems more natural that the greater movement should be at the top, where the pressure of the overlying mass of strata is less; but in the case of the novaculites the deeper movement was rendered easy by the presence below of a considerable thickness of graptolite and other shales which furnished good sliding planes and were easily crushed to conform to the bends of the novaculites. From the conclusion that massive strata belonging to the overlying Lower Carboniferous series furnished the necessary resistance for the underthrowing process, it is obvious that the folding of the novaculites was completed before the surface of erosion had approached the tops of the folds, since a large thickness of strata would be necessary. Thus the evidence is that probably all the novaculite folds were actually in existence and completed before erosion had exposed this horizon of rocks. The great thickness of the overlying strata renders this supposition entirely probable.

The deductions thus made are entirely in accordance with the views expressed in the paper by C. W. Hayes,* that the result of horizontal pressure upon a rigid stratum is folding when the superincumbent load is great and faulting when the load is small.

Outlying anticlines of the Cossatot range. Fancy Hill anti-

*Bul. Am. Geol. Soc., Vol. II, 1891, p. 151.

cline.—Included in the Cossatot Mountain system also are some anticlines lying north and northwest of the Cossatot anticline. These begin at the east with the Fancy Hill in township 4 S., 26 W., section 37, northwest quarter. The nose of this anticline has been cut away by the South Fork of the Caddo and the bare ledges show clearly a sharp anticlinal structure which gave rise to the name Fancy Hill. The ridge rises to a height of 500 feet or more and trends north of west. An affluent of the South Fork has cut through the ridge in the northeast corner of section 29 and the southeast quarter of section 20. Half a mile northwest of this gorge the direction of the ridge changes to west. In township 4 S., 27 W., section 24, north half, another branch of the South Fork flows north through a gorge in which the rocks are well exposed. The columnar section of the rocks at this locality is given in page plate III. The details of the section are as follows:

Overlying sandstone and a little shale......	80 feet.
Novaculite..............................	8 "
Argillaceous sandstone..................	3 "
Novaculite..............................	60 "
Shale, chiefly gray and blue..............	115 "
Shale (?)...............................	60 "
Shale	15 "
Siliceous shale and novaculite............	150 "
Novaculite..............................	150 "

Two miles further west, in the northwest quarter of section 22, the Little Missouri River gorge interrupts the continuity ity of the ridge. The direction from here changes again to north of west, and the ridge unites with the south side of Sugar Tree Mountain, which rises in sections 17 and 18. Sugar Tree Mountain is one of the highest points in the novaculite region, nearly approaching the elevation of East Hannah Mountain. The highest point is at its east end, and it declines gradually to the west. It is formed by the union of the Fancy Hill anticline with another anticline rising in township 4 S., 27 W., section 16, northwest quarter. The jam resulting from the union of these ridges has the south dips reversed. The north anticline soon separates from the south one in the northern part of section 18, taking a direction north of west and having the name of McKinley Mountain. Sugar Tree Mountain ends on the west side of section 18, at the Long Creek gorge. The broad, high anticline that forms the ridge, however, continues on the west side of the creek under the name of He Mountain. The ridge continues broad and high for three miles when it almost disappears, but rises again in a much lower ridge. The head waters of Long Creek cut across a depression in this ridge in township 4 S., 28 W., section 8, southeast quarter, and it again re-appears, but disappears entirely in township 4 S., 29 W., section 12, northeast quarter. This is the end of the original Fancy Hill anticline, which in its length of sixteen miles, is broken by five gorges.

McKinley Mountain is cut by Straight Creek in township 4 S., 27 W., section 7, southwest quarter. West of the gorge the mountain rises gradually as it continues steadily in a north of west direction across township 4 S., 28 W., its elevation reaching 900 feet or more. In the west part of this township and the eastern part of 29 W., there is a slight change toward a west trend for a few miles, when it turns north of west again, and is cut by the Cossatot River, in township 3 S., 29 W., section 32, southwest quarter. The anticline is depressed here, but rises rapidly to the northwest to a high peak called the Bald Eagle, which is nearly as tall as East Hannah. It has a broad flat top, showing a synclinal structure and divides toward the west into two anticlinal ridges; thus the peak is the result of the union of two anticlinal ridges. The southern one of these two ridges is scarcely more than a nose. Its length is about half a mile, and it disappears in township 3 S., 30 W., section 25, southwest quarter. The northern ridge continues strong and high in the same general north of west direction, till in township 3 S., 30 W., section 22, northwest quarter it divides to the west from a high peak. The two ridges resulting seem to be the sides of the anticline which here widened out and was breached. The south ridge is much the higher, and a peak rises where the two reunite between sections 17 and 20; the drainage of the breach escapes through a gorge in the north ridge in the southeast quarter of section 17. The course of the anticline from here to the end is nearly due west, and the western nose is in township 3 S., 31 W., section 14, southeast quarter. The entire length of the McKinley Mountain anticline is about twenty-five miles. If the anticline were considered as continuous through the Sugar Tree Mountain jam, the total length would be between thirty-two and thirty-three miles.

South of the western end of the McKinley anticline are several short, isolated, anticlinal ridges. One of these is very closely connected with the western end of the McKinley anticline by a high novaculite divide in township 3 S., 30 W., between sections 20 and 21. The eastern end of the anticlinal ridge rises abruptly between sections 21 and 28. The ridge is high and spreads out widely and is considerably breached on the south side in the southern part of section 20. It is cut by a stream in township 3 S., 31 W., section 24, and is continued on the west side by a ridge half a mile long. Its length is about four miles.

A high divide also connects the eastern end of this anticline with another one just south of it called Ward's Mountain. This divide, like the last one north, appears to be a high, closely pressed syncline of novaculite. Ward's Mountain seems to be an anticline with a low dip on the north side and forming the top of the ridge. Low dips, 0°, 25°, and 45° were the observations taken. Such dips are unusual in novaculite anticlines and may here be attributed to the existence of the high syncline on the north side, for the 45° dip was the farthest west, and it is in this direction that the syncline is plunging. The dip on the south side of the ridge is steep. Apparently the change from the flat position of the rocks on top of the ridge to the steep south dip caused a line of weakness in the ridge, for the south side is several times broken. The mountain divides also at its eastern end on the west side of Brushy Creek. Each arm of the division is continued by a ridge on the east side of the creek. The ridges are approximately parallel and trend south of east; both terminate in Fodder Stack Mountain in sections 35 and 36, though the connection of the northern ridge of this peak has been considerably obscured by erosion. The Fodder Stack is a remarkable peak; it is almost as high as Bald Eagle peak and it has very uniform slopes of 30° on all sides; its top is a sharp point, scarcely more than twenty feet across. Seen from East Hannah Mountain the Fodder Stack resembles a perfect volcanic cone. It is actually an anticlinal nose that has been sharply squeezed, and has maintained itself while the anticline has been breached to the west and the two arms much eroded away. The Fodder Stack anticline, including Ward's Mountain, is six miles long. Between the north side of this anticline and the west end of the short anticline coming from Bald Eagle in the southwest corner of section 25, is another sharp conical peak of novaculite. This peak connects with no ridges, but as one axis is rather longer than the other, it seems to be an anticline which projects as a point. There is a similar conical peak, though not so high, in the southwest corner of section 36.

The last of this group of anticlines, a ridge between 200 and 300 feet high, rises in township 4 S., 29 W., section 36, southwest corner. The dips in the gorge here are 82° north and 80° south, showing the anticlinal structure well. Another southward flowing stream cuts the ridge in the southwest corner of section 35. From here the ridge is unbroken to the Brushy Fork of Cossatot, where it ends. Its entire length is four miles.

THE INDIAN TERRITORY MOUNTAIN SYSTEM.*

About five miles southwest from the westernmost points of the ridge south of Tall Peak ridge, known as the Twin Mountains, rises the eastern nose of a ridge called Cross Mountain, and belonging to another system of novaculite mountains. This is in township 5 S., 31 W., section 2, northeast quarter. The ridge rises gradually with a strike due west. A deep gap,

*The observations upon the Indian Territory system as here described were made by Mr. James Perrin Smith, one of the assistants of the Survey.

probably representing an old stream channel, divides the ridge in section 5, northeast corner. It regains its former height west of the gap, keeps it for over a mile and falls away as gradually as it rises. The ridge has its south dip underthrown to north for part of its length; it is as low as 40°. The length of the ridge is five miles and its greatest elevation is 400 feet above the valley.

South of the western end of Cross Mountain, in township 5 S., 32 W., section 1, south part, the novaculites appear at the surface in two short east and west anticlinal ridges. In the southwest corner of the same section a stronger ridge rises with a west course, and continues on the line between the two northern rows of sections of this township. Between the southwest quarter of section 3 and northwest of 10 a small stream divides the ridge. Just west of the gap is Potato Hill, the highest elevation in the vicinity. It is about 450 feet high; the rest of the ridge is not more than 400 feet.

Almost parallel with this ridge and a mile south of it extends the South Mountain, whose eastern end rises on the west side of West Creek between sections 11 and 14. Its direction is west for two miles, then south of west; its general elevation is about 400 feet. The ridge is cut by a stream in the northwest corner of section 16, where the anticlinal structure is clearly shown.

The novaculites of these ridges do not appear so massive as those of the Cossatot Mountains, but this may be because the the lower massive novaculite beds have not yet been uncovered by erosion. Both the Potato Hill ridge and South Mountain extend westward into Indian Territory, where their western ends are lost in a confused mass of much higher ridges and peaks, which extend westward as far as the eye can see.

CHAPTER XIV.

DETAILED GEOLOGY OF THE NOVACULITE AREA.—*Continued.*

THE OUACHITA ANTICLINE.

Having obtained an understanding of a new anticlinal area with simple breached anticlines as exhibited by the Trap Mountain system, and having seen what the result of erosion is on a similar area which has been longer exposed to denudation in the review of the Cossatot anticline, it is now easy to understand a similar anticline that has been very much more eroded in consequence of greater elevation. The features and divisions of the Ouachita anticline have already been given, and it remains to give the details of outline as shown by the novaculites, with such details of structure in the underlying rocks as have been collected.

The Caddo Mountain Range.

Close to the north side of the Cossatot Mountain system lie the ridges of the Ouachita anticline which have been separated as the Caddo range of mountains. The Caddo range for the greater part of its length consists alone of the south monocline of the great anticline doubled and twisted into numerous anticlinal noses and short synclines; but for about twenty miles from its western end it is made to include, rather arbitrarily, depending on the topography, some ridges belonging to the north monocline as well as the anticlinal termination of the great anticline.

As is usually the case with the novaculite anticlinal areas, several isolated anticlines form the final termination of the system. The most western of these is the one that sinks below the overlying sandstones just west of Potter in township 2 S., 31 W., section 28. At the western end of the ridge the strike of the rocks is north 40° west and the dips are steep. Erosion has given the ridge the appearance of having a strike north. The northwest end is not very high and is rather irregularly eroded; to the southeast, however, it rises rapidly to a height of several hundred feet and also spreads out widely as it rises. The strike swings nearly to east and west. It has been deeply cut in several places by ravines. Through the high gap made by one of these ravines in township 3 S., 30 W., section 6, northwest corner, passes the trail from the Brushy Fork of Cossatot to Dallas. Here are shown a south dip of 60° on the south side of the ridge, and a north dip on the north side. The ridge may be said to end in the southeast quarter of section 5, for here in a high divide it loses its identity as a ridge.

On the north side of this ridge in the northeast quarter of section 6, also in township 2 S., 30 W., section 31, southwest corner, and in township 2 S., 31 W., section 36, southeast corner, a short and lower anticline is closely jammed. This has been cut in two by a spring branch of Prairie Creek between sections 31 and 6, the head of the branch being at the gap noted in the ridge just south. The way in which these ravines head together is peculiar, and suggests that they were formed by the remnants of an old stream that had its course through the gap.

Closely jammed against the southeast end of the first ridge is a broad, high mountain, about a mile and a half long, also presumed to be anticlinal. This is probably the mountain known in the neighborhood as Two Mile Mountain.

A little over a mile west of this mountain rises the sharp peak of Blowed Out Mountain in township 3 S., 31 W., sections 1, 2, 11, and 12. The eastern end of this mountain in its symmetrical shape and steep slopes, resembles very much the Fodder Stack peak near Rhode post-office. It is believed by some of the people of the neighborhood that part of this mountain was once blown off by volcanic action. No igneous rocks were found thereabouts, however; the peak is an anticlinal nose which rises very abruptly from the overlying rocks. The ridge extending from the peak is short, with an axis pointing nearly northwest. Owing to the peculiar way in which the anticlinal nose spread out as it was squeezed upward, a stream that started to breach the fold from the west side has been working back toward the peak, forming a diagonal cut across the novaculites, a very uncommon occurrence. The erosion of the overlying sandstones also helps to give the idea from the topography alone that the anticline has two noses plunging westward.

The highest of these ridges and peaks south of Dallas are given elevations of 600 to 800 feet above the valley levels by the maps of the U. S. Geological Survey. The elevation of 1000 feet for East Hannah Mountain seems relatively too small in comparison with these elevations.

The western nose of the great anticline also rises in this group of ridges, forming the most northern and reaching within two miles of the western nose at Potter. It rises in township 2 S., 31 W., section 26, southeast quarter of the southwest quarter. The anticlinal structure is clearly shown by dips of 45° either way from the sides of a rather low anticlinal nose. The upper Ouachita statum of the novaculite series about this anticlinal nose has a particularly spongy appearance. It contains many cavities which are very suggestive of brachiopod forms, but in view of the fact that the rock is full of concretions and concentric shells of dense and porous layers undoubtedly formed by concretionary action, it seems more probable that the cavities are traceable to the same action.

The ridge extends eastward, broadening and increasing in height. The dip grows steeper on the north side, and two branches have cut back into the ridge and have eroded out small strike valleys. In section 25, the southwest quarter of the southeast quarter, the north dip becomes overthrown to a steep south one, the north side of the ridge changes direction from east and west to southeast and northwest, and the ridge becomes narrower, though still maintaining its elevation of about 400 feet. In township 2 S., 30 W., section 31, the ridge falls off as it approaches the gap made by Prairie Creek at Bethesda Springs. The dip is here 60° S., 25° W., and the ridge has the appearance of a monocline. The ridge is continued on the east side of Prairie Creek by a knob called Observatory Mountain. From this knob the direction of the ridge changes suddenly to south, and is considerably broken by erosion; it is nowhere very high. The south course is only for half a mile, when it changes to southeast and then to east. In township 3 S., 30 W., section 4, south part, at the cut made by Carter's Creek, the dip on the east side is 75° south, while on the west side it is 40° south. Thus the overthrow of the anticline continues, appearing like a monocline, and here on Carter's Creek shows clearly the effects of one of the sudden twists in the structure which are common in the area. That the stream took advantage of the weak place caused by the twist is a noteworthy fact.

East of Carter's Creek the ridge is much stronger for a mile and a half, in which distance its course is due east. In township 3 S., 30 W., section 2, southwest quarter, the direction changes to southeast and the ridge becomes low again owing perhaps to the local depression of the anticline, or perhaps to the weakness caused by the overthrow, the dip of 45° south being a common one. This part of the ridge in sections 2, 11, and 12 of 3 S., 30 W., is cut four times by small streams flowing northeast.

Board Camp Creek makes another cut through the ridge in 3 S., 29 W., section 18, northeast of the northwest quarter. The dip here is vertical, though it is slightly south on the east side of the cut. This is the locality of the "Standing Rock" described by Owen and illustrated in the frontispiece of this volume. There is a ledge of novaculite consisting of a single stratum four feet thick, which rises perpendicularly from Board Camp Creek on the west side to a height of seventy-five feet or more. It affords a splendid example of the resistance of novaculite to weathering. Corresponding with it on the east side is a broken ledge called the "Devil's Pulpit."

The structure of the ridge, according to the evidence of the anticlinal nose at its western end, should still be anticlinal; but the massive bed so clearly defined in the "Standing Rock" is not found a second time in the section on this creek. The

ridge appears more like a monocline, yet the conclusion regarding it must be that it is an anticline with the north side eroded away.

The ridge is higher again on the east side of Board Camp Creek, and the direction changes more to the east. The ridge rises gradually for over a mile, when it presents a pretty sharp slope to the east, then continues at a lower elevation. A high divide passes over to a parallel ridge lying north. This high divide pretty certainly represents the syncline beginning the north monocline of the great anticline, but the usual anticlinal peak is wanting, or at least is poorly represented by the increased elevation and abrupt eastern slope of the Board Camp ridge. The novaculites in this northern ridge are much less massive than in the ridges south, and the formation is weaker, as shown by the presence of only one massive stratum at Standing Rock, where, ordinarily, there is a large thickness of massive beds. This will explain the absence of an anticlinal peak in the eastern part of section 17, where the monoclines become distinct as ridges.

The north monocline.—The high divide from the Board Camp ridge swings into the south side of an anticline in the northeast corner of section 17. This ridge strikes considerably north of west. It is cut by Board Camp Creek in section 7, northwest quarter, and the anticlinal structure was here distinctly observed by Mr. Smith. The ridge is low here and soon disappears to the west. From its eastern end the monocline takes a south of east direction. Near the center of section 16 it is interrupted by a gorge, and a second gorge breaks it in the south central part of section 15. East of this gorge there is a sharp synclinal turn sending a monocline back northwestward and continued eastward by a synclinal ridge between six and seven miles long. This ridge is twice interrupted, first, by Mack's Creek in the southeast of section 14; second, by a wide gap in township 3 S., 28 W., section 21, the northwest quarter. The ridge ends in the extreme south central part of section 15; the ending is the typical synclinal one, though the steep dips do not indicate the structure.

The monoclinal ridge last mentioned has a pretty direct northwest course, but there was formerly a high fold in it, which produced the synclinal ridge extending eastward from the northern part of section 15. The monocline runs into an anticlinal nose which ends in the northeast quarter of section 8. The anticlinal peak is in the south central part of section 9, where a high divide connects with the next ridge north. The synclinal ridge last mentioned is cut by Mack's Creek in the northeast quarter of section 15, and here shows the evidence of the synclinal structure, for the novaculites of the ridge top are not exposed in the creek bed, but, instead, the underlying graptolite shales are found. The inclination of the strata here, as in many other places, does not reveal the structure for the dip is north only. This synclinal ridge extends eastward with a pretty even back for three miles. In township 3 S., 28 W., section 18, east central part, a branch of Mill Creek breaks the ridge. Another branch of the same creek breaks it again in the east central part of section 17. Massive beds of novaculite are here cut by the stream, but they clearly owe their existence at this lower level to a depression of the syncline rather than to an anticlinal or monoclinal structure. The strike of the ridge changes to a little north of east, and the ridge ends abruptly in section 16, northwest quarter. The ending is clearly synclinal according to the evidence of the underlying rocks which form the base of the ridge; the novaculites on top show only a dip north of 61.° This synclinal ridge has a length of between five and six miles.

The ridge connecting with the section 9 divide of 3 S., 29 W., on the north side, has a more northerly direction than the others of this group, and is generally lower. It ends in section 5, southeast quarter. Like the ridge just south it appears to have been crushed in a high synclinal fold, which is cut by Mack's Creek in the extreme east central part of section 9. East of this gap the ridge is continuous for three miles, in a direction a little south of east. A small branch of Mill Creek flowing south has cut it in township 3 S., 28 W., section 18, northeast quarter. The dip is here 50° north. In the northwest quarter of section 17, is the Mill Creek gap; the dip here is north as usual. The ridge continues east of the gap but grows weaker; a gap of over half a mile follows with a short continuation in the southeastern part of section 9. The finding of graptolites on Mill Creek in section 8, on the north side of the ridge, in what are clearly the underlying shales, and the chopped up condition of the ridge, give evidence of its synclinal structure in spite of the fact that the only dips seen are north. In the vicinity of the eastern end of this last syncline, to the north, east, and southeast, are numerous short ridges that stretch east and west as a rule, and are surrounded by the underlying shales though capped by novaculite. Undoubtedly they are remnants of old synclines though north dips prevail.

The north monocline when last mentioned formed the northwest and southeast ridge in the northern part of section 9, of 3 S., 29 W. This ridge ends in an anticlinal nose in the east-central part of section 5. The monocline extending back toward the east does not show in a prominent ridge till the east side of Mack's Creek is reached. At this point, the southeast corner of section 4, the novaculites have a dip north of from 60° to 80°, and form a sharp ridge extending in a north of east direction. From this point the low ridges of the great northern monocline separate distinctly from those thus far described as belonging to this part of the structure, so here is arbitrarily made the dividing place between the Northern Range of mountains and the Caddo Range.

The south monocline.—The ridge forming the continuation of the Board Camp ridge from the eastern part of section 17, township 3 S., 29 W., represents the beginning of the southern side of the Ouachita anticline. The dip which should be south is underthrown to north. In the south-central part of section 16 a small branch of Board Camp Creek has cut back deeply into the ridge, making it still lower at this point. As the ridge continues south of east, however, it becomes stronger and overtops the ridges lying north. The dip remains north varying between 40° and 60°, though sometimes steeper. In section 23, southeast quarter, a small branch of Mack's Creek has broken down the ridge. Half a mile east, in the southwest quarter of section 24, the ridge rises to a peak that swings through the south to the west, clearly a synclinal curve. The ridge extending westward forms the north side of an anticline which is breached for a few miles at the eastern end. This ridge is cut immediately in the southwest corner of section 24 by the same branch of Mack's Creek that cuts the ridge north. The dip is 40° north. The course of this small stream is a strange one, cutting as it does twice through the novaculite rocks, when it lies in the natural drainage basin of Board Camp Creek instead of Mack's. It is undoubtedly the remains of an old superimposed stream, and the position of the divides between it and Board Camp Creek shows that the Board Camp drainage is gaining.

Board Camp Creek cuts the north side of the anticline in the south part of the southeast quarter of section 23. Here the dip is low to the north. It is again cut in the southwest corner of section 23 by a branch of Board Camp. The Board Camp valley, as it extends north of west, between this north side of the anticline and the Board Camp monocline, previously described, is a narrow one. The dependence of the elevation of these ridges, particularly the northern one, on the position of the stream in the valley is noticeable, depressions in the ridge crests occuring as the stream cuts into the base of either ridge. West of the cut in the southwest corner of section 23, the north side of the anticline forms a stronger ridge; in the south part of section 21 it joins the south side of the anticline, forming Kirkendall Mountain. On the west side of section 21 Kirkendall Mountain is again separated into two ridges by a branch of Gap Creek. The main creek cuts squarely across the anticline in the northeast corner of section 19, and and through this gap passes the Dallas road. The sides of the anticline join soon on the west side of this gap, and the mountain rises gradually to a high peak in 3 S., 30 W., section 11, middle of the section. The direction, which has been northwest, changes to west; the mountain slopes off and ends in an anticlinal nose terminating in section 10, northwest quarter. The

anticlinal structure of Kirkendall Mountain is clearly seen in the Gap Creek section; here the dip on the north side is 55° northwest, and on the south side 45° to 60° southwest. Farther to the east the south dip becomes underthrown to a steep north dip. As in the case of the north ridge of the Kirkendall anticline, the southern one is twice cut by the headwaters of Board Camp Creek. In township 3 S., 29 W., section 25, northwest quarter, and section 24, southwest quarter, the two sides of the anticline come together; on account of the local weakness of the formation the resulting single ridge is not so strong as might be expected. The total length of this anticline is about ten miles.

After the south side becomes distinct as a monocline between sections 24 and 25, the ridge rises higher. In a peak near the township line it is seen that the dip has returned to the south here 80°. The monocline pursues a somewhat wavering course a little south of east into township 3 S., 28 W., the dip becomes north again and the strata are almost completely underthrown to a horizontal position. Another sharp syncline follows in section 29, east central part, and the monocline becomes the north side of another anticline running west. This anticline is cut and considerably breached by the headwaters of Board Camp Creek in the middle of section 30. The nose of the anticline extends into township 29 W., to near the center of section 25, giving a length of a little over two miles.

Fork Mountain.—The south monocline again becomes distinct in Fork Mountain, a high ridge with an irregular crest. The peculiar character of the top of this ridge seems to be due to the great underthrow of the strata here, which have a north dip of 20° on the top of the ridge, but become steeper on going down the north side. In consequence of this reversion of the strata we have the underlying shales forming in some places the highest part of the ridge, and apparently overlying the novaculites. The synclinal turn at the eastern end of Fork Mountain is a clear one though very sharp, and underthrown. The south side of this syncline runs southwest for a mile, as a distinct ridge having northwest dips. It is cut by Big Fork Creek in the northwest corner of section 27.

The Little Missouri Mountains.—In the center of section 33 this ridge joins with the Little Missouri Mountains, which here consist of two parallel anticlines. These anticlines continue westward, sometimes forming practically one, while at others the synclinal fold between the two is deep and has been much eroded. Both anticlines are broken occasionally by the streams draining this syncline. The more southern anticline is first to disappear; it separates from the northern one in township 3 S., 29 W., section 26, southwest corner; a branch of Mine Creek breaks through it a short distance to the west; it rises into a high ridge which is even higher than the northern ridge, but from here west the height decreases and the ridge ends in the southeast quarter of section 29. The northern ridge continues steadily north of west with a high unbroken back to the gap in section 19, already discussed in relation to the Cossatot River, through which passes the Dallas road. In township 3 S., 30 W., the north dip is constantly overthrown to the south. The anticline ends in this township, section 8, northwest quarter, on the south side of Two Mile Mountain, and is jammed against it. This anticlinal ridge is between fourteen and fifteen miles long.

The south side of this anticline becomes the south monocline east of the junction with the south side of the Fork Mountain syncline in township 3 S., 28 W., center of section 33, but jammed with it is the southern one of the Little Missouri anticlines, forming as before sometimes a single high ridge, sometimes two ridges separated by a high, narrow synclinal valley. The direction of strike is now very nearly east and west. The Little Missouri Mountains are everywhere high peaks, but they reach their greater elevation between townships 3 and 4 S., 27 W., where the height is over 800 feet.

In section 33 of the township 3 S., 27 W., a new high ridge starts with an abrupt western ending which was clearly synclinal. This ridge extends due east, the greater part being north of the township line. With it in the western part of

section 35 is joined the south side of another syncline having a synclinal valley that has been hollowed out by erosion. Farther to the east the sides of the syncline are more closely jammed together, and the stream rising in the synclinal hollow cuts obliquely across the novaculites of the south member of the syncline, and flows in the breach of the anticline for two miles of its course eastward. The length of this northern syncline is four miles, the eastern end being in township 3 S., 26 W., section 31, northwest quarter. The original syncline is a broader and higher ridge; it ends in township 3 S., 26 W., section 31, southwest quarter, with a good synclinal ending; it is also four miles long.

State House Mountain.—The structural continuation of the Little Missouri Mountains is found in the ridge south of the high syncline. This ridge forms the westward continuation of State House Mountain in township 4 S., 27 W., the northern half of sections 2 and 3; it is separated from the Little Missouri Mountains in the northeast quarter of section 4, by a branch of Crooked Creek, which here cuts a gorge through the mountain. The section below (figure 5), constructed from observations made by Mr. Smith, who did the entire field work on this part of the Caddo Range, shows that the monocline present in the Little Missouri Mountains has been eroded away on the east side of the gorge. As the mountain broadens to the east, however, it again comes in to form part of the high back of the ridge. The part of the fold which is here wanting, though present elsewhere, is lettered A. The angles of the dips here point conclusively to the existence of a sharp

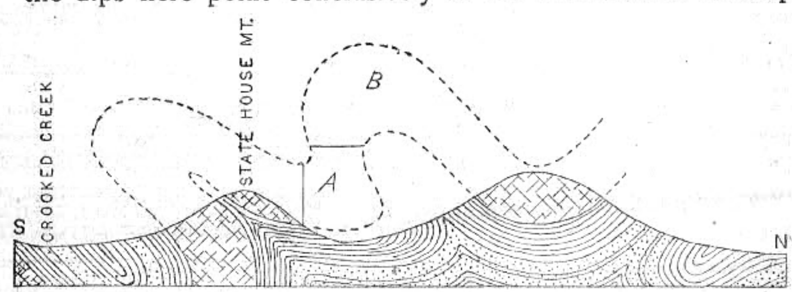


Figure 5. Section across the west end of State House Mountain.

anticlinal fold at B, now completely eroded away, which was considerably underthrown. The State House Mountain anticline is also much underthrown.

The arm of State House Mountain rises somewhat toward the east, until it is in the neighborhood of 1000 feet high in the southeast quarter of section 1, where the monocline again becomes distinct in a very high synclinal spoon. The highest parts of State House Mountain, however, are on the south side of the syncline between sections 1 and 2 before the monocline becomes the north side of the State House anticline, and in the northwest quarter of section 12, where the south side of the State House anticline turns in another syncline into the Cogburn Mountain anticline. The State House anticline is a broad mountain lying in sections 1, 12, 11, 2, and 3. In the north part of section 11 it has been slightly breached by the headwaters of the South Fork of Caddo. It is very short for an anticlinal ridge, being scarcely two miles in length; the western nose slopes off sharply ending in the southwest quarter of section 3.

Cogburn Mountain.—The Cogburn Mountain lying on the south side of State House is an anticline west of the synclinal turn between sections 11 and 12 about on the half mile line, and east of the syncline it is the south monocline again. The Cogburn anticline is cut by the headwaters of the South Fork of Caddo in section 11, south central part. Its direction is very steadily north of west and through its eastern extent it is underthrown so that both dips are north. It is considerably broken by small streams flowing either way from its crest; it is deeply incised by Crooked Creek in the northwest quarter of section 8, and half a mile farther west the Little Missouri flows through another gorge. The ridge beyond this gorge is known as Lost Mountain; it is unbroken for over seven miles; its western end is in township 3 S., 29 W., section 36, southeast quarter. The total length of the Cogburn anticline is twelve miles.

The monocline forming the eastern end of the Cogburn Mountain has the normal south dip. The Black Springs Road

passes over this ridge through a high gap, in township 4 S., 26 W., the southwest corner of section 7. The name Cogburn Mountain is not applied to the ridge east of this road. In the south central part of section 7 there is a sharp turn to the north and then the ridge swings again to the east; the turn is a syncline spooning out west; the anticlinal nose of this turn is represented by a short lower ridge ending in the southeast corner of section 7. A small branch has cut across this anticlinal nose near the synclinal turn, giving it an isolated position topographically. The direction of the ridge from the synclinal turn is south of east; the ridge is everywhere high, being between 600 and 700 feet; in section 16, northwest quarter, there is a rise to 800 feet. In section 14, western part, the monocline turns south and west into the last west plunging anticline of the Caddo range.

In the northeast quarter of section 16 there is a curious freak of erosion; the synclinal valley between this last anticline and the monocline just north is drained for two miles by streams flowing toward each other as though about to join and cut a single gorge as a means of escape; instead, however, of one there are two gorges, close together with a very sharp divide between, which projects south from the monocline like a tongue. It is hardly possible that two streams could cut back through such a ridge so near together and not at least reduce to a low level the softer rocks of the divide, represented by the high tongue already mentioned; so it seems evident that these streams are the survivors of older and larger streams; and also from the fact that the anticlinal ridges slope steadily up from the gorges both east and west, it would seem that these streams had been approaching each other as they have been cutting across the novaculites and have been tending toward a union in a single gorge. At the present gorges the anticlinal structure of the ridge is very finely shown. As it continues westward the ridge is again cut in section 18, northeast quarter, by a small branch. West of this cut the ridge becomes lower. The Black Springs road passes up the valley of a small branch, which also transects this ridge near the west line of section 18. Scarcely half a mile farther west, in township 4 S., 27 W., section 13, northeast quarter, there is another gorge. The ridge ends in the northwest quarter of section 13.

Fodder Stack Mountain.—North of the eastern end of this anticline, together with its syncline in township 4 S., 26 W., section 14, is the western end of a high isolated ridge extending east. The western end of the ridge, in the southeast quarter of section 10, has the appearance typical of the synclinal peak; on the southwest side are found the graptolite shales dipping northward 70°. In the southeast quarter of section 11 the ridge divides into two, the northern arm extending in a straight line a little north of east, the southern one a little south of east; the strata of the north arm dip south 70° or steeper, in the south arm the dip is north and decreases toward the east; thus the synclinal structure is clearly shown. Owing to the existence of soft underlying rocks, the more oblique position of the strata on the south side of the syncline has given the best opportunity for a break through the novaculites for the escape of the drainage of the basin of the syncline. The break is in the north central part of section 13, where the dip is 40° north. East of this gorge the direction of the ridge changes to north of east, the dip grows steeper, and the ridge rises. The two arms join in a sharp synclinal curve which forms a high peak known as Fodder Stack; this is the third peak with this name in the southwestern part of the novaculite area. Its elevation is 800 feet or over; the location is in township 4 S., 25 W., section 7, southeast quarter. The maximum length of this syncline is three miles and in its widest part it is but little more than half a mile wide. The strength of the ridges and the complete isolation makes this syncline one of the clearest and most beautiful pieces of geologic structure in the novaculite area.

Broad Top Mountain.—The south monocline continues south of east as a single ridge from the southwest quarter of section 14, of township 4 S., 26 W. In the southwest quarter of section 13 the ridge rises into a very high peak, the highest for some miles around, having an elevation of about 900 feet above the valley. This peak has a flat top comprising several acres of good land; it is the broadest of all the novaculite peaks, and might well be given the name of Broad Top. South of east from this peak extend two ridges. Of these the south one is a very sharp anticlinal nose a mile in length; the north one is the continuation of the monocline. Thus the peak results from a very close jam of an anticline and a syncline. The monocline steadily decreases in height until a high gap is reached in township 4 S., 25 W., section 19, northeast quarter. The back of the ridge is pretty even east of the gap. The dip is generally steep to the south, but is often vertical and sometimes north. In the southwest quarter of section 21 the dip south becomes lower and the ridge sinks slightly, but a peak rises just to the east on the north side of which the dip is found to be north; the north dip swings through the east to the south as the ridge turns in the same direction. The structure involved in this change of dips consists of a short anticlinal nose plunging east with the necessary syncline joining on the north side. The course of the monocline for the next two miles is more nearly east, though the direction is changeable for short distances; thus from an extreme south of east to an extreme north of east direction a difference of 45° was noted. It is possible that this sinuosity of the ridge top represents the beginning of eroded folds like the short anticlinal noses here so commonly represented.

The Gap Mountains.—In the southeast quarter of section 23 there is another higher anticlinal peak with a longer nose plunging east. The dips swing about the syncline as before, the ridge, however, does not continue directly east, but is separated by a small stream valley from a ridge on the north side which represents the south monocline. This north ridge, Gap Mountain, shows vertical, north, and south dips, so that the attitude alone of the rocks does not reveal much in regard to structure. The western ending in the southwest quarter of section 14 is the typical synclinal one; and this fact, together with the dip and strike of the rocks on the south side of the break, makes it pretty evident that the small stream has broken down part of another anticline and syncline in carving its valley. Gap Mountain is a high ridge extending nearly due east. According to the aneroid measurement by Dr. Penrose of this Survey the height of the ridge just north of Caddo Gap post-office is 580 feet above the Caddo River at its base. Just west of the Caddo Gap the monocline is very sharply folded in an anticline and syncline, and the river has cut across the anticlinal nose, as well as the monocline. The dips here seem to be south, so the anticlinal nose is only apparent from the topography and from the reduplication of the thickness of the novaculites. The observations on the strata exposed in this gorge have been formulated in the Caddo Gap section found on plate III. The thickness of the overlying quartzose sandstone here is noteworthy, and the fact that these are so completely worn away while the novaculites rise in high ridges, shows well the comparative resistance of the two to the processes of erosion. North of the monocline the graptolite shales are found in various places.

On the east side of the Caddo River the anticlinal nose is scarcely a quarter of a mile long; a divide connects it with the high ridge of the monocline and makes it appear like a spur of that ridge. The monocline is a high straight ridge running due east with a very even crest. The strata are about vertical, changing to both north and south dips. In township 4 S., 24 W., section 22, northwest quarter, there is a pretty case of a combination anticlinal and synclinal peak. The curve of the syncline is clear and the anticlinal nose is nearly half a mile long. There is another straight stretch east as the monocline comes from the north side of the syncline. As before, the dip swings both ways through the vertical. It runs into the south side of a high anticlinal peak which lies about half a mile northwest of Hickory Station. The dip on the south side of this anticlinal peak is 50° south, and on the north side 74° north. The north side of the peak has been much eroded away and the indications are strong that a stream formerly flowed close

to the north side of the peak at the elevation of the top of the ridge which is here hollowed slightly, forming a high gap.

The south monocline now runs north of west and west with a prevailing dip slightly north. For much of the distance a single massive stratum six or eight feet in thickness forms a backbone for the ridge, sometimes projecting twenty feet above the vegetative portion. In the western part of section 15 the ridge becomes higher, and continues westward with this greater elevation. The western end of the ridge is very abrupt, having the synclinal appearance, and further examination of the structure shows that it is a very sharp synclinal fold. A ridge leaves this one in section 16, northwest quarter, which soon shows a dip northeast as the ridge runs northwest; it is clearly the continuation westward of the south monocline, and its peculiar position with relation to the high south ridge shows that the western end of the south ridge must be a syncline, while the succeeding anticlinal nose is jammed into the eastern part of the ridge to produce its more than ordinary height. The ridges of flinty shales east of Vaut's Mill represent the westward continuation of the high sharp syncline in the underlying rocks.

The monocline starting northwest from section 16 swings more to the west, while the dip decreases. In the extreme east central part of section 7 the monocline bends pretty sharply round to the east, the dip getting as low as 23° east. The syncline is a fine one; the structure is clear, the western end high with a steep slope; there is a partial repetition of the synclinal curve at a much lower level west of the peak in the underlying strata of siliceous shales. From the north side of the syncline the monocline swings to a direction 10° south of east; the strata soon have a steeper dip of 75° south to vertical. In section 10, southeast quarter, the ridge runs into the south side of another anticlinal peak. On the north side of this anticlinal nose the dip is 72° north, but as the monocline becomes a separate ridge toward the west the dip is vertical. The monocline extends westwards scarcely a mile before it swings in another syncline; this is in the northeast quarter of section 9. Like the last one this syncline is broad and open, and no high peak results as when the sides of the syncline are closely jammed together, though as before the western slope is steep. The monocline runs east again from the section 9 syncline, but with a lower dip than usual, 60° being the steepest noted. As the ridge approaches the next anticlinal nose between sections 11 and 2, west quarters, the dip goes down to 45° south. About 150 feet north, across the anticlinal nose, the dip is 67° north. This change within such a short distance gives a fair example of the sharpness of the folds of these massive beds. It should be noted also with regard to these anticlinal noses that while they slope eastward at an angle of 10° to 15°, this is merely the angle resulting from erosion, and the novaculite strata which support the folds dip eastward at angles commonly between 30° and 45°, and oftentimes much steeper.

Following the monocline west from the last mentioned anticline the strata soon become vertical in attitude. In the southwest quarter of section 4 the monocline is broken by a small stream flowing south to the Caddo drainage. This is the first break east of the Caddo Gap, the novaculites furnishing elsewhere a very high narrow divide. As a result of the zig-zag structure of this region, marked by the novaculite divide, the spectacle is presented of streams flowing parallel to each other for some miles, though in opposite directions, and distant from each other scarcely half a mile. Half a mile west of this break in the middle of section 5, the ridge turns in another wide syncline, and again runs east with a south dip. The dip becomes underthrown to north 82°, but swings back again to the south and the ridge runs into the south side of a very sharp peak, the highest peak of the Caddo Range east of the river; the elevation must be between 900 and 1000 feet.

Three Sisters Mountains.—In structure this peak consists of a short anticlinal nose plunging very sharply to the southeast, against the north side of which is jammed the succeeding syncline. The dips are all apparent; on the south side of the peak they are south, on the north side it is steep northeast, while at the lower level of the divide which runs east, it is

south 59°. The syncline of this peak is continued west by a straight ridge, lower than the ordinary monoclinal ridge; it extends west nearly four miles, ending in the northwest corner of section 6. The high peak is situated in the northwest quarter of section 2; it is the westernmost of three high peaks situated near together which are known as the Three Sisters. The south dip noted on the ridge extending east from the north side of the above peak represents the continuation of the monocline. In less than half a mile, however, there is another jam of an anticline and syncline which forms the middle peak of the Three Sisters. This peak is considerably lower than the western one and indeed is the lowest of the three. A rather low anticlinal nose extends east from this peak for about a mile before it disappears. As before, the north side of the syncline is the monocline extending east. In a quarter of a mile it becomes the south side of a broad anticline, the easternmost of the Three Sisters peaks. This anticlinal nose is very symmetrical, having dips low for this region both north and south and plunging gradually to the east. It reaches almost as great an elevation as the western peak. It is situated about on the township line between 3 and 4 S., 24 W., sections 36 and 1 respectively and the nose extends east between sections 31 and 6 of 23 W., 3 and 4 S.

From the Three Sisters to the Ouachita River.—The monocline extends west from the north side of this anticline with a generally low dip. The ridge is considerably broken down and the next syncline in township 3 S., 24 W., section 35, is rather low and obscure. The north arm of the syncline runs east again. It is noticeable now that the eastwardly extended arms of the monocline are much longer than those extended westward. The change in dip of the rocks belonging to the novaculite monocline, even in a simple section at right angles to the strike, is a very common occurrence; thus in ascending the above monocline in township 3 S., 23 W., section 31, southwest quarter, a change was noted from 72° south, at the base of the ridge to vertical at the top. A north underthrown dip is found in this ridge, though farther to the east it becomes 45° south. This south dipping ridge forms the south side of an anticlinal peak which rises in the east central part of section 31. A spur runs northwest from the north side of the peak showing a dip of 42° northeast. The ridge is a continuation of the monocline, but is much broken down here. As it returns east from the syncline in township 3 S., 24 W., section 35, northeast quarter, it is stronger again; the reason for the greater strength of the ridge is found in the steeper dip, which is in this ridge close to the vertical. This ridge extends into township 3 S., 23 W., where it runs about on the line between sections 30 and 31, and 29 and 32. It turns southeast into a high peak in the northeast quarter of section 32. This peak is an anticlinal nose, and from its north side the monocline continues northwest with a dip northeast. The dip swings through the east to southeast as the ridge swings through the north into the south side of another high anticlinal peak in the central part of section 29. A ridge runs northwest from this peak showing the north dip. The direction changes to nearly west and the ridge becomes low. In the northwest quarter of section 30 there is a gap through which a branch flows northward. West of the gap about a quarter of a mile there is a low synclinal peak and from its north side the monocline starts on a straight course north of east for nearly five miles. The rocks frequently stand in a vertical position; at the gap cut by Mazarn Creek in the middle of section 22, the dip is slightly south. The ledges on either side of the gap do not join in a strike line and it is clear that the creek has taken advantage of a weak place caused by a twist in the beds at this point to cut its way across the novaculites. The Dallas road passes through this gap.

The next anticlinal turn is in the central part of section 23. The peak seen at this point is sharp. The north-dipping ridge which runs west from this peak is partially cut by a small branch which rises in the breach of the anticline just west of the peak and flows north and then east; again it is cut by a branch of Mazarn Creek, in the northwest corner of section 22. At the northwest corner of this section there is another syncline, and the ridge turns eastward with a south dip for nearly seven miles. There is but one break in this distance, and that is the Meyer Creek gorge in township 3 S., 22 W., section 16, west-central part. On either side of the creek at this gap there is the unusual occurrence of two strong ridges; of these the northern ones are composed of the massive novaculites commonly found in the monoclines, but the southern ones seem to owe their existence to a local thickening of some of the topmost novaculite beds, reinforced by the overlying sandstones. Such outlying ridges have been noted in other places, but nowhere are they so prominent as here; the western one is very nearly as high as the main ridge, while the eastern one becomes even higher. The Meyer Creek ridge swings about to a northwest direction, forming an anticlinal peak in the north-central part of section 15. The plunge of this anticline is remarkably steep, the rocks standing close to the vertical position as they bend round the nose. The overlying beds form a secondary ridge here which can be clearly traced by the eye as it follows the anticlinal structure. Another peak somewhat lower than the anticline in section 15 is found in the southwest quarter of section 10; its elevation seems due to the vertical position of the strata, which are somewhat inclined from the vertical on either side of the peak and consequently have been broken down. From this peak the ridge swings to a west direction, the dip lowers to 40° north and the elevation decreases rapidly. In the central part of section 9 there is another turn to the east through a low and much-broken syncline. The change of direction is for a short distance only, for at the adjoining corners of sections 3, 4, 9, and 10 there is a low anticlinal peak, from which point the ridge runs westward again. A branch flowing north has cut through this ridge in the northwest quarter of section 9. The return of the ridge east is through a rather high, though broken and obscure, synclinal peak, situated near the neighboring section corners between sections 5, 6, 7, and 8. The return ridge has a prevailing steep south dip.

West of these last folds and north of the Meyer Creek ridge are high isolated ridges with a capping of novaculite. The structure of these ridges is obscure, but their isolated position and topography indicate very certainly a synclinal structure. The more important one of the two has an abrupt western end in township 3 S., 23 W., section 15, northwest quarter. It runs parallel with the Meyer Creek ridge for nearly four miles, ending in township 3 S., 22 W., between sections 7 and 18. The other ridge is irregular in outline and unequal in elevation. It has a general course south of west and north of east, extending from township 3 S., 22 W., section 7, northwest quarter, to township 3 S., 23 W., middle of section 13, a distance of two miles.

The ridges and peaks northeast of the Three Sisters grow noticeably lower toward the northeast and the last monoclinal ridge mentioned is scarcely more than 300 feet high in its course north of east through sections 5, 4, 3, 2, and 1 of township 3 S., 22 W., even though the dip of the rocks, which are vertical or very steep, is most favorable for the existence of a high ridge. It is clear that the formation has become weaker. The monocline continues traceable, though frequently cut by small streams, in a northeast direction across section 36 of 2 S., 22 W., and sections 31, 32, and 29 of 2 S., 21 W. In this latter part of its course from Crystal Springs to Bear other broken ridges of novaculite lie parallel with the monocline on its north side. East of Bear also the monocline is accompanied by parallel ridges on the north side. The formation continues to grow weaker toward the northeast till the Ouachita River east of Alum Cliff causes a considerable break in the monocline and ends the Caddo Range of Mountains.

At Alum Cliff in township 2 S., 21 W., section 24, the siliceous shales with some beds of quartzose sandstones form a low anticline which plunges southwest and is cut away by the Ouachita River on the east side of the section. Alum Cliff presents a kind of structure which is rarely identified in the novaculites; this is a small fault. It is very probable that in the highly contorted novaculite area small faults are abundant; but it is difficult to identify them on account of the similarity

of the different novaculite beds and the rapidity with which the dips change. The fault in Alum Cliff, observed by Mr. Smith, was identified by means of a quartzose sandstone stratum interbedded with the flinty shales. The vertical displacement was estimated at 30 feet, the lateral throw at 100 feet. The south monocline does not appear in strong relief as a ridge again until the eastern part of township 2 S., 20 W., is reached; but siliceous shales are very commonly found in low ridges in the country intervening and represent the formation.

CHAPTER XV.

Detailed Geology of the Novaculite Area.—*Continued.*

THE ZIGZAGS.

Glazypeau Mountain.—East of the Ouachita River the novaculites of the south monocline make their first appearance as ridges in association with the overlying sandstones. Thus they appear in the valley of Glazypeau Creek on the south side of the stream in township 2 S., 20 W., in the southwest quarter of section 9, in the north part of section 10, in the southeast quarter of section 4, and in section 2. The structure is not clear; the dip where seen is northwest so may sometimes be underthrown. It would seem as though the monocline passes up this valley for the siliceous shales are found in township 1 S., 19 W., the west central part of section 28, about the end of the sandstone ridge which extends southwest from this point into township 2 S., 20 W. The presence of siliceous shales at the northeastern end of this ridge called Glazypeau Mountain suggests that the structure is anticlinal, and this view is strengthened by finding flinty shales outcropping in various places along the crest of the ridge, the overlying sandstones being found on either side; the only dips found, however, are northwest. The monocline apparently passes down the valley of Bull Bayou into a group of flinty shale ridges found at the head of Clear Creek in township 2 S., 20 W., in section 11, 12, 13, and 14. No outcrops are found in these ridges.

Clear Creek Mountain.—In the central part of section 14 the novaculites become stronger and rise into a ridge of considerable size, which extends southwest. A west dip is noted in these novaculites, and they shortly plunge below the sandstones of Clear Creek Mountain which is apparently an anticline. Several flinty beds occur amongst the sandstones; this fact might make it appear that the sandstones here replaced beds of no-

vaculite, a thing which is quite possible according to the theory of the origin of novaculites, yet farther to the southeast in the Zigzags the novaculites are developed in full thickness below the sandstones, and since the sandstones, overlying the novaculites, are very generally present, it is not necessary to suppose that the sandstones of Clear Creek Mountain belong to a different horizon.

Turkey Mountain, the Dripping Springs, and Short Mountain.—Just southeast of Clear Creek Mountain is Turkey Mountain, a ridge mainly of sandstones but also showing flinty strata. The south side of this mountain shows the dip east of south. Bull Bayou cuts across this ridge in the northeast quarter of section 13. From the ledges of Turkey Mountain, which overhang the clear waters of Bull Bayou, issue very numerous but small streams of chalybeate water; the whole forms a group of "dripping springs" which far surpass in beauty the better known "Dripping Springs" situated east of Hot Springs. At this gorge, just northwest of Turkey Mountain and separated from it by a narrow strike valley, is a lower and narrower ridge of massive novaculite. These novaculites dip 50° northwest. East of Bull Bayou the two ridges unite to form Short Mountain. This mountain is a part of the great south monocline; the dip, however, is constantly underthrown to northwest, and the novaculites that were at first on the northwest side of the ridge, appear at times to change to the southeast side. This last phenomenon can be explained by the erosion of the ridge, which causes local changes in the direction of the strike, and thus brings different strata to form the crest of the ridge. Short Mountain ends pretty abruptly in township 2 S., 19 W., section 4, west central part. Novaculite ledges at the end of the ridge dip 60° N. 30° W. It is evident that the end of Short Mountain formerly connected with the ridge which runs east from the northeast quarter of section 4, for the novaculite connection is complete at the lower level of the gap. The width of this gap indicates that it resulted from the work of a large stream.

Blow-out Mountain.—The continuation of Short Mountain, starting in the northeast quarter of section 4, is a spur of another higher ridge that extends both east and southwest from its junction with this spur. The southwest extension is an anticlinal ridge four miles in length. It is largely quartzose sandstone, through which the upper beds of the novaculite series are exposed. The name of Blow-out Mountain is given to this ridge, but there is no sign of any disturbance other than a land-slide on the southeast side of the mountain in the southwest quarter of section 9. The mountain ends in the south-central part of section 19.

Blow-out Mountain to Sugar Loaf Mountain.—The higher ridge in the north part of section 3, extending east from the junction with the spur above mentioned, has thin strata of novaculites on its north side. The spur also shows similar novaculite beds on its north slope; this is the proper position of the novaculites with reference to the sandstones, and shows that they are underlying, even though the dips are generally underthrown northward. The higher ridge forms a syncline in the northwest quarter of section 2, from which a lower arm extends west of south, having novaculites forming the crest of the ridge with sandstones on the west side. The dip is northwest as usual and the monoclinal structure is clear. In the south-central part of section 16 the monocline doubles in an anticline plunging southwest. The anticlinal structure is distinct, the southeast dip being found on the southeast side as well as the northwest dip. The nose of the anticline is prolonged by a lower ridge which is three times cut by small streams before the end is reached in the central part of section 30. The southeast dip of the anticlinal nose turns in a synclinal curve in the southeast quarter of section 16 to a direction south and southwest into the reservoir ridge. Just northeast of the synclinal turn a spring stream has cut back deeply from the southeast side into the mountain folds and disguises the structure; yet it is very certain that the sharp ridge running northeast from the west-central part of section 15, to the southwest quarter of section 1, is the continuation of the syncline. The syncline is underthrown so that the dip is northwest, but

good evidence of the synclinal structure is found in the fact that the novaculites found on either side of the ridge are capped by the overlying sandstones.

Sugar Loaf Mountain.—The south monocline, which was last identified in the ridge on which is situated the Hot Springs reservoir, continues into the Sugar Loaf Mountain just northwest of the upper part of the City of Hot Springs. The elevation of Sugar Loaf above the junction of Whittington and Park Avenues, Hot Springs, as measured by Mr. J. H. Means of this Survey, is 540 feet. The ridge loses in height toward the west, but does not again become so low as to the northeast of Sugar Loaf. The mountain owes part of its height to the thickening of the novaculites and to their vertical position; but it is also evident that this peak was left an isolated point by the ancient streams which elsewhere eroded the ridge. The trace of one of these old streams is found in the high gap in township 2 S., 20 W., section 36, east-central part, through which passes the continuation of Whittington Avenue.

West Mountain.—Beyond this gap the ridge rises rapidly into the peak of West Mountain, in which the monocline swings about in anticlinal fashion, though with dip nearly vertical, and returns to Hot Springs in the West Mountain ridge. The peak of the mountain is very nearly 1000 feet above Bull Bayou on the west side, and 1450 feet above sea level. The view from the top is a widely extended one and includes some remarkable mountain scenery. The West Mountain peak is separated from the ridge by a high gap in township 3 S., 20 W., section 1, northeast quarter. Like the Whittington Avenue gap this one gives evidence of an ancient stream which broke through the novaculites when the general land level was near the elevation of the present ridge tops. This gap is evidently older than that on Whittington Avenue for its elevation is 180 feet higher, the greater elevation indicating that it has been longer abandoned. It would seem from the existence of these two gaps that the breach of the anticline now entirely drained by the Hot Springs Creek was at least partially drained first by the stream that flowed through the high gap, second by the one flowing through the Whittington Avenue gap, and finally by Hot Springs Creek. The present Hot Springs gorge is 230 feet lower than the Whittington Avenue gap.

The West Mountain ridge from the high gap to the Hot Springs gorge has steep slopes, with a rocky crest for much of the distance; the elevation of the ridge falls off on going east from a height of 500 feet to 300 feet. The dips are vertical or underthrown northward; in the Hot Springs gorge the north dip varies from 45° at the north end to about 25° at the south end. The section here is a good one, and based upon it is the columnar section given with the others in plate III. The distance of the underlying graptolite shales from the massive novaculites is not easily made out here, neither is it possible to determine certainly the character of the strata between the novaculites and the graptolite shales. On the other hand, the overlying strata (here appearing to be underlying in consequence of the reversed dip) are well exposed. The quartzose sandstones directly overlying the novaculites here appear to have a thickness of about 200 feet. Above these massive coarse sandstones there are softer argillaceous sandstones about 250 feet in thickness containing frequent hard layers. Overlying these, but not exposed in the section, are soft gray shales, black shales frequently graphitic, red, and yellow shales, with thin beds of sandstone. In the sandstone beds of these overlying strata on Malvern Avenue, Hot Springs, Mr. C. S. Prosser, of the U. S. Geological Survey, found fossil plants which are referable to the Lower Carboniferous rocks.

Novaculite conglomerate or breccia.—At the top of the novaculite series there is one stratum which is worthy of special mention. This is a bed about twelve feet in thickness, having the appearance at first sight of a brecciated novaculite. It is clearly not an ordinary novaculite bed that has been fractured and cemented together again, for the angular and subangular fragments composing it are not uniform in character; all are siliceous; some are dense and hard, others porous. The colors are various, black and white fragments are common, though a dark bluish gray variety predominates; the siliceous cementing material has a light gray color. A few fragments are translucent. As shown by the microscope* the groundmass of silica is not essentially different from that of the other novaculites. As a whole, the rock is dense, though small cavities are common; some of these have been filled by quartz, and quartz in well rounded sand grains is sometimes present in the groundmass. Iron is present in red fragments and in stains. In size the fragments composing the breccia vary from a fraction of an inch to several inches in longest diameter. In the Hot Springs section the fragments are larger, and the stratum is thicker than at any other observed locality.

This conglomeritic stratum has been identified at the top of the novaculites from Brodie Creek, a few miles southwest of Little Rock, to Indian Territory, hence the causes which produced it were evidently widespread. Though made up of similar materials it is evidently not a conglomerate composed of fragments of the underlying rocks, for it lies conformably upon the novaculite strata; the change of dip of 20° in the Hot Springs gorge is distributed throughout the section and does not denote unconformity. The rounded and subangular pebbles give no suggestion of an organic origin. It is evident that the bed has been brecciated in places to some extent, for instances are numerous where the angular pieces of the same pebble are noticed a little separated, but showing perfectly fitting angles. The fragments in such cases are grouped closely together; it is possible that the larger rounded pebbles were formed by the grinding which occurred where the movements were greater. Specimens show that the slipping movements took place along lines of jointing, as expressed by Prof. T. McKenny Hughes, in his paper on the "Brecciated Beds at St. Davids,"† especially, in this instance, parallel to the stratification. But to produce such a stratum as the novaculite conglomerate, requires some further supposition regarding the character of the beds before brecciation, and the conditions under which the action took place.

*See Chap. VII, Slides Nos. 21 and 24.

†Geological Magazine, Decade II., Vol. X., No. 7, p. 306, July, 1883.

To account for the mixed character of the material in the bed, two suppositions are possible: first that the original sediments were heterogeneous in composition, consisting of concretionary lumps in a siliceous matrix that were broken by the brecciating movement; or second that many thin beds differing in character were jammed together till their individualties as single beds were lost. The second supposition is not a probable explanation since in many places thin beds of much contorted siliceous shale occur which always retain their character as siliceous shales. This view, however, is suggested by the presence in the novaculite conglomerate, of the grains which might have come from the overlying beds, and of lumps of soft white siliceous rock like the Ouachita stone found in the stratum just underlying. The existence of these two components is, however, no objection to the first supposition, for since the novaculite conglomerate lies between the sandstones and Ouachita stones it may well represent a transition stratum containing both. That there has been at some time a tendency in this bed to form concretions is shown by the examination of thin sections under the microscope*, but at what time it is not possible to say.

The supposition that this bed was one of heterogeneous materials having concretionary forms, to some extent sustains the view of brecciation. To suppose that a single stratum in a large thickness is brecciated throughout a large area is an extraordinary conception, especially in a region of such complicated structure. That it is somewhat brecciated in many places is evident, but in many other localities it is a massive rock that has, owing to its heterogeneous composition, the appearance of a breccia. Furthermore, where it is brecciated the movements have probably been only on the joint planes that everywhere intersect the novaculites, but may gain greater local developments in this stratum, which, because of its heterogeneity, shows the displacements along these planes better than the ordinary homogeneous novaculite. It is probable that this

See Chapter VII, slides, 21 and 23.

conglomeritic stratum much resembles the chert and hornstone breccias of Wisconsin and Michigan.*

Equally as well known as the conglomerate stratum is the one just underlying, called in this report the iron and manganese bed from the very general development of these minerals in small quantities. It is by the float specimens of these ores that the bed is traced. The rock containing the ore is the upper Ouachita stratum and is usually a soft stone which often becomes very friable. Where the rock is hard the ores have sometimes segregated in the joint planes and forced them apart forming a breccia which is very commonly found throughout the region. This bed has been described by Dr. R. A. F. Penrose, Jr., in the report on Manganese,† and his drawing of the breccia is presented here.

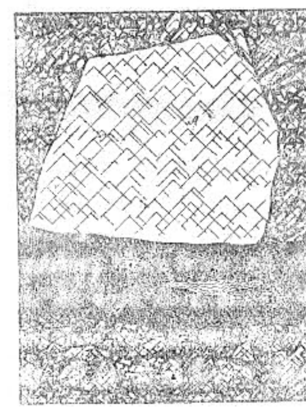


Figure 6. Novaculite breccia.

This stratum can be located easily in any part of the novaculite area and its character determined if the structure of any ridge or peak as indicated in this report is known, for this bed will usually be found toward the base of the ridge on the side next the overlying sandstones.

The large number of quarries and cuttings that have been made in and about the city of Hot Springs affords an unus-

*See page 155, "chert breccia."

†Annual Report of the Geological Survey of Arkansas, Vol. I, 1890, pp. 320, 326, and 352.

ually good opportunity of studying the lesser structural features. Thus in many places the wrinkles are well exposed. At one of these localities on Park Avenue near the car stables the strata consist of siliceous shales in beds varying from a fraction of an inch to eight inches in thickness; the general dip of the beds is steep and the exposure shows a part of one of the wrinkles, but further, the individual beds are cast into curves that begin and end within the small limits of the exposure.

North, Observatory, and Indian Mountains.—On the northeast side of the gorge the south monocline is continued in North Mountain, also called Quarry Mountain. In township 2 S., 19 W., section 28, southeast quarter, it doubles back southwest and then immediately turns in the anticlinal nose of Hot Springs or Observatory Mountain. The syncline between North Mountain and Hot Springs Mountain has been cut down

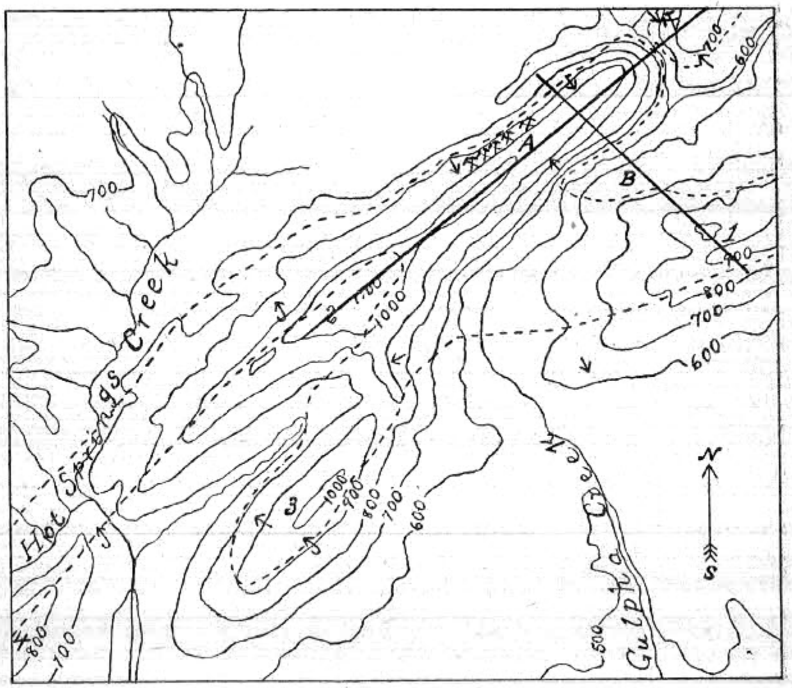


Figure 7. Topography about Hot Springs.
Scale: Two inches = one mile.

PLATE V.

GEOLOGICAL SURVEY OF ARKANSAS, VOL. III., 1890.

CONTORTED SILICEOUS SHALES, PARK AVENUE, HOT SPRINGS.

and forms the little valley called Happy Hollow. The synclinal fold forms the summit of North Mountain and prolongs the mountain northeastward into section 23. The south monocline emerges from the Hot Springs Mountain to form the Indian Mountain ridge. Across this crushed mass of strata a creek has cut its way, forming the "Royal Gorge." The erosion occasioned by this stream renders it more difficult to solve the general structure here, but on the other hand it brings to light several interesting details which would not have been learned had the conditions been different.

In figure 7, which is the topographic sketch of the Hot Springs district, the structure described in the paragraph above may be traced by means of the arrows showing the changes of dip of the novaculites. In this figure the rocks north of the novaculites are those underlying and include the graptolite shales, while those south are the overlying sandstones and shales.

A study in detail about Gulpha Creek shows that in the squeezing of the folds at this locality two faults were developed. The evidence for one of these is found in a northeast and southwest section from the top of North Mountain across Gulpha Creek. This is a section along A of figure 7, the axis of a syncline which plunges southwest; the much greater thickness of the novaculites shown in this section than is present in the Hot Springs section can only be accounted for by the supposition of a fault as shown in figure 8. The vertical displacement given by this fault is about 500 feet. The novaculites

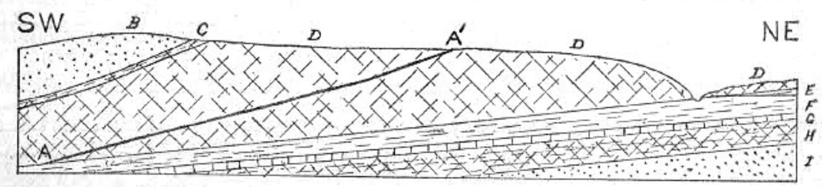


Figure 8. Section along A of Figure 7.

- A–A. Fault plane.
- B. Overlying sandstones.
- C. Siliceous shales.
- D–D. Novaculites.
- E. Brown and red shales.
- F. Black graptolite shales.
- G. Limestones.
- H. Underlying siliceous shales.
- I. Underlying sandstones.

also slipped over the underlying shales, and in this movement some of the shales were cut out in places. Thus brown and red shales found at E are wanting in the gorge of Gulpha Creek.

A section along B of figure 7 from northwest to southeast across the northeastern end of North Mountain to the top of Indian Mountain shows the form of the second fault. This is represented in figure 9.

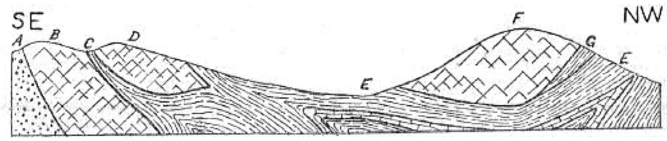
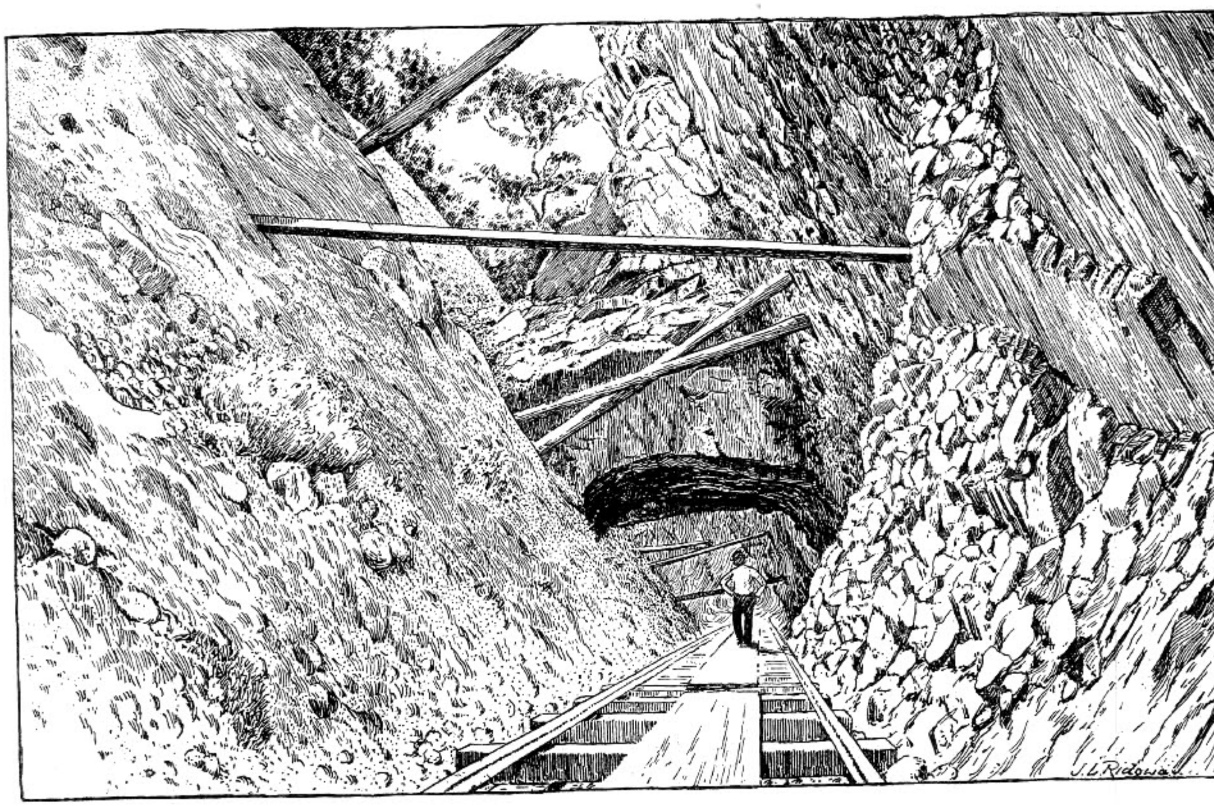


Figure 9. Section along B of Figure 7.

A. Overlying sandstones.
B. Novaculites, Indian Mountain.
C. Underlying shales and fault line.
D. Novaculites, faulted part of Indian Mountain
E-E. Graptolite shales.
F. Novaculites, North Mountain.
G. Brown and red shales.

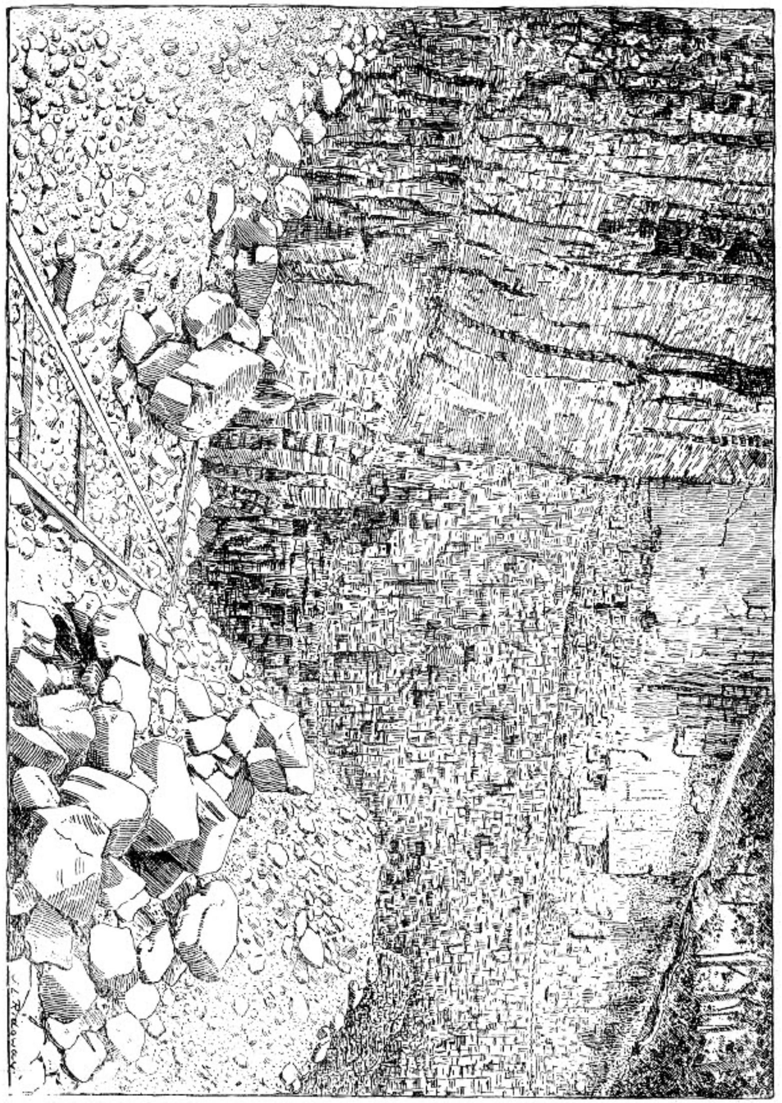
The strike of the second fault plane is about parallel with the axis of the North Mountain syncline.

It is evident that all the folds and faults of this locality resulted from the same series of movements, though there is such a difference in character. It seems probable that in the case of the fault in figure 8 the slipping movement was not exclusively northeast, as might be supposed by the cut, but rather north, the slope of the fault plane being south. In this way the vertical displacement is acquired with a smaller lateral movement than otherwise. The upthrow in this case is on the south side. In figure 9 the movements were different; the plane of movement sloped north and the faulted portion apparently moved downward to the north instead of upward. Large slickensided surfaces belonging to this fault plane may be seen near Gulpha Creek and in the ravine between the two portions of Indian Mountain. The lateral displacement by this fault is about 500 feet. The faulting was probably subsequent to the folding in both instances, and resulted from a continuation of the pressure which formed the folds. Such is the character of these faults that their effect upon topography is only local.



J. J. SUTTON'S NOVACULITE QUARRY NO. 7. NEAR HOT SPRINGS.

GEOLOGICAL SURVEY OF ARKANSAS, VOL. III., 1890. PLATE VII.



ABANDONED NOVACULITE QUARRY OF BARNES BROTHERS NEAR HOT SPRINGS.

The Indian Mountain ridge east of th
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Drawings made from photographs of Su
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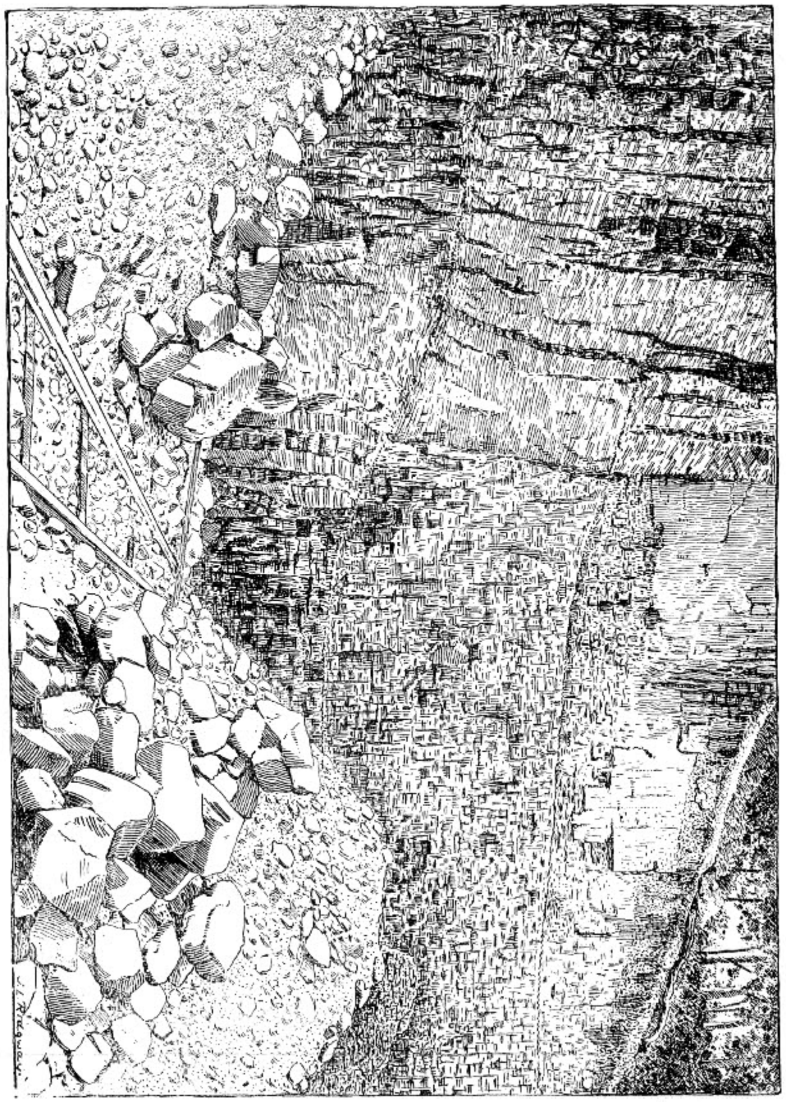
GEOLOGICAL SURVEY OF ARKANSAS, VOL. III., 1890.

PLATE VII.



ABANDONED NOVACULITE QUARRY OF BARNES BROTHERS NEAR HOT SPRINGS.

The Indian Mountain ridge east of the Royal Gorge has a general direction which is nearly east at first, but swings gradually to the north so that within two miles it is trending due northeast. There are numerous local changes in direction, depending perhaps on erosion or on changes in the position of the strata, which bring out clearly the relations of the sandstones to the novaculites; when the direction is east of northeast the sandstones come in to form the crest of the ridge, and when it is north of northeast the novaculites are the predominating rocks on the crest. The whole formation is completely underthrown, the dips varying from 13° to 35° northwest. In township 2 S., 19 W., section 24, the strata swing through the vertical to the normal dip, and in Sutton's whetstone quarries Nos. 6 and 7, the dip is 60° southeast; thus within a distance of a mile the formation turns through an arc of 90° or more. The change of dip seems to produce a change of strike of the ridge, thus it has a direction nearly north in the center of section 24 and swings to northeast in the northern part, near the quarries. It often happens in the Indian Mountain ridge that the thinner beds of softer rocks lying between the massive sandstones and the massive novaculites, as seen in the Hot Springs section, are much crushed and so separate the massive formation by a distance greater than the normal. This softer mass has been much more eroded than the harder ones on either side have been, and so two ridges are formed which are separated by a deep ravine. This is the case near Sutton's quarries 6 and 7, and farther to the northeast is common. The quarries of Ouachita whetstone are located upon these beds of novaculite as they continue northeast along the ridge. The whetstone strata lie near the bottom of the novaculite series; the shales are not many feet below, but the exact position of the contact line cannot be determined on account of the covering of novaculite fragments.

Drawings made from photographs of Sutton's quarry No. 7 and Barnes' big quarry are presented in plates VI and VII respectively. The two quarries differ considerably in form and manner of working owing to the difference in the position of the whetstone strata in the two localities. Sutton's quarry No. 7 is about a hundred yards long and has been worked downward from the surface, following the steep dip of the strata. The thickness of good Ouachita stone is twelve to fifteen feet. In Barnes' quarry (plate VII) the nearly horizontal position of the beds necessitates the removal of the cap rock as fast as work is carried forward into the ridge. The increasing expense of this labor has been one cause of stopping work in this quarry. Another cause is the deterioration in the stone caused by an increase in the number of joint plates. These give the much fractured appearance in that part of the quarry wall seen at the end of the track. In this plate the stratification is shown by the two wavering lines sloping from left to right across the quarry. Thin clay seams existing in the quarry along these planes present much corrugated instead of straight lines.

The dip of the novaculites northeast of Sutton's quarry No. 7 at first grows steeper; thus in township 2 S., 18 W., section 18, at Sutton's quarry No. 3, the dip is again very nearly vertical. In the southwest quarter of the southeast quarter of section 7, at Whittington's "red" quarry, the dip has fallen to 77° southeast, and in less than a mile, in the south part of section 8 at Barnes' and Whittington's quarries, it is down to 15.° The strike has changed to about east and west and the rocks here form the north side of a synclinal spoon which has its northeastern end in section 9, northwest quarter of the southwest quarter. At this end of the syncline the plunge is but a few degrees southwest; this is sufficient, however, to give a considerably higher elevation to Sutton's No. 1 quarry, which is located at the end of the spoon, than the quarries of Barnes and Whittington have in section 8. The syncline has been considerably broken down by erosion, the ravines on the north side at the section 8 quarries and a large one on the south side destroy the symmetry of the synclinal curve, but the structure is evident when the relation of the sandstones and novaculites is shown by plotting on the map.

Cutter's Mountain.—The south arm of the syncline passes west of south through the middle of section 17, and the east central part of section 19. The sandstones are on the west side of the ridge and form its crest for most of the distance; the novaculites on the east side are weak in this locality. The middle fork of Gulpha Creek breaks through this ridge in the northwest quarter of section 30, and from the novaculite ledges overhanging the stream on the south side come the waters of the well known "Dripping Springs," visited by many tourists from Hot Springs. The ridge is much stronger south of the stream and rises into a sharp peak in township 2 S., 19 W., middle of section 36. The whole is called Cutter's Mountain, and the peak has an elevation of over 600 feet above the level of Gulpha Creek at its base. In structure it is an anticlinal nose much resembling West Mountain Peak. On the north arm of the anticline are some ledges of Ouachita stone which are quarried for use as curbstones. About the mountain are numerous mineral springs, the finest of which are Cutter's and Cartney's "Cluster Springs." Gillen's Spring on the south slope of Indian Mountain is a well known health resort.

Cutter's Mountain to Ten Mile Mountain.—The other arm of the Cutter's Mountain anticline starts east from the peak, and swings gradually to a northeast direction. The overlying sandstones on the south side of the anticlinal nose have been separated widely from the novaculites and form a pretty high ridge, thus accenting the anticlinal structure. They join with the novaculites in township 2 S., 18 W., in the north central part of section 31, to form a single ridge. Whetstone quarries have been worked on both sides of this ridge in sections 31, 30, and 29. There must be two distinct whetstone beds here, for neither the dips nor strikes of the strata in any of the quarries indicate any connection between the quarries on opposite sides of the ridge. It is possible, however, though not probable, that the thickness of the novaculites has been reduplicated by a fault. On the supposition that there are two distinct beds, the one on the north side of the ridge corresponds with the Indian Mountain Ouachita stratum, and the one on the south side is the upper Ouachita or iron and manganese bed at the top of the series. The ridge continues northeast, underthrown for almost its entire length, with a somewhat sinuous crest, everywhere high, to the north central part of section 15, where it turns in another syncline. This fold is more closely jammed than the last syncline and is better preserved. Some lower ridges prolong the axis for a short distance.

The other arm of the syncline, extends west of south from the curve about parallel with the corresponding arm of the last syncline. The ridge ends in section 33, northwest quarter, without joining into any anticlinal peak. The returning northeast ridge starts in the southwest corner of the same section, so it would appear that the north side of the nose of the anticline has been entirely cut away by the streams that breach this anticline. It seems at first strange that the nose of an anticline should be broken down, for they usually present the highest peaks, but there seems to be a simple explanation in this case. Within the breach of this anticline there are two considerable ridges which give indications that the anticline instead of being simple, was crumpled in several high folds. One of these ridges is particularly strong toward the northeast; it is capped by heavy novaculite beds containing the Ouachita stratum, and shows the synclinal dips at its northeast end. From the southwest quarter of section 12, the ridge stretches southwest in a nearly straight line for more than four miles, decreasing in elevation in consequence of having lost the heavy novaculite cap, but pointing toward the breach of the anticline. Thus it would seem that the anticline was so crumpled at the nose, that it was more easily broken down here than elsewhere. The southeast side of the anticline turns in a sharp syncline in the northeast corner of section 23. The succeeding anticline is a mere nose about half a mile long. The southeast dipping part of the nose continues the south monocline northeastward. The next synclinal turn is less than two miles distant. The curve is located in township 2 S., 17 W., section 18, southwest quarter. It is a broad one and the

overlying sandstones form the highest part of the ridge, as the rule seems to be when the spoon is shallow. The novaculite formation is also weak here though it predominates over the sandstones in the ridges east of Hot Springs.

The northeast end of the last synclinal trough is drained by a small stream that cuts a gorge in the monocline in township 2 S., 18 W., the east central part of section 24, and flows southeast to Ten Mile Creek. The dip is here 20° northwest. The formation becomes stronger to the southwest and the monocline rises in a high ridge. One of the head branches of Gulpha Creek incises the ridge in the southwest quarter of section 26, and through the high gap thus formed passes the Hot Springs and Benton road. Here the dip is 75° northwest. Half a mile southwest this ridge stops abruptly, and connects by a high divide with a higher ridge close to its southwest side. The abrupt ending may signify a very short anticlinal nose, with a sharp syncline connecting through the divide with the ridge southeast, or it may be simply a result of erosion. However this may be, the southeast ridge slopes off in an anticlinal nose, which ends in township 3 S., 18 W., section 3, northeast quarter. The monocline from this anticlinal nose may be distinguished as a separate ridge northeast of the high divide mentioned just above. On the northwest side of this ridge is located Mr. Sutton's "Ten Mile" quarry. The dip of the formation, as shown in this quarry, is underthrown to 57° northwest. This ridge reaches its greatest elevation in the southeast quarter of section 26. From here the ridge falls off rapidly and swings somewhat to the east. The ridge ends pretty abruptly in the center of section 25, but from it a high irregular divide of sandstones and novaculites extends southward; this divide is all that is left of the old synclinal curve. In the north central part of section 36 the divide connects with another ridge extending southwestward, which constitutes the south side of the syncline and the continuation of the monocline. The ridge rises to the southwest and the dip is found to be 45° northwest. In township 3 S., 18 W., this ridge becomes the southeastern side of a jam of folds. The first one northwest is almost exclusively a sandstone ridge, though novaculites do outcrop at the surface occasionally. This ridge is lower than the others, and seems to have two noses toward the southwest. It may be that another smaller anticline is jammed between the two and causes this appearance. The next and last ridge northwest is not so closely connected to the mass, but is the highest; its name is Bald Mountain. It is a sharp novaculite ridge about three miles long, anticlinal in structure, with very steep dips. The overlying sandstones form prominent outliers at the southwest end of the ridge.

To return to the monocline: This ridge, together with the sandstone ridge lying just northwest, has been cut and considerably eroded by a small stream, the head of the west fork of Boss Allen Creek, in the northwest quarter of section 9. In the northwest quarter of the same section the monocline is doubled into several folds; at least, there seem to be three noses projecting southwestward. Of these the northern one disappears just east of Potash Sulphur Springs. This one is only a spur of the overlying sandstones from the more western of the two others. The central one of the three is the most prominent and extends nearly to the southwest corner of section 17; the first mentioned nose is a spur of this one. On the north side of this ridge, near the northeast end at the top, the dip of the novaculites is 32° south. It is hardly probable that this dip indicates so great an overthrow so near the nose of the anticline; the more probable explanation is, that this dip represents the south side of the anticline, the north side being eroded away and covered up so that the structure is not clearly shown. The syncline between this nose and the third or southeasternmost one is shallow. The third nose is high at the northeast end, but slopes off rapidly to the southwest, ending in section 17, southeast quarter. The overlying sandstones, which did not appear in the last syncline, mount high on the south side of this third nose.

Teager Mountain.—The monocline starts again from the south side of this nose, forming a ridge lower than ordinary for this region and extending due east. The dip is here nearly

vertical though inclining slightly southward. Boss Allen Creek cuts the monocline in the northeast corner of section 15. There is a fine gorge here in which a very complete section of the rocks is exposed. (See the columnar sections, plate III.) The dip in the lower part of the gorge is vertical, changing slightly in the upper part of the gorge to south. The gorge appears to have been cut at a bend in the monocline, for on the east side of the creek the strike of the ridge is northeast. It is here called Teager Mountain, and is a much stronger ridge than on the west side of the creek.

Within the breach of the Teager Mountain anticline and included in the Boss Allen basin are several small ridges. The most prominent one of these lies in the south-central part of section 10 and southeast quarter of section 9. Its position with relation to the monocline together with its topography would indicate that this ridge represented a continuation of the synclinal fold that lies between the anticlinal noses southeast of Potash Sulphur Springs.

In about a mile northeast of the Boss Allen gorge the dip becomes underthrown to the northwest. Observations made in crossing this ridge from southeast to northwest in the northeast quarter of section 11, show a dip of the overlying quartzose sandstones on the southeast side to be 65° northwest, while the novaculites on top give 40° northwest. A similar section made about a mile and a half further to the northeast exhibits the same structure more strongly exaggerated. At the base of the ridge on the southeast side the shales have a general north dip, though one south dip was noted. On the southeast side of the ridge sandstones are seen having an underthrown dip of 24° northwest. The novaculites at the top of the ridge have a low dip of 19° northwest, on account of which they present a much greater surface exposure than usual, and extend far down the northwest slope of the ridge. The dip increases toward the northwest the novaculites themselves showing 37° northwest, and when the graptolite shales are reached the dip has increased to 57° northwest. A profile section illustrating these details is given in figure 10.

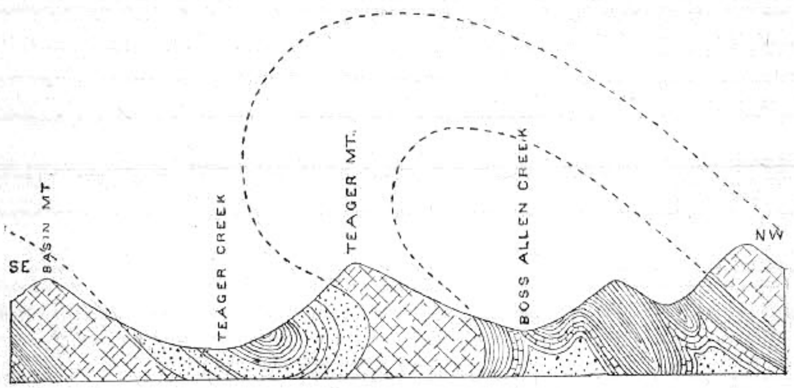


Figure 10. Section across Teager Mountain.

A third section across Teager Mountain in township 2 S., 17 W., about in the northwest quarter of section 32, and a mile and a half northeast from the last section shows a return to normal southeast dip, here 60°. Thus within this distance of a mile and a half there is a change in the position of the formation of about 100°. When it is considered that the strata involved in this folding have a thickness of 1775 feet as shown by the section on Boss Allen Creek the amount of deformation is astonishing. The Boss Allen Creek valley, like the other breached anticlinal valleys of this region, is occupied by numerous wrinkles which have been eroded to form ridges with very little bottom land.

Teager Mountain becomes lower northeast from this last locality and across it passes the road leading from the Teager Creek valley to the Hot Springs and Benton road. In sections 28 and 27 of the same township the monocline swings about a broad syncline returning somewhat in a ridge parallel to Teager Mountain, thus forming a fine synclinal valley a mile wide and five miles long. The axis of the synclinal spoon at the head of the valley plunges at a low angle southwest and the slope on this side is gradual. On the other hand the north and east slopes are very steep having the typical synclinal angle of erosion. As it changes direction in this synclinal curve the monocline is considerably broken and owing to the broad flat top here presented it is not easy to follow the curve.

Dips were noted as follows: On the north side of the syncline 57° S., on the east side 24° W., and on the ridge extending southwest from 26° to 37° northwest.

Basin Mountain.—This southwest arm of the Teager syncline is the north arm of Basin Mountain. In it the dip grows steeper to the southwest. The top varies considerably in elevation, though it does not have the decidedly hummocky appearance of Teager Mountain. Basin Mountain rises to a sharp peak in township 3 S., 18 W., section 12, south part. From the south side of this peak starts the south arm of Basin Mountain; thus it is the anticlinal peak of the two ridges. The anticlinal nose slopes pretty steeply southwest and the disappearance of the novaculites below the overlying sandstones is well marked. The axis of this anticlinal nose must plunge sharply, for the first outcrops of novaculite found near the top of the peak, show a northeast strike and vertical dip. The south arm of Basin Mountain is a strong ridge stretching north of east from the peak. The dip remains nearly vertical, though inclining toward the south. In township 3 S., 17 W., section 9, northwest corner, the creek draining the breach of the anticline has cut a gorge through this arm and flows south into Cove Creek. As in the case of the Boss Allen gorge the cut is made at a point where there was a bend in the monocline, only the bend, as now shown by the change of direction of the ridge, was not so great as at the Boss Allen locality. The south arm of Basin Mountain northeast of the gorge is sometimes known as the Spanish Diggings Mountain from the existence of numerous pits in its crest commonly believed by the people to be the work of old Spanish miners, but shown in chapter IX, page 176 of this report to belong to the category of Indian quarries. The position of the strata in this part of the ridge is nearly vertical. The ridge extends into township 2 S., 17 W. In section 36 of this township it bends southeast and doubles in a syncline. In the southern part of this township also the two sides of Basin Mountain are connected again by divides and ridges of the underlying strata thus forming a very complete basin topographically. This basin is not more perfect, however, than those of Boss Allen Creek and Hot Springs Creek above the gorge.

Southeastern ridges of the system.—The synclinal curve forming the south arm of Basin Mountain resembles the Teager Mountain syncline in the breadth of curve and gentle plunge of the axis; topographically it has also a broad, flat top with abrupt slopes north and east which have a broken outline. This syncline is prolonged, however, by a broad, flat topped ridge extending due east along the line between townships 2 and 3 S., 16 and 17 W. A section across this syncline about three-quarters of a mile east of the township line between ranges 16 and 17 west shows the structure clearly. The prolongation east of the creek extends about two miles east consisting only of flinty shales forming a low ridge. About a mile north of this syncline is another ridge of flinty shales irregular in outline, though with a pretty level back. The excellent opportunity furnished by this ridge for constructing a hard, dry road has been improved by private enterprise; and here as elsewhere it is demonstrated that broken novaculite forms a remarkably fine road-bed. The ridge is about three miles long and probably represents an old syncline.

The novaculite formation now thins out locally for the ridge connecting the Basin Mountain syncline with the next anticline extending southwest is scarcely more than a high divide of siliceous shales. The change to more massive beds is sudden, for the new anticline rises abruptly from the divide. The structure of this anticline is not shown by dips, but by the relative position of novaculite and overlying sandstones. This anticline does not present a breach with a short nose like previous anticlines of this system, but forms a single ridge of medium elevation. This ridge is in township 3 S., 17 W., sections 2, 3, and 10. Another broken divide of flinty shales forms an apparent synclinal connection with the next ridge south and is the only representative of the monocline. The new ridge, however, is strong again, and has an elevation of three hundred feet above the valley level. At its northeast end it shows a dip of 71° northwest. The ridge is anticlinal

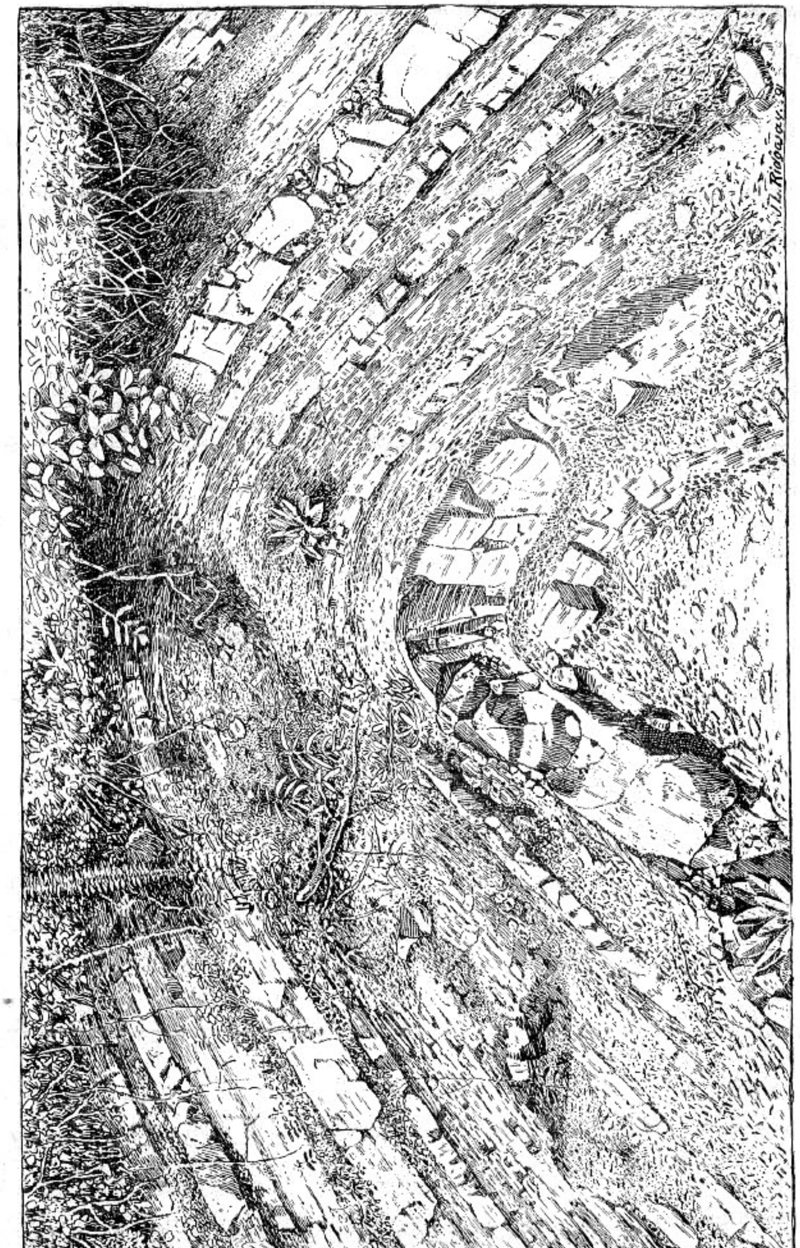
in structure, as shown by the presence of the overlying sandstones on either side. Probably it is this double thickness of the novaculites which has caused the preservation of the anticlinal ridges of this locality, while the crushed, yet open, synclines which had but one thickness have been worn away faster as the beds thin out. This anticline extends to the southwest. In the southeast quarter of section 10 a spring stream on the north side of the ridge has cut far back into it, making a depression in the mountain. The dips, as seen on the north side of the ridge, are 82° south, indicating an overthrow in this part of the ridge. This is worthy of remark as being the first overthrow in this system. Its occurrence may indicate that the shearing movement which apparently gave the northeast and southwest trend to the ridges of this system, and is here becoming weaker, as evinced by the change in direction of the ridges to a more east and west direction, was productive of the underthrows so common in the more disturbed part of the system to the northwest. The ridge continues as an overthrow nearly to its end in the east central part of section 17. A third broken divide region extending southeast across section 12 again forms the monoclinal connection with another anticline. This divide is not merely a broken syncline, but has several folds in it, as shown by the presence of some low northeast and southwest ridges. Also the divide does not seem to be directly connected with the first strong ridge lying south, but with the second one. Thus there is an isolated anticlinal ridge lying between the regular members of the system. It rises abruptly from the sandstones of Scull Creek valley, in the southwest quarter of section 12, extends south of west with a broad rounded back and ends at Chamberlain Creek just north of Magnet post-office, about on the line between sections 16 and 21, the novaculites disappearing below the metamorphosed sandstones. The next anticline belonging to the regular system of the south monocline connects with the last broken divide mentioned just above in township 3 S., 16 W., west central part of section 18. The anticline extending south of west from this locality is at first underthrown, the dips on the south side in the vicinity of Reyburn Creek being about 30°, and this dip increasing to 36° on the north side of the ridge at Reyburn Creek. The structure is not traceable to the west because the ridge is covered with gravel deposits which here form a plateau; still, the anticline can usually be followed by a slight elevation above the plateau. Farther west again the erosion of the gravels leaves the ridge well marked, though it is nowhere high. In township 3 S., 17 W., section 22, west central part, a branch flows south through a depression in the ridge. Massive novaculites do not outcrop here, so the structure is decided to be anticlinal from the existence of sandstones surrounding the western end of the ridge at Magnet post-office. The strike of the ridge at the western end is due east and west. In township 3 S., 16 W., section 18, where the south side of the anticline becomes the monocline, the strike is northeast. A small stream has cut across the ridge in section 18. The structure is not clear since the massive beds that will show the dip are wanting; the ridge, however, is distinct and without parallel ridges. It bends more to the east, and in section 8, south central part, is cut by Nine Mile Creek. Some massive beds are exposed in this cut and show a north dip of 15°, which indicates that the underthrow continues at this point. East of this cut the direction of the ridge changes to due east, and about on the east line of section 8 it is cut by Ten Mile Creek. Here the dip is 56° south, as shown by the sandstones on the south side of the ridge; the novaculites here do not satisfactorily show the the structure. That the ridge is a monocline is, however, evident, for the sandstones are found on the south side of the ridge, and are succeeded on the north by the weak representatives of the novaculites; fragments of the graptolite shale, found among the stream pebbles, indicate that these beds cannot be far distant up the stream, though exposures were not found. The section necessary to prove a monocline is thus complete. The difference in the dips noted in the cuts of Nine Mile and Ten Mile Creeks, little more than half a mile apart, offer another marked example of the extreme contortion of the area, although this instance is less remarkable from the fact that the formation here contains few massive beds.

East of the Ten Mile Creek cut the ridge soon disappears below the gravel deposits. This is the last seen of the south monocline belonging to the great northern anticline, the region from this locality to the eastern end of the north monocline in township 1 N., 13 W., section 33, being covered by deposits of Tertiary or Pleistocene age.

Lying south of the western part of this last ridge are several isolated anticlines of novaculite which are more or less jammed together. Thus two low anticlines seem to be united in the first novaculite elevation found on going south from the monocline. Outcrops are scarce on these elevations, a large portion being covered by the drift of Tertiary or Pleistocene age. The dips of the rocks seen in the section along the Military road in township 3 S., 17 W., section 24, together with the topography of the district are the only proofs of the double anticlinal structure which can be offered. The northern one of the two rises in township 3 S., 16 W., section 20, southwest corner, and extends in a westerly direction while spreading out to the north. Joining with it in the extreme southwestern part of section 19 is the second anticline which also extends over the northwestern corner of section 30. The two united form a level topped plateau from which toward the west in 3 S., 17 W., independent ridges project. In section 26, northern part, the two branches of Franceway Creek have eroded a small valley on the north side of a ridge connecting with this jammed mass. It is not clear what the structure of this ridge is; the only dip found was at the more western of the creek cuts and was about 60° north. As this is on the south side of the elevation it must be an underthrown south dip; this underthrow disguises the structure, for it could not be ascertained here whether this ridge was a complete anticline separated from the rest of the jam, or whether it was a monocline and the valley north a breached anticlinal valley. The latter supposition is strengthened by the fact that the first outcrops on the north side of the little valley in the extreme south central part of section 23 dip north and so may represent the north side of a breached anticline; still it is also possible that they too represent an underthrown south dip. The two ridges thus separated join again to the west in a divide generally covered with gravel. The western end of the mass has been cut across and eroded by Stone Quarry Creek. The novaculites disappear on the east side of the creek, first showing, however, a south dip on the south side of the southern ridge. The overlying sandstones on the west side of the creek form a prominent ridge and swing about in a fine anticlinal curve which includes the entire jam of novaculites. This anticlinal nose is chiefly included in section 29.

A single narrow ridge about two miles long lies just south of the western part of this jammed mass. It is not over a hundred feet high at any place. Ravines in the ridge show south dips on the south side of 15° to 26° and north dips on the north side of 66° to 70°. Three short anticlinal ridges about three miles west of the ridges last described may also be included in this system, since they lie in the same axes of folding. They are in township 3 S., 18 W., for the most part in the south part of section 23 and the north part of section 26. They are scarcely more than 100 feet high, and the novaculite barely crops out through the sandstones. The two northern ones are practically the same ridge which is cut into two parts by Teager Creek. Between the two eastern ones passes the Hot Springs Railroad. North of the western end of the more northern of these ridges and south of the railroad track is a lower ridge of sandstone through which the novaculites do not appear. These ridges indicate the continuation of the folds into the Mazarn Basin, and show that the novaculite beds are not far below the surface. The nearness of the novaculite beds to the surface is also shown in the valleys between the last ridges of the Zigzags system by occasional outcrops of this rock. A drawing made from a photograph of one of the anticlinal folds of this district is presented in plate VIII. The view was taken on the Hot Springs Railroad, about three-quarters of a mile east of Cove Creek Station. The

PLATE VIII.



AN ANTICLINE EXPOSED ON THE HOT SPRINGS RAILROAD EAST OF COVE CREEK STATION.

strata involved are shales and sandstones overlying the novaculites.*

Through the folded novaculites the volcanic rocks of Magnet Cove burst, as shown by the presence of dikes penetrating the novaculite anticlines. Compared with the novaculites they are much younger.†

Conclusions regarding the Zigzags.—The system of the Zigzags is the most contorted of all the mountain ranges comprised within the novaculite area. The abnormal change of direction of the folds from east and west to northeast and southwest, while at the same time the general trend of the monocline is southeast is the most noteworthy feature. It is scarcely possible to suppose that these folds were forced up by a distinct pressure acting from southeast to northwest because there are no signs that such a pressure influenced the rest of the great anticline of which this forms a part. The curious structure can best be explained by the supposition that in the general south to north movement there was a local shearing motion which has produced the north of east trend in the Zigzags, the western part of the Trap Mountains, and in the Pigeon Roost Mountain and Mazarn Ridge. More concerning the origin of this structure is given in the next chapter under the heading "folds between Blocher and Brazils post-offices."

The second noteworthy fact is the very common occurrence of the underthrow of the south dips to north; so common is this, indeed, that there are more miles of underthrown dip in that part of the monocline which should dip south than there are of the normal dip. As previously suggested on page 317 it would seem as though the underthrow had some connection with the shearing movement for it is noticeably less common where the strike of the ridges becomes more nearly east and west, as, for example, in the western part of the south side of Basin Mountain, and the prolongation of Teager Mountain west of Boss Allen Creek.

*A photograph of a syncline was not secured, but the conception of one may be gained by inverting the picture of the anticline. A monocline is composed of the beds dipping in the same direction, or one-half of an anticline or a syncline.

†See Ann. Rep. Geol. Survey of Ark. for 1890, Vol. II. The Igneous Rocks of Arkansas, by Dr. J. Francis Williams.

CHAPTER XVI.

Detailed Geology of the Novaculite Area.—*Continued.*

THE NORTHERN MOUNTAIN RANGE.

A very general description of the range of mountains which defines the northern side of the great Ouachita anticline has been given in the chapter on Geography. It has been said that the western end of the range is near Board Camp post-office, in Polk county, township 3 S., 28 W., sections 3 and 4, where there is a marked topographic change. Structurally, this limit is an arbitrary one, for considered as the north side of the Ouachita anticline the range should include other ridges south of Board Camp post-office, but which have already been included in the Caddo Range.

Characteristics of the Range.—There are three ways in which the Northern mountain range differs from the other ridges of the system. First, it is much more broken and the occasional absence of ridges along the general strike indicates that the formation is not here continuous as a massive one. The second noticeable point is the lack of certain characteristics of a region of synclinal and anticlinal folds, namely, curved ridges and sharp peaks connecting the parallel ridges. The absence of such connecting ridges may be due to the same causes which make the Northern range of mountains so disconnected, namely, the general weakness of the formation, in consequence of which the sharp folds where the rocks have been greatly crushed have been more easily worn away. This has undoubtedly been the case to some extent. There is, however, another explanation for this lack of connecting ridges, and that is that the north side of the anticline is not so crumpled as the south side, so that the monocline is more nearly a straight line. This seems to be evident with regard to the western end of the range, where one straight ridge rep-

resents the north monocline for nearly twenty miles. The other ridges of this part of the area are probably outlying isolated anticlines or synclines; the rocks are so completely broken up that their structure is not often apparent, but the anticlinal fold has been distinguished in several instances. The monocline is also distinctly traceable as a single ridge at its eastern end for nearly twenty-five miles. In the east-central part, between Blocher and Brazils post-offices, there is evidence of a folding similar to that of the Zigzags; the general trend of the monocline is north of east and south of west, but within the anticline there are numerous ridges in this locality which strike northwest and southeast. The third point in which the ridges of the northern mountain range differ from those of the southern ranges lies in the fact that they show two horizons of graptolite bearing shales. Over the entire southern part of the area the graptolite shales have only been found below the novaculites, though they may yet be found in the black novaculites at the top of the series or in black shale beds in the overlying sandstones. The underlying graptolite shales have been found in five localities along the northern range, proving that the horizon extends from one end of the formation to the other; the easternmost locality is in township 1 N., 15 W., section 2, and the westernmost in township 2 S., 28 W., section 34. The latter locality is not far from localities on Mill and Big Fork Creeks which have been identified with the underlying shales of the south monocline. The overlying graptolite shales have been found in numerous places along the north side of the monocline from township 2 S., 26 W., section 8, to township 1 N., 14 W., section 11, so the continuity of this horizon is also established.

Mack's Creek to Big Fork Creek.—The separation of the two horizons of graptolite shales is clear, for the novaculite monocline has been traced continuously across the country. Beginning with the ridge rising sharply on the east side of Mack's Creek in the southeast corner of section 4, the monocline trends in a north of east direction. The ridge is a sharp one, but is much lower than those lying south of it in the same township. It is broken by the two branches of Sulphur Creek in section 2; but rising in a stronger ridge beyond these it bends in a sharp syncline in the northeast corner of section 1. A ridge continuing the axis of this syncline extends eastward just north of Big Bend post-office, but is separated from the synclinal turn by the valley of Little Sulphur Creek. The monocline from the north side of the syncline extends westward along the township line; it is twice cut by the branches of Sulphur Creek, then turns a little northward. A broad anticlinal nose in township 2 S., 29 W., section 34, marks a change of direction again to the east. Sulphur Creek has made a broad gap in the ridge in section 35. In the northern part of section 36 the structure of the monocline is not evident, but there is clearly a change about a mile and a half northward; this change is probably effected by a synclinal and anticlinal fold but the formation is so weak here that not only are no dips exposed but the structure is not clearly manifested in the topography. From the northern part of section 36 the monocline is continued through numerous short low ridges to Mill Creek in township 2 S., 28 W., section 29. These ridges are often scarcely more than knobs about 150 feet in height, yet they are higher than any neighboring ridges on either hand and extend in a very continuous line. On the east side of Mill Creek a stronger ridge a mile or more in length extends northeastward to near Big Fork Creek.

Big Fork Creek to Cates' Creek.—East of Big Fork Creek, in a strike line with this last ridge a strong ridge rises and continues eastward unbroken for more than four miles to Cates' Creek. A peculiar distortion in this monocline is shown between townships 2 S., 27 and 28 W., sections 30 and 25 respectively, where within a length of two miles it is bent laterally a quarter of a mile or more from a straight line connecting the two limits. The remnants of old folds in the great anticline are shown by some ridges south of this portion of the monocline. A short irregular ridge in township 2 S., 28 W., sections 27 and 28, has a general northwest-southeast axis and connects by pretty high divides with the monocline on the

north and with other isolated ridges on the south, but its structure is not apparent. The two parallel east-west ridges in the north parts of sections 34, 35, and 36 are remnants of synclines, completely isolated by graptolite bearing shales.

From Cates' Creek to Muddy Mountain.—East of the break in the monocline made by Cates' Creek in township 2 S., 27 W., section 29, northwest corner, the monoclinal ridge having a course north of east is partly broken several times. The outcrops alone, however, are insufficient to show the structure. Both north and south dips are exposed, and there is evidence that the rocks have been very much crushed. Outlying ridges occur on either side of the monocline. In township 2 S., 26 W., the complete anticlinal structure is visible in several of the outlying ridges on the north side of the monocline. In this township the main ridge runs northeastwards from the southwest corner of section 19 to the southeast quarter of section 12. The novaculite is chiefly of the black or bluish black variety, and its dip is uniformly north about 65°. In its highest portions it is 500 feet above the valleys: the Oden road passes through a high gap in the extreme east central part of section 15. The same ridge continues unbroken across township 2 S., 25 W., from the southwest quarter of section 7, through the south part of section 1. There are occasional ridges on the north side of the main ridge and while their structure is not apparent their isolated position indicates that they are independent anticlines. Almost all the dips seen are north ones and vary from 30° to vertical. One anticlinal arch was noted. The novaculite is of the black variety, partly siliceous shale. The beds are weaker in the eastern part of this township, so that the ridges north of Mt. Ida are not more than 300 feet in height. The formation becomes still weaker in range 24 west, and the ridge which has maintained itself as a continuous divide for sixteen miles is broken by a small south flowing stream. A parallel ridge lying just north becomes the more prominent though both are several times broken by small streams. No direct stratigraphic connection seems to exist between the two ridges, and the northern one is probably an outlying anticline. The southern one ends in township 1 S., 24 W., middle of section 34. Low ridges of siliceous shales are found farther northeast in the strike line in sections 34, 26, and 25. In the northwest quarter of section 26 the monocline is cut by the Ouachita River. The formation here consists of thin beds of siliceous shale, chiefly blue-black or gray, dipping steeply to the north having an east-west strike. To the east, in a strike line with these beds is the most northern of the ridges mentioned above. To the west it disappears in a gravel covered plateau from the northern part of which in the north parts of sections 22 and 23 some irregular knobs and ridges rise to form a series trending generally east-west.

Muddy Mountain.—Muddy Mountain, on the northern line of section 24 is a sharp ridge which undoubtedly forms the continuation of the monocline eastward. It is about three miles long and 400 feet high at the highest point; between townships 23 and 24 W., there is a deep gap in the ridge made by an old stream, probably the ancestor of the present Muddy Creek. On Muddy Creek in the southeast quarter of section 14 are the well known Sulphur Springs. On the north side of Muddy Mountain is the continuation of the broad valley that is occupied by the Ouachita River toward the west, marking in a general way the line between the Silurian and Lower Carboniferous rocks. Between this valley on the north side and the valleys of Ouachita and South Fork on the south the ridges of the monocline stand out prominently. From the higher peaks of the Crystal Mountains the monocline can be plainly seen stretching for many miles across the country in its somewhat broken line of ridges.

From Muddy Mountain to North Fork.—Muddy Mountain has other lower ridges parallel with it at its eastern end. All are considerably cut by the erosion of small streams, and there remain a lot of dome-shaped hills known as the Bald Knobs. The name is derived from the fact that tornadoes have blown down the timber which formerly covered these mountains. There is a change of direction for the monocline in these ridges, and they form a strong divide leading north-

east. There are usually two or three parallel ridges in this divide, but just which one represents the monocline is not clear; altogether they are not more than a mile wide, and it is sufficient to know that the monocline passes through them. These ridges are much scored by Fourche Cedar Creek in township 1 S., 23 W., sections 11 and 12. In this vicinity, on the Fort Smith road, is a chalybeate spring which has considerable notoriety in the country around for the medicinal properties of its water. A short distance south of the spring the underlying graptolite shales are exposed. East of the creek the trend of the formation continues northeast into township 1 S., 22 W., sections 6 and 7, where there is a change to south of east. The North Fork of the Ouachita is the next stream to cut the monocline; this is in section 9, northwest quarter. There is but one main ridge in this portion, though a lower dip frequently gives opportunity for the formation to spread over greater surface, so that erosion has produced long ravines and detached knobs and ridges. In the same way the monocline continues in an easterly direction on the east side of the North Fork cut. From the ridges in sections 10 and 11 some fine specimens of wavellite are collected and carried to Hot Springs, where they are sold to visitors.

From North Fork to Blakely Creek.—In sections 12 and 1 of this township (1 S., 22 W.) the ridges change their direction sharply to the north. It does not appear from the topography that this is all due to a change in direction of the monocline, but rather that one or two anticlinal and synclinical folds have been formed here. This supposition is strengthened by the existence in this district on the south side of the monocline of some supernumerary ridges which are best accounted for as synclines. The monocline turns east again at the northeast corner of township 1 S., 22 W., and continues east along the base line for about a mile and a half. East Fourche Cedar Creek then cuts across the ridge at a bend in the monocline, the ridge east of the creek taking a northeast direction. Several parallel ridges on the south side extend about two miles toward the east, after which the monocline is sometimes a solitary ridge, though generally a second ridge to the south follows parallel to it a short distance. In this way the monocline extends east for over five miles, through township 1 N., 21 W., sections 27, 26, and 25, and in township 1 N., 20 W., sections 30 and 29. Within this distance it is seven times broken by streams.

Blakely Creek to the Alum Fork of Saline River.—In township 1 N., 20 W., section 28, southwest quarter, Blakely Creek cuts across the formation, which is here composed of siliceous shales only. On the south side of Blakely Creek in sections 33, 34, and 35, the monocline forms a subordinate ridge to a strong ridge of the underlying sandstones which continue parallel to and separated from it only by narrow strike valleys. In sections 25, 26, 27, 22, 23, and 24 of the same township, the novaculites are apparently crushed in several folds which have been so eroded that an elevated tract of country supporting a few small ridges extends eastward from the southeast quarter of section 24. This ridge is undoubtedly the monocline, as shown by the steep north dip and by the relation to the overlying and underlying strata. This ridge is cut off to the east, by the valley of the Middle Fork of Saline River. It does not appear again on the east side of the river valley in the strike line, and the next novaculite ridge is nearly a mile north of the monocline. This new ridge has a strike toward the eastern end of the monocline, and as it connects with other novaculite ridges extending in a general direction eastward, it doubtless represents the monocline. The ridges forming this portion of the monocline are all low, still they form a line of elevations higher than the surrounding country just as the monocline does farther west. They are much cut up by streams and, change frequently in the direction of their axes, thus indicating considerable contortion in the old anticline in this part. This portion of the monocline extends through parts of sections 20, 18, 17, 8, 9, 10, 15, 14, and 11.

In the northeast corner of section 11, the novaculite formation appears on the east side of Cane Creek, but the monocline is presently lost below the gravels and cobbles of a somewhat elevated plateau which occupies the country between

Cane and Angling Creeks. On the east side of Angling Creek, in the northwest quarter of the northeast quarter of section 12, the monocline continues eastward from a bluff rising above the creek. Its direction is east-west, and the ridge rises in sharp relief for a distance of over a mile. The formation has been eroded away and covered over for nearly half a mile in township 1 N., 18 W., section 7, northeast quarter, and section 8, northwest quarter. It appears again in the northeast quarter of section 8, having a direction south of east. In section 9 the formation spreads out to a width of nearly a quarter of a mile, and is cut by sharp ravines into short ridges and knobs which rise above the level of the gravel covered country. In section 10, however, the siliceous shales become covered by the gravels and coarser detrital material, though fragments of the bed rock occasionally appear on the surface. The formation is again wanting in topographic importance in the southwestern part of section 11, but on the south side of the Mount Ida road, probably in the northeast quarter of section 14, a new ridge of siliceous shales and impure novaculites marks clearly the continuation of the monocline. Again, however, the eastern end of the ridge is hidden beneath the pebble deposits.

Alum Fork to Brazils post-office.—The monocline becomes even more indistinct on the east side of the Alum Fork. The ledge which first represents the formation consists of gray shales with a few siliceous layers. The ridge continuing eastward is largely gravel covered. It comes to an end in half a mile, but in a strike line the axis is continued by some short ridges having the same characteristics as the last. In township 1 N., 17 W., section 18, northern part, the direction of the ridges changes to northeast. In section 8, southwest quarter, the ridge becomes somewhat stronger, but is lost again beneath the gravels in the central part of the section. Section 8 consists chiefly of a high, broad divide, undulating in surface and irregularly eroded about its borders. The higher portion, however, of this divide extends southwest-northeast with but one hollow interrupting; and from this higher part emerges some well defined ridges of impure novaculite, in section 4, southwest quarter, just northwest of Snyder's mill. These ridges are about two hundred feet high. They extend northeastward across the section, but decrease in elevation and lose their identity in another flat divide district in the western part of section 3. Through this divide region the last ridges of the monocline probably connect with Prilliman Ridge in the southeastern part of the section.

Prilliman Ridge is made up of three parts, united at the northwest end to form a mountain of three peaks. The elevation of these peaks is about 300 feet above the surrounding country; the middle one is the lowest and the ridge extending southeastward from it is unimportant. Of the others, the southwestern one has a length of half a mile; it rises abruptly at both ends. The northeastern ridge is the strongest one, and is over two miles long; its termination on the southeast is abrupt, but the northeast slope is gradual. These ridges appear to represent several folds in the monocline at this locality. The monocline continues from the northwest end of the main ridge into a divide region which must contain an anticlinal nose, for a short east and west ridge in the north part of section 2 marks the return of the monocline eastward. In the northeast of section 2 is a broken syncline which shows another turn to the northwest. This new ridge extends northwestward into township 2 N., 17 W., section 35, and joins a group of broken ridges of siliceous shales and novaculites which occupy parts of sections 33, 35, and 36. It is through these that the monocline returns southeast into the knobs and ridges southwest and south of Brazils post-office, where the monoclinal dip and structure are once more clearly distinguished. The east and west trend is more strongly accented in these last ridges than in the Prilliman Ridge.

Ridges about Blocher post-office.—South of the monocline in township 1 N., ranges 17 and 18 W., there are numerous ridges of siliceous shales and impure novaculites, which generally show a dependence in structure of one upon another, though some are isolated. They are the remnants of old synclines, and show by the direction of their axes that the novaculites of this region were pressed into folds which were not as uniformly parallel as those in other parts of the area. One line of ridges seeming to represent a single bent axis, starts in township 1 N., 18 W., section 17, southeast quarter.

The ridges are weak and broken, being composed only of siliceous shales, and are low by contrast with the sharp ridges of the underlying sandstones which rise just south of them. The direction of the axis is at first east into the southwest quarter of section 15; thence it changes suddenly to southeast and in somewhat stronger ridges, twice interrupted passes just north of Blocher post-office ending in township 1 N., 17 W., section 31, central part.

North of the southeastern end of this series of ridges in township 1 N., 18 W., section 13, 14, and 24 are two sharp, parallel ridges having a northwest and southeast strike, and extending into township 1 N., 17 W., section 19. The southern one of the two is one of the strongest novaculite ridges of this part of the area, and shows a considerable thickness of massive beds where it is crossed by the Hot Springs road. They approach pretty near the monocline toward the northwest, and since they must have been closely connected with it the difference in the directions of the axes of the ridges affords good evidence of the irregular character of the folds.

South of Blocher an isolated ridge starting in township 1 N., 18 W., section 36, northwest quarter, extends southeast into township 1 S., 17 W., sections 5 and 6. The dips of the siliceous shales composing the ridge are east of north. In the north central part of section 5 the ridge becomes very low, rising again with a strike nearly south, forming practically a new ridge. This new ridge shows no structure. In the south part of section 9 it swings to an easterly direction and ends just over the east line of this section. To this ridge a smaller one, also of siliceous shale, with a northeast dip, forms an outlier in the southeast quarter of section 8, the southwest corner of section 9, and northwest quarter of section 16. These last ridges stand very prominently above the comparatively flat region of the Saline River basin.

Southwest of the Blocher post-office ridge is a much higher elevation called Goosepond Mountain, in which the rocks are sufficiently massive to deserve the name of novaculites. This mountain has an elevation of over 550 feet. Three east and west ridges unite at their east ends to form the mountain, the highest point being a part of the northern ridge. The rock is largely black novaculite. A north dip was seen in each ridge, which might imply that there was a great local development in the thickness of the novaculites at this place. Such a supposition is unnecessary, however, for the separation of the ridges and the similarity of the rocks in them all may be taken as very good evidence that the same strata are involved, and that the reduplication is caused by slip faults or by folds closely jammed together and underthrown. The change of strike from northwest and southeast in the Blocher ridge to east and west in Goosepond Mountain is noteworthy, for it furnishes another link in the proof of the crushing that took place throughout the great anticline.

A short ridge of siliceous shales about a mile northwest of Goosepond Mountain in township 1 N., 18 W., sections 33 and 34, is another representative of these isolated synclines. The dip of the rocks was not made out, but the strike of the ridge is nearly northeast and southwest, thus indicating a still greater complication of the anticline in this small area.

The folds between Blocher and Brazils post-offices.—The ridges composing this group comprise a peculiar portion of the Northern range. The trend of the monocline in this region is nearly east-west, and with the exception of the portion between Prilliman ridge and Brazils there are no clear indications that it is much folded. The distribution of the ridges south of the monocline, however, indicates a remarkable system of folds in this district. The northwest and southeast trend of these ridges is clear evidence that there was a strong divergence from the general east-west folds of the novaculite area, and that here was a state of things which resembles that existing in the Zig-

zags, except that the axes of the folds are at right angles to those of the Zigzags, while the complete connection of the folds is not clearly visible. The prevalence of the northeast dip does not necessarily conflict with this theory because in the Zigzags the south dips are underthrown to north in more than half the distance, and an underthrow is likely to be even more general where the formation is weaker. It may seem that this view has but little foundation in the facts observed; but any other theory which will account for the existence of these folds must involve geological movements not commonly known in the novaculite area. The spectacle of two such series of zigzag folds having axes at right angles to each other, not very widely separated, and yet lying within the same lines of the supposed great movement from south to north is a remarkable one. To account for this second and lesser series of folds requires the supposition of a second shearing force acting in a northwest direction. The existence of these two systems of zigzag ridges indicating shearing movements at angles of approximately 45° with the direction of the pressure and angles of 90° with each other is entirely in accordance with the results obtained by Daubrée in his experiments upon prisms of sealing wax.* Daubrée does not produce folds, but cracks having angles in the above relation to each other and to the direction of pressure showing shearing movements; but the principle is the same in either case, and whether cracks or folds result depends upon the conditions of confinement of the part undergoing strain.† These two mountain ranges present on a grand scale the facts demonstrated by Daubrée's experiments.

In plate IV (see page 212) the axes of the folds of the Ouachita uplift are represented diagramatically by solid or dotted lines, indicating respectively anticlines and synclines. The variation, even of the strongest axes, from the normal trend of the uplift (10° south of west) is seen to be of common occurrence throughout the area. The most extraordinary region, however, is inclosed by dotted lines and includes the folds

*Géologie Expérimentale, A. Daubrée, Paris, 1879, pp. 316 to 320.

†See page 267.

discussed above, namely, those of the Zigzags and the ridges about Blocher post-office, situated respectively about A and B. South of the Zigzags the folds change direction through the normal to east-west and even north of west and south of east. The folds about A and B of this enclosed area are the ones compared to the cracks produced by Daubrée in his experiment.

Brazils post-office to Little Maumelle.—From the ridges in township 2 N., 17 W., sections 35 and 36, near Brazils post-office, the connection of the north monocline through to the end of the system is distinctly traceable through straight ridges having as a rule a simple structure. The first link in this chain, in the southeast corner of section 36, is a sharp knob of novaculite a hundred feet in height, which has a dip to the north. In township 1 N., 16 W., section 6, northwest corner, the north dip is continued in a much stronger ridge; it is here northeast at an angle of 45°. The ridge is about 200 feet high and three-quarters of a mile long. The ridge ends abruptly, and it is evident that the gap between it and the next ridge east was caused by erosion to a large extent, because the novaculite formation is strong in each ridge and would naturally form a closer connection than is indicated by the present topography. A narrow gap interrupts the continuity of the monocline where the North Fork of the Saline River crosses it, in section 4, east part. East of this gap the strike becomes north of east again, and several anticlinal folds are indicated by the occurrence of parallel ridges on the north side of the monocline, in the southeast corner of township 2 N., 16 W. These ridges vary considerably in the directions of their axes, changing to a strike very nearly east and west in the east part of the township. One ridge belonging to this group, the one west of Cave Creek, in sections 33, 34, 27, and 23, is composed chiefly of sandstones overlying the novaculites, the latter sometimes reaching the surface through the former. The novaculites also crop out on a short ridge between sections 22 and 27, but north of this group of ridges is the usual valley in

the Lower Carboniferous rocks, with strong ridges of sandstone further north.

The Little Maumelle ridges.—The monocline crosses the south part of section 36 into township 2 N., 16 W. In the latter township the trend becomes a little south of east, so that the ridge passes out of section 36 of this township into section 1 of 1 N., 15 W. Within this distance of over seven miles it is cut six times by small streams, yet it may be considered as the divide between the north and south drainage systems. The ridge sometimes approaches an elevation of 300 feet above the adjacent valleys and may be distinguished from the ridges parallel with it by the outcropping ledges of novaculite on its summit, which show north dips of 45° or more. On the south side of the monocline is a single parallel ridge accompanying it for most of the distance; this ridge is formed for the most part of the underlying graptolite shales and the interstratified flinty beds; it is usually low, but sometimes reaches nearly the elevation of the monocline just north.

North of the monocline in township 2 N., 15 W., numerous parallel ridges extend in more or less broken lines, sometimes higher, sometimes lower than the monocline. The dips and the repetition of the beds on either side show the stronger ridges to be anticlines. Oftentimes these anticlines are not very sharply jammed, the dips being as low as 30° to 45°, and in such cases they have been eroded so as to form three ridges, the overlying siliceous shales forming inferior broken ridges on either side of the main ridge of hard novaculite. Between the anticlines are many sharp ridges composed of the overlying shales in which are some sandstones. The upper part of the valley of Little Maumelle River separates these anticlines into two groups. In the southern group there is one main anticline following nearly on the section line between sections 26 and 35 to sections 30 and 31. At the east corner between sections 26 and 35 the direction suddenly changes to southeast, and the ridge passes across section 36, through the southwest corner of section 31 of township 2 N., 14 W., to the center of section 5 of township 1 N., 14 W. The eastern portion of this ridge is known as Bald Mountain. In the group north of Little Maumelle there are three pretty strong anticlinal axes shown which have a length of five miles or more. The middle one is the strongest and forms an unbroken divide between Little Maumelle and Nowlin Creek. This ridge starts in township 2 N., 16 W., in the southeast quarter of section 23; its course lies about through the centers of sections 19 to 23 inclusive, of 2 N., 15 W., and it ends in about the southeast quarter of section 24. The two other anticlines are twice broken by streams draining either way. North of Nowlin Creek in the northern parts of sections 16 and 17 the Lower Carboniferous sandstones form a pretty sharp ridge, having a north dip and overlying a considerable thickness of gray shales also dipping north. At this place the Lower Carboniferous sandstones approach nearer the novaculites than at any other along the whole east-west extent of the Northern range, the ordinarily broad valley being here reduced to a width of half a mile. Both groups of the Little Maumelle ridges are continued southeastward in townships 1 and 2 N., 14 W., and 1 N., 13 W., on either side of the east fork of Little Maumelle, and joining with the monocline into a single group of ridges. Among the anticlines of this district graptolites have been found in numerous places among the overlying shales. Two localities in township 1 N., 14 W., section 11, northwest corner, have yielded forms which have been identified by Dr. R. R. Gurley as belonging to the Calciferous horizon of Canada. The beds containing these forms closely overlie the novaculites and the evidence in both localities is that they belong at the base of the group of strata overlying the novaculites and containing the graptolites.

Eastern end of the Northern Range.—The ridges of township 1 N., 14 W., often occur in well defined groups of three, which grouping has been explained as a result of erosion on low anticlinal folds.* The monocline accompanying these ridges from section 6 of 1 N., 14 W., and completing the Fletcher Range, usually forms a stronger ridge, often exceeding 200 feet in elevation. The dips taken at various places along the ridge vary between 40° and 50° northeast or north-northeast. Erosion has frequently separated portions of the ridge on both the north and the south sides forming a double ridge for short distances; the crest is usually very narrow; small peaks are common; occasionally the ridge broadens out and is much incised by ravines, this is particularly noticeable in the north part of section 24 of township 1 N., 14 W. The last portion of the monocline extending southeast is unbroken by streams for a distance of twelve miles, though there are several high gaps in it. The extreme southeastern portion is a broad elevation scarcely more than 75 feet above the valley and showing no structure. Where it comes to an end at the Little Rock and Benton road in township 1 N., 13 W., section 28, southeast quarter, ledges of siliceous shale show a strike of N. 60° W., and a dip of 45-50° north-northeast. This is not the most eastern locality at which the novaculite formation is found, however, the ridges on either side of Brodie Creek in sections 23 and 26 being two miles farther east. These are continuations of the anticlines of this district, most of which are irregularly eroded and show but little of their structure.

*See page 335.

It might be urged that since scarcely any but north dips are found in this region of the north monocline that the section from north to south is one continuous one without folds. A study of the map of the region will show that such a supposition is improbable inasmuch as it would necessitate the existence of thick local deposits of novaculite in various horizons, while by the theory of folding a single stratum of novaculite will account for all the ridges; then too underthrows are so common over all the novaculite area that it is not at all improbable that some of the north dips in this district are really underthrown south dips. It may also be urged that the continuous north dips are produced by a series of faults. There is no good evidence of this in the repetition of the beds, however, and as the faulty structure has not been found of importance in other parts of the region it is improbable that it exists here.

The manner in which the north monocline ends is clearly indicative of a greater extension of the novaculites in former times. The general direction of the ridge for the last fifteen miles of its length would seem to indicate that the Ouachita anticline was coming to an end; that is, it approaches rapidly the locality where we should expect to find the eastern extension of the southern monocline. The more recent drift deposits completely cover the part occupied by the former nose, as well as the south monocline east of township 3 S., 16 W. section 19, so that the location of the anticlinal nose is almost purely hypothetical.

CHAPTER XVII.

Detailed Geology of the Novaculite Area.—*Concluded.*

THE GREAT NORTHERN BASIN.

The outline of the great northern or Ouachita anticline as expressed by the novaculite ridges composing the Caddo range, the Zigzags, and the Northern range of mountains, encloses an area of softer strata by the erosion of which a great natural basin has been formed. This basin has a length of a hundred miles and a maximum width of nearly twenty miles. It is not perfectly defined as a complete basin, however, for the novaculite wall is absent on the south side at the eastern end and there are some gaps in both the north and south walls large enough to destroy the complete continuity of the basin's rim. The continuity of the basin, also, is interrupted in itself by a range of mountains rising within the basin area. These mountains, known as the Crystal Mountains, are near the central part of the arêa, the middle of the range following pretty closely the south monocline, while each end crosses the basin diagonally to the northern side; thus the great basin is divided into three smaller ones, which have been named from the principal streams, the Saline, Ouachita, and Caddo basins. The range of mountains forms the great feature of the large basin and deserves attention first.

The Crystal Mountains.

Structure.—Since the Crystal Mountains stand within a great anticline it would be supposed that the general structure of the range would be anticlinal; and so it is. The thickness of the sandstone beds involved in these folds is about the same as for the novaculites, namely about 600 feet, so the folds of the two series have a similar magnitude. The sandstones, however, show a tendency to form steep-sided anticlines with nearly horizontal strata on top, thereby producing small plateau-like elevations. Where sharply folded the topography is like that of the novaculites.

Formations.—The sandstones of this horizon differ somewhat from those just overlying the novaculites. In color the fresh surface is somewhat greener and it weathers to a deep red; the stone is more altered to a quartzose rock by the formation of secondary silica and some layers have the appearance of quartzite with globular grains.* Along the joint planes, or better still on lines of bedding, especially those having a vertical position, quartz has been developed in the form of crystals. This development is very general; the veins formed vary from those of microscopic size up to ten feet in thickness. The greatest thickness is found at the so-called "pockets" which are local expansions of the veins, often partly empty, containing clay in which are embedded loose crystals, and also having the crystals attached to the sides of the cavity.

Eastern end of the range.—The eastern end of the Crystal Mountain range is just north of Goosepond Mountain in township 1 N., 18 W., where there are several sandstone ridges having elevations of from 200 to 400 feet. One of these follows parallel with a novaculite ridge representing a synclinal fold; it begins at the centre of section 26, extends northwestward nearly two miles then turns sharply to west following a corresponding bend in the syncline. Its east and west length is over three miles, in the last mile and a half of which toward the west where the fold was broader the anticline has been breached diagonally at a small angle with its axis. Another northwest-southeast ridge approaches the western termination of this east-west ridge in the southeast corner of section 19. It has a length of two miles. Its parallelism with the northwest-southeast trend of the monocline is noteworthy since it lies between two of the east-west trending ridges. The east-west ridge on the south side begins in township 1 S., 18 W., the extreme northern part of section 4; it is interrupted by Mill Creek at the adjoining south township corners of 1 N., 18 and

*A description of this stone is given in Chapter VII, Slide No. 47.

19 W., and from this locality it continues due west along the base for four miles. This latter part of the ridge is known as Line Mountain. North of the western end of Line Mountain is a short sandstone ridge two miles long having a course north of west and south of east and known as Bly Mountain.

Cedar Mountain.—The stronger ridges of the Crystal Mountain system begin south of the short ridges just described. One of these rises in the northwest part of section 8, of township 1 S., 18 W.; it runs due west for four miles, then turns sharply to the southwest for a distance of three miles more. It is a broad ridge, nowhere much more than 400 feet high; outcrops showing north dips were found on it, but though the south dips were not seen, it is certain that in structure it is an anticline. Parallel with the southwest striking portion on the west side lies Cedar Mountain, another and higher sandstone ridge, the highest point of which is over 600 feet above the valley. Its sides are steep, and its length is six miles. The dip of the sandstones is north on the south side of the ridge, indicating an underthrow corresponding with those of the Zigzags on the south. The prevailing north dip of the rocks suggests the possibility of these sandstones belonging to the monocline of a greater anticline, or of their having been brought up by a fault. But there is no corresponding south side to complete an anticline, while the occasional south dips in the valleys show that folding is the prevailing kind of disturbance in the region. Furthermore, the ridges of sandstone belonging to the same formation further west show the anticlinal structure clearly where cut by the Ouachita river.

Blakely and Mill Mountains.—Next west of Cedar Mountain and separated from it by the valley of the north fork of Glazypeau Creek are Blakely and Mill Mountains. Blakely is the more southeastern and is also the larger of the two ridges, consisting in places of several ridges jammed together. Its northeast end is in township 1 S., 20 W., section 14. The elevation is from 600 to 700 feet, with a depression in the southwest of section 28 and northwest of section 33, through which passes the Hot Springs-Cedar Glades road. The section seen along the road as it goes over the divide shows the sandstones, which are here quartzose, appearing through the shales at the top of the mountain. The dip of the sandstones is steep northwest on the southeast side, and vertical on the northwest side; which indicates that this anticline, like many composed of novaculite, bulged at the top of the fold besides being underthrown. Where the Ouachita River cuts across Blakely Mountain in townships 1 and 2 S., 21 W., the southeast and northeast corners respectively, it consists of three ridges the southern one of which is a continuation of Little Bear Mountain on the west side of the river. The structure of these three ridges is not clear, but the section along the new Cedar Glades road shows plainly the anticlinal form of the middle ridge, the north dip being from 60° to 80° and the south dip from 20° to 30°. This anticline is really composed of two low folds in the axes of which the underlying limestones are exposed. The north dip of the anticline forming the southern ridge is also seen, but beyond this the structure is not determined in this section. West of the Ouachita River, however, Little Bear Mountain is an anticline, so that the third and last ridge on the east side must be one also. The north spur of Blakely Mountain branches off in township 1 S., 20 W., section 28, and follows a course more nearly west. It is cut by Mill Creek, in section 30, and by a branch of Mill Creek in township 1 S., 21 W., sections 25 and 36. Thence it forms a wall on the north side of the Cedar Glades road, with some breaks by small streams, as far as Blakely Creek in section 33. The sandstones are not the most important rocks in this ridge, as they merely form the axes and are exposed only in stream cuttings. The overlying limestones are the most prominent strata; they correspond in geologic position and lithologic appearance with the limestones of Crystal Springs, but the thickness here is apparently 150 feet, while at Crystal Springs, only ten or twelve miles away, the thickness is barely 50 feet. Above the limestones are soft shales with siliceous layers, about 250 feet, then soft argillaceous shales for 250 feet or more; above these are siliceous shales apparently representing the novaculites which are here

undoubtedly but the remnant of an old syncline. The softer rocks above the limestones are much contorted, so that the structure has not been definitely determined; north dips of 50° to 60° were seen in the interbedded soft and siliceous shales, while the overlying soft shales are nearly horizontal.

Mill Mountain, northwest of Blakely, rises in township 1 S., 20 W., section 10, and is connected near the northeast end with Blakely Mountain by a high divide. The valley of Mill Creek separates the two mountains. Mill Mountain consists for the most part of but a single ridge which is not as high as Blakely Mountain the greatest elevation being 600 feet at the northeast end; from this peak the ridge as a whole falls off to the southwest and the strike swings more nearly west. In township 1 S., 21 W., section 24, the ridge is divided into two parts by a small stream which has breached the anticline. The fold is broad and the dips are rather low, that on the south side, however, is 60° southeast; the northern ridge is here higher and shows on the south side a dip of 30° to the north. The underlying rocks exposed are gray shales and some limestones. From this locality the ridges representing the two sides of the anticline steadily separate and at the southwest end there is no clear evidence of an anticlinal nose, the ridges being very much lower than at the northeast end and so cut by erosion that the characteristic topography is not seen. The south side of this anticline in about the central part of section 26 shows a south dip of 30.° At a point still farther south of west the dip is south but nearly vertical. Where the ridge ends in township 1 S., 21 W., sections 27 and 33, on the east side of Blakely Creek, it is not more than two hundred feet in height.

On the west bank of the Ouachita River the extensions of the ridges of Blakely Mountain unite to form a continuous bluff often several hundred feet high and following the river for five miles. The strike of the folds continues the same. The mass is divided into two parts by a narrow strike valley, often gorge-like, which lies north of Little Bear Mountain. On the north side of this valley the mountain mass is broad and high, and a separation into three divisions by ravines along the strike line suggests that they form the continuation of the three corresponding folds on the east side of the river. The limits of this mass to the west are in sections 4 and 9 of township 2 S., 21 W., where anticlinal noses plunge steeply to the southwest. A short fold is pressed up on the north side of this mass, forming an isolated axis which is divided into several short ridges by small streams flowing northward into the Ouachita. The dips of the rocks do not indicate the anticlinal structure clearly, being on the south side 45° S., and on the north side 80° S.; the sandy shales and sandstones composing the strata also are not characteristic enough to serve in positively determining the structure, but it can safely be inferred to be anticlinal. The narrow valley mentioned above as dividing the mass on the west side of the river is cut in gray and blue shales and limestones; one limestone bed several feet in thickness has a conglomeritic appearance caused by the peculiar distribution of the sand grains in a network of lines through the rock.

Bear Mountain.—Little Bear Mountain on the south side of this valley, by its divisions into two ridges at both the northeast and the southwest ends, shows a double anticlinal structure. In the middle part the two anticlines are pressed closely together and in the northeast quarter of section 15 the dip is south 70° and in the southeast of section 10 it is north 40° showing the anticlinal form of the whole. The northern division of the Little Bear anticline forms the natural eastward extension of Bear Mountain; and just north from where the road from Cedar Glades to Bear crosses the high divide a section exposed in the ravine by the stream flowing northward shows the anticlinal fold very distinctly. The fold at the axis is complete; within a distance of fifty feet the sandstone beds are doubled in a sharp loop, and each individual bed may be followed by the eye completely over the curve. The dips decrease either way from the axis to 40° and lower toward the north and to 30° toward the south. Still further south however the south dip becomes steeper. Bear Mountain, reaching

west from this locality is therefore a broad anticline, and the divide at this point seems to indicate a structural depression which separates the two mountains. Farther west the dips are much steeper and the mountain considerably higher in consequence. The mountain is six miles long, and maintains a very even elevation of 850 feet above the level of the Ouachita River. The mountain nominally ends at the Walnut Fork in township 2 S., 22 W., section 16. The stream does nothing more than break the ridge, however, for on the west side of the stream the fold is continued by another ridge. The western end of the anticline is in township 2 S., 23 W., section 13. The total length of this anticlinal fold to the northeast end of Blakely Mountain is over twenty miles.

The Blakely Creek ridges.—North of Mill Mountain and between the two forks of Blakely Creek two parallel ridges run side by side for several miles. The northern one is over eight miles long, extending from the corners of sections 10, 11, 14, and 15 of 1 S,, 21 W., section 6, the northwest corner. The southern one is shorter and smaller, extending parallel with the west end of the northern ridge and distant about half a mile from it. Another ridge belonging to the same group as these two extends nearly six miles east and west across the extreme south part of township 1 N., 20 W. This ridge lies close to the novaculite monocline from which it is separated by narrow strike valleys.

Broken Rock and Blue Mountains.—South of Bear Mountain are several lower ridges of sandstones having the same general east-west strike. Broken Rock Mountain (named from the great angular sandstone boulders which cover it) rises farther to the southwest covering parts of sections 29, 30, 31, and 32, of township 2 S., 22 W. The eastern end consists of two strong ridges, both probably anticlinal noses, rising abruptly on the east, the height of the peak being 550 feet above the Walnut Fork. The axis of the ridge is a little north of west, and its western end is in township 2 S., 23 W., section 26, where it approaches the southwestern end of Blue Mountain and the two are connected by a high divide formed by the syncline between the two.

Blue Mountain is probably an anticline, though its form and structure are extraordinary. It extends from township 2 S., 23 W., middle of section 26 to the northwest quarter of section 19 of township 2 S., 22 W. In its length of less than three miles the axis bends through nearly a right angle the greater part of the distortion coming near the southwest end. Here in the northeast quarter of section 26 the dip of the rocks on the east side of the ridge is about 45° south of east, the same strata bending into the Broken Rock Mountain to form its north slope. On the northwest slope of Blue Mountain the dip again is 45° southeast near the top of the mountain becoming steeper toward the base. The anticline seems to have been overthrown and broken along the crest, the portion with southeast dip being pushed over on the northwest side. The evidence of the anticlinal structure consists in the fact that the overlying limestones occur on both sides of the ridge.

Logan, McGrue, and Crystal Mountains.—Another prominent sandstone ridge rises just north of the village of Crystal Springs in 2 S., 22 W., section 34, and has a south of west direction. The eastern end of this ridge has clearly the form of an anticlinal nose. Overlying the sandstones here are the blue limestones fifty or more feet in thickness, above which are the graptolite shales which perhaps increase the thickness by a hundred feet. The ridge is cut by the Walnut Fork in section 32, southwest quarter, west of which point it has the name of Logan Mountain. The strike remains the same, and the mountain ends in township 3 S., 23 W., section 10, northeast quarter. Another sandstone ridge runs parallel with Logan Mountain, starting in the central part of section 31 of township 2 S., 22 W., and connecting with the main ridge of the Crystal Mountains to the southwest, under the name of McGrue Mountain. Between McGrue and Broken Rock Mountains is Crystal Mountain, a sharp ridge of sandstones over four miles long and extending nearly parallel with McGrue Mountain. A curious feature of this ridge is a deep gap in township 2 south, 23 W., section 35, west central part, which discloses the fact that the overlying limestones here form the summit of the ridge. Thus the hollow seems to represent the syncline following the plunge of the anticlinal nose of Blue Mountain just north. Crystal Mountain is closely connected with Broken Rock Mountain by a high divide; in fact all four of the last mentioned ridges form a jammed up mass of sandstones giving a generally elevated area deeply incised along the synclines.

The McGrue Mountain anticline.—McGrue Mountain separates into two ridges in sections 4 and 9 of 3 S., 23 W., that is, the anticline is breached at this place. The evidence of the breaching is found further west in section 8, the southeast quarter, where Mazarn Creek has cut through an anticlinal nose along the axial line. The plunge of the anticline is 15° east; on the north side of the creek the north half of the anticline bends immediately through the north to north of east into the south arm of McGrue Mountain. The synclinal curve thus formed is not identified by actual dips of the sandstones, but the topography is identical with that of novaculite synclines; then, too, the shales on the north side of the ridge near the bend have a southeast dip of 48°. These shales are therefore presumed to be underlying; they are gray, black, and yellowish-brown in color, and all of them are fissile. The section is not well exposed, so the thickness and character of the strata cannot be estimated. If there were no reduplications by small folds the thickness would be nearly 500 feet. On the south side of the north arm of McGrue Mountain the dip is 69° north. Thus the few dips found favor the idea of a breach in the sandstones. The north arm of McGrue Mountain maintains a straight course westward. In township 3 S., 24 W., section 11, northeast quarter, there is a very sharp depression in the ridge, known as Logan Gap. The elevation here is about 200 feet lower than the ridge top; moreover, it is cut through the sandstones, and is not therefore a structural depression.

West of Logan Gap the ridge connects by a high, broken divide with some strong ridges lying to the south. The dip of the sandstones in the dividing ridges is nearly horizontal, though slightly south, so they seem to form a part of the old anticlinal arch or span that connected the two sides of the McGrue Mountain anticline. The south side of the anticline in this part shows a steep south dip; it becomes low towards the east and connects by low elevations with the south side of the anticlinal nose mentioned above as being cut by Mazarn Creek. The south branch of the headwaters of Mazarn Creek has cut a gorge diagonally across the south side of this anticline in township 3 S., 24 W., sections 10, 11, and 14, and through this gorge drains a small part of the breached anticlinal basin which would otherwise belong to the Williams Creek drainage. The peculiar course of the Mazarn branch seems to have been given by an old stream which settled down upon the nearly horizontal sandstones. West of this gorge the south monocline of the McGrue Mountain anticline is jammed against the ridges on the south which go to make up the most massive part of the Crystal Mountains. Separating again from these ridges on the western side of township 3 S., 24 W., it extends in a north of west direction, forming a strong ridge that is the divide between the waters of the South Fork of the Ouachita and the Caddo for eleven miles. Where the Black Springs Mount Ida road crosses the ridge, in township 3 S., 25 W., section 5, the dip on the north side of the ridge is low to the south. Then in township 2 S., 26 W., section 34, the main South Fork flowing north cuts across the ridge. West of this cut the ridge continues again unbroken, but on the line between townships 2 S., 26 and 27 W., sections 31 and 36, it changes its direction to south of west and joins with ridges from the north to form Bear Den Mountain. This mountain presents the outline of an anticlinal peak plunging westward and the overlying rocks seem to be the ones exposed at the surface at the western end of the mountain on Big Hill Creek; yet the dip of the rocks on the south side of the ridge, even at the nose, is north, though near the vertical.

The north monocline of the sandstone anticline returns east from Bear Den Mountain parallel with, and less than a mile

distant from the northern novaculite monocline. This ridge is secondary to the novaculite monocline and is considerably cut by small streams draining from the monocline. When the two monoclines are separated by the South Fork valley the sandstone ridge becomes a prominent feature on the landscape and remains so as far as Logan Gap, though it is several times cut by streams. In township 2 S., 25 W., the two Cedar Creeks furnish interesting sections. Limestones occur just above the sandstones in close conjunction with them, and correspond with the overlying limestones seen at Crystal Springs. On the south side of the ridge, the dip being constant to the north, there is another series of limestones. This group seems to be much thicker than the overlying horizon; the beds immediately below the sandstones contain a large percentage of sand, the grains of which are sometimes distributed evenly through the rock, sometimes in the form of a network which gives the rock a conglomeritic appearance. Some of the beds also near the conglomeritic bed and occasionally merging into it, contain small lumps and nodules of black chert which are sometimes several pounds in weight. Lower in the series the limestone beds become thinner and have layers of shale between them. Brown shales succeed the limestones below. The limestones are the predominating rocks in the basin formed by the breaching of the sandstone anticline; they are commonly nearly horizontal, though bent into small wrinkles or locally jammed into small, confused bunches. The same underlying limestone characterized by the development of black chert oc-occurs on the Black Springs road south of Mt. Ida. Where this road crosses the north monocline in township 2 S., 25 W., section 26, there is a wide gap. The stream which now flows northward through it on the west side of the hollow is a small one.

West of the Black Springs-Mt. Ida road within the breach of the sandstone anticline are several pretty sharp ridges composed of limestone at the base surmounted by sandstone. These ridges are characterized by an extensive development of quartz.

East of the Mt. Ida-Black Springs road, the sandstone monocline becomes involved in several folds. The first of these forms the eastern end of the mountain south of Mt. Ida. In this mountain the monocline is doubled into an anticline which plunges beneath the overlying strata in township 2 S.,. 24 W., section 30, southwest quarter. The arm of this anticline returning westward is cut by Williams Creek in township 2 S., 25 W., section 35, northern part. Just west of this stream there is a synclinal turn from which the monocline passes eastward again into another anticlinal nose which extends farther east than the last one into township 2 S., 24 W. The arm returning westward from this nose appears to be sharply pressed into another syncline and anticline in township 2 S., 25 W., section 26, southeast quarter, but the structure is not shown and owing to erosion the topography throws no light upon it. Still, the distribution of the ridges seems to require such an explanation, for the monocline is next clearly defined in a sharp synclinal fold in township 3 S., 25 W., sections 1 and 2, northern parts. From this syncline the monocline stretches away in a nearly southeast direction to Logan Gap. In township 3 S., 24 W., section 4, an anticlinal ridge extends east from the monocline for three miles, cut once in this distance by the headwaters of Twin Creek. On this ridge quartz crystals have been mined to a considerable extent.

The Collier's Creek Mountains.—The massive part of the Crystal Mountains in township 3 S., 24 W., mentioned previously in connection with the south monocline of sandstones, shows the character of the folding in the great northern basin more clearly than has been determined elsewhere. In the mountains just west of Logan Gap there has been a strong resistance on the part of the sandstones to the crushing forces which operated there, as shown by the nearly horizontal attitude of the strata which form the span across the McGrue Mountain anticline. In this group of mountains a few miles southwest of the Logan Gap the evidence of this nature is much stronger. The mountain mass may be considered as composed of three east-west anticlinal folds. The northern

one is closely pressed against the monocline and only appears as a distinct fold in a short anticlinal ridge and nose in township 3 S., 24 W., section 18, northern part, and in township 3 S., 25 W., section 13, northern part. The eastern end of the next fold south is pressed against the two ridges on the north, thus forming an elevated mountain mass supporting knobs and ridges. In township 3 S., 24 W., section 18, middle of the section, there is a steep north dip on top of the ridge; the ridge is high and sharp and rises still higher toward the west. The highest point is in township 3 S,, 25 W., section 13, centre of the section; this peak seems to be as high as the one called High Peak a mile or more to the southeast and said to be the highest peak of the Crystal Mountains. This ridge decreases in height as it continues west through section 14, on the west line of which it comes to an end. The third anticline is a broad fold comprising two or three smaller ones. A broad high divide connects its eastern end with the mass of mountains formed by the union of the two northern folds; its eastern portion is a mile wide, but this width decreases toward the west. High Peak, mentioned above, rises from this western part in township 3 S., 24 W., section 19. This mountain extends westward into township 3 S., 25 W., where it divides into two ridges, the northern one of which extends farthest west of all the ridges of this group. The whole elevation of the mass is several hundred feet above the valley levels and the highest peaks approach a thousand feet in elevation. The erosion of the mass is worthy of notice. Instead of following the structural depressions Collier's Creek has cut diagonally across the two southern folds forming very sharp gorges; the southern gorge in particular is extraordinary and would seem to be similar in origin to the Mazarn gorge. In the Collier's Creek gorge the structure of the southern fold is shown, though not completely; the rocks for the most part are nearly horizontal, dipping usually to the south. There are some north dips, also, giving evidence of low folds, and on the south side of the elevation there is a distinct east-west anticlinal axis with dips of about 45° either way. The largest crystal mines of the region are along this lower gorge.

Two ridges lower than the main Crystal Mountains form outliers less than a mile distant on the south side. The more eastern one of these starts with a southwest trend in township 3 S., 23 W., section 17, east central part. The ridge broadens, and in the south part of section 18 is breached by a north flowing branch of Mazarn Creek. In township 3 S., 24 W., between sections 13 and 14, the sides of the anticline come together again in a single ridge, which extends west to Collier's Creek. The other ridge rises less than a mile south of the western end of the last ridge, in township 3 S., 24 W., section 23. Its strike is at first southwest; but on the west side of the gap made by Collier's Creek the direction changes to due west and continues nearly in this course for more than six miles. It is a comparatively low ridge, but maintains the character of a divide very constantly. It ends on the west in township 3 S., 25 W., on the west side of section 27.

Conclusions regarding the Crystal Mountains.—The Crystal Mountain range is especially interesting on account of its broad structural features. The spectacle of a new anticlinal area, as presented in the Crystal Mountain range, comparable with the Trap Mountain or Cossatot ranges, within a great eroded anticline is a noteworthy one. This range is of necessity included among the Ouachita Mountains since it is entirely surrounded by the novaculite ranges, but the rocks involved are very different. Its relation to the forces which folded the south monocline is most apparent in the directions of its principal axes. This would seem to indicate that the folding of the Crystal Mountains was more nearly synchronous with that of the south monocline than with the north one and that the disturbance was greater on the south side of the great anticline since the lower rocks were here to a greater extent brought to the surface; yet the fact that the two ends of the range approach closely to and conform in trend with the north monocline favors the belief that the crushing in the area of the great novaculite anticline took place simultaneously, though differing in intensity in different localities. A section compiled from observations made at various points in the Crystal Mountains indicate the following thicknesses of strata:

Crystal Mountains strata; composite section.

Massive sandstones (quartzose)	600 feet.	
Limestones	100 "	
Gray and black shale	300 "	(?)
Yellow shale	100 "	(?)
Total	1,100 feet.	

This thickness added to that of the strata belonging to the novaculite folds gives a total of 3700 or 3800 feet for the whole series of rocks in the novaculite area.

The Saline basin.

The easternmost of the divisions of the great northern basin is drained by the Saline River and its tributaries, except a very small area in the extreme eastern part, which is drained by Fourche Bayou. The novaculite wall on the southeast side of this basin is wanting, and the Tertiary border line in this part undoubtedly encroaches somewhat on the natural limits of the area; still it is the largest of the three divisions of the great basin. With the exception of the isolated ridges in the extreme northeastern part, in the Fourche Bayou area and those extending southeast from Blocher post-office which have been included as part of the northern range, it contains no high ridges.

Isolated ridges.—The ridges of the Fourche Bayou district are generally low and sharp, but their geologic structure is not clearly shown in the exposures of rocks which are not massive. The direction of their axes, however, and their isolated position in what are clearly the underlying shales make it evident that they are isolated synclines. They occur on the north side of Fourche Bayou, in township 1 N., 14 W., sections 27, 26, and 35, and on the south side of the creek in sections 34, 33, 28, 29, and 30. These ridges are composed of very broken siliceous shales and seldom have an elevation greater than 100 feet. At first their strike is northwest-southeast, but toward the west it swings more toward east-west. Another group of ridges in township 1 N., 15 W., sections 13, 14, 15, and 16 and extending eastward into township 1 N., 14 W., are of similar composition and structure, but in accordance with the change in direction of the northern monocline their axes strike east and west. The most western of these ridges in section 15, rises to a height of 250 feet.

Formations and structure.—The rocks of the basin, except in the ridges just mentioned, are soft shales and sandstones, with a few thin beds of limestone. Quartz has been developed in large quantities all through the area, particularly in the shales. The strata are bent into complicated small plications (classed as wrinkles in this report) which render the complete solution of the structure difficult, if not impossible. The prominent feature of interest, however, is that the rocks covering this basin belong to the group lying between the novaculites and the Crystal Mountain sandstones. In the typical section their thickness is only about 700 feet, though in this area the development may be greater. Thus the small size of the wrinkles compared with the folds and with the great anticlines is understood when it is considered that the largest of the folds involve less than a thousand feet of strata, and it is extremely doubtful whether a thickness of more than two or three hundred feet is really bent into a single loop. The vertical range of these wrinkles also is small, being but a few hundred feet, while the folds originally had a height of several thousand feet and the great anticlines of several miles.

Such wrinkles are common all over the Saline basin, as shown by the constantly changing dips along the stream cuttings. The detailed observations made by Dr. Branner on the rocks north and west of Benton afford a good illustration of the complexity of the structure. Observations made in the northern part of the Saline basin, and along the Upper Hot Springs road running through townships 1 N., 15 and 16 W., and 1 S., 16 and 17 W., show north dips, becoming more westerly nearer Hot Springs. This gives the appearance of

an extensive monocline within the basin bending in an anticline at the west end. This anticline should be completed by pretty uniform south dips in the south part of the basin if such is the structure. The south dips are not found, however, and since the evidence of small wrinkles is so common, and inasmuch as the strata of the Crystal Mountains are not brought up within the basin as they should be if there were a large anticline, the peculiarities of dip along the line referred to must be regarded as purely local and due to some other cause than the existence of an anticline within the basin. The evidence of the underthrow of the northern novaculites in this region may explain the general north dip, since the soft shales would be influenced by any movement affecting the adjacent strata. A very decisive argument in favor of the theory of many wrinkles would be the frequent occurrence of graptolite shales within the basin, but the search for these strata has not been carried on with sufficient detail to give this evidence, and as yet the greatest distance from the novaculites at which they have been found is one and a half miles.

The breached anticlinal folds of the Zigzags enclose small areas which may be included in the Saline basin, though all of them are drained to some extent by small streams that do not belong to the Saline drainage. The wrinkles spoken of above are well shown in these breached anticlines. It might be expected that the underlying rocks within the limits of the folds would conform to those of the great curve, but such does not appear to be the case in any instance; on the other hand, the only conformity is in the directions of the axes of folds and wrinkles, which are practically parallel, while the wrinkles themselves are much more numerous than the folds, and are crushed together and perhaps faulted so that it is hardly possible to determine the details of the structure.

Upper Saline basin.—The small basin drained by the upper part of the middle fork of Saline deserves notice. It is bordered on the north by the novaculite monocline, and on the south and east by the ends of the Crystal Mountain range. The strata exposed are the same as in the Saline basin and present the same structural and topographical features. The presence of somewhat elevated, flat topped areas of considerable extent, covered with gravel and small rounded boulders is noticeable in this small basin. These areas are between 600 and 700 feet above the tide level. Evidences of recent submergence occur elsewhere in the novaculite area.

The Ouachita basin.

The central division of the great Northern basin is crossed by the Ouachita River, which is joined in this division by its North and South Forks. Almost the entire valley of the South Fork is contained in this basin. Although abounding in large streams the surface of the country is much more uneven than the Saline basin owing perhaps to the alternation of massive strata with soft shales.

Formations and structure.—The character of the strata in the Ouachita basin is different from that of the Saline, but several points of similarity may be noted. The Ouachita basin abounds in limestones, while in the Saline basin limestone strata are scarce. Beds are exposed on Buckner Creek in the southeastern part of township 1 S., 22 W., where they have a total thickness of about 150 feet; some low folds give these beds an appearance of a much greater thickness. On Cedar Fourche in township 1 S., 21 W., section 20, the limestone beds are not so massive and are interbedded with shales, but they have a thickness of 500 feet; it is probable that this thickness comprises several overturned folds, the folds being so closely pressed that the dip is constant. The stone is blue and hard and the separate beds are ordinarily but a few inches thick. No fossils have been found in them. Some of the other localities where the same beds occur are Buckville, in the north part of township 2 S., 23 W., about Silver City, at Mt. Ida, and on the north side of Crystal Mountain ridge in township 2 S., 25 W., section 20, southwest quarter, on Cedar Creek. These limestones should not be confused with those on the south side of the ridge which are geologically in a lower position, while those on the north side are correlated with the

strata at Crystal Springs which also overlie the sandstones. At Crystal Springs these overlying limestones are associated with the graptolitic shales, but no graptolites have yet been found in this association in the Ouachita basin. In the Silver City district the pockets of argentiferous galena and other ores are commonly found in these limestones.

Yellow and red shales are the most common rocks in the Ouachita basin, as in that of the Saline, and here too they abound in quartz veins. The development of quartz is much greater than in the Saline basin, the veins sometimes reaching a thickness of thirty feet, and the crystals weighing many pounds, though the large ones are not clear. A little argentiferous galena is also found scattered through the quartz veins.

In the southern and western part of the basin the contortion of the strata is great, but the evidence of great disturbance is not so clear in the northern part. In the latter district the prevailing dip is low toward the north, sometimes nearly horizontal. This is the case in townships 1 and 2 S., 23 W., sections 32, 33, 34, 35 and 2, 3, 4, and 5, where there is a very slight north dip. The thickness is more than 100 feet, but could not be determined accurately. There is no reason to suppose that limestones are locally developed in several horizons, and that they form an unusual thickness of strata in the northern part of this basin; so it is legitimate to suppose that the repeated limestones found in this particular area belong to the same horizon and are reduplicated folds which are often underthrown, and so give the prevailing north dip. The underlying graptolite shales have been found in several localities on the northern side of this basin.

Cleavage phenomena.—On the northern side of the basin black and gray shales occur near the limestones, stratified in beds from an inch to several inches in thickness. Where they have been seen these shales are nearly vertical, but possess an almost horizontal cleavage into very thin plates. The combination of differently colored bands, with the peculiar effects given by the cleavage, produce a very pretty ribbon-like appearance where the shales are exposed for considerable distances, as they are on the road from Buckville to Cedar Glades. On the road along the valley of Blakely Creek, in the south part of township 1 S., 20 W., the same black and gray shales occur. Here the dip of the beds is steep, northwest and pretty constant. The cleavage, however, changes; in going from northeast to southwest the dip of the cleavage is low toward the north; then it changes to the horizontal, and in section 31 it is west at a low angle. The existence of this horizontal cleavage is somewhat puzzling. It was hardly possible that it was induced before the beds were tilted, because the tilting would not produce the change in the dip of the cleavage unless the original cleavage varied considerably in the position of its planes. It might be supposed, also, that the cleavage was produced by the pressure which caused the tilting of the rocks at some time during the folding process; but there is still the difficulty of accounting for its horizontality. An explanation which occurs to the writer is that the cleavage was induced after the folding was finished; and was caused by the weight of the superincumbent strata which had been greatly augmented as a result of the doubling into sharp folds.

Terraces and gravel plains.—The town of Mt. Ida is built on a broad gravel terrace, fifty feet above the level of the South Fork, and 700 feet above sea level. The gravels are twenty feet or more in depth according to measurements made in different wells. In this plain the South Fork has cut another terrace at a lower level and much narrower than the upper one, and below this is the present stream bed. The upper terrace rises in a gentle slope to the base of the sandstone ridge south of the town.

At the eastern end of this ridge in township 2 S., 24 W., section 30, southwest quarter, the presence of a large number of rounded boulders at its base together with the steep slope seem to indicate the existence of a temporary shore line at this point. This line is not a noticeable feature at other localities, but it was not sought with care since it did not come directly within the writer's province. Very likely the locality mentioned shows the existence of a shore line more strongly because it was an exposed headland in the body of water which

covered the South Fork valley. Other extensive gravel deposits were noted on the divide region between the South Fork and the main Ouachita in the south part of township 1 S., 23 W., and north part of township 2 S., 23 W. These gravels were either spread out as a thin covering over an uneven surface or else erosion since their deposition has given the region its rolling topography. No measurements of the depth of the deposits were obtained; the appearance is that of a thin covering, yet on the other hand but few rock outcrops were found projecting through the gravels even though they occupy the position of a divide between the two streams and must at times reach an elevation of 200 feet above the river. The highest parts of this divide are, according to the topographic maps of the United States Geological Survey, at the same elevation as the Mt. Ida terrace. The pebbles are of novaculite and quartzose sandstone intermingled, and are frequently several pounds in weight.

Another phenomenon observed in the Ouachita basin that may be connected with the submergence during which the gravels were deposited, is the occurrence of a high bench in the northern part of township 3 S., 24 W., and the southern part of township 2 S., 24 W. This is very noticeable in descending northward from Logan Gap. A hundred feet or more below the gap there is a marked change from the steep mountain slope to a flat area which has a general width between the streams of nearly two miles. In this bench the streams have cut deeply and even the small ravines are well developed, suggesting that they were already defined before the submergence, that the portions between the streams were high tongues projecting from the mountain, and that during the submergence these tongues were cut away leaving the present bench. The road from Silver City to Mt. Ida crosses a large portion of this bench in township 2 S., 24 W., section 28. The area is apparently almost isolated, the top is flat and contains some small swamps. This bench is higher than the Mount Ida terrace, being 750 feet according to the United States Geological Survey's topographic maps.

The Caddo basin.

The western division of the great northern basin has a maximum length of ten miles. It is drained chiefly by the head waters of the Caddo River, though a large part of the northern and western portions of the basins belong to the drainage of the South Fork and to other branches of the Ouachita. This basin has a newer appearance than the others; that is, the surface is more uneven being broken by many ridges; the bottom lands are less extensive, and the fall of the streams is more rapid.

Formations and structure.—The representative rocks of the other basins are also found in that of the Caddo. There is less limestone, however, toward the west; the graptolitic shales increasing as the limestones decrease in thickness. This gives the black shales much more prominence in this basin than in the others, and they are particularly noticeable along it southern side. There is the same evidence of great crushing into wrinkles as before but the trend of the larger folds of the Caddo system often noticeably controls the wrinkles. Thus several of the synclinal folds can be traced in the basin by a prolongation in the underlying black shales, which have also suffered the lesser disturbances which form the wrinkles. The shales of the Caddo basin are freer from the quartz which is so abundant in the other two.

Drainage.—The relations of the two general drainage systems of the Caddo basin are brought out in an interesting way by the study of the divides. That between Big Fork Creek and the head of the Caddo in township 3 S., 27 W., section 30, has a very steep slope toward Big Fork Creek and a gradual one toward the Caddo. This would indicate that the Big Fork drainage is increasing at the expense of the Caddo, or that the longer drainage way is gaining over the shorter since the Big Fork drainage passing into the Ouachita travels two or three times as far to reach the mouth of the Caddo than it would if it went by way of the Caddo valley. This is but a local instance, however; in another place, the northwest corner of township 3 S., 25 W., the steep slopes are in favor of the Caddo drainage over that of the branches of South Fork.

THE DALLAS BASIN.

In the western part of the area, between the northern ridges of the great novaculite anticline and the sandstone mountains from six to ten miles north, is a generally level country, in which lie the upper valleys of the Ouachita and of the Mountain Fork of Little River. The portion forming the divide between the headwaters of these two streams is a flat plain abounding in swamps; apparently an area that has been recently submerged, made level by the deposition of sediments but not yet cut into by a new drainage system. The sediments are fine gravels and clays with a thickness of ten feet or more noticed in some stream cuttings; how much thicker they may be it has not been determined. The plain extends east-west from the swampy divide for a number of miles, the stream valleys being small depressions in the plain. Dallas, the county seat of Polk county, is built upon this plain, and from the town the area has been named.

On the north side of the Board Camp Ridge in township 3 S,, 29 W., section 18, Board Camp Creek cuts through coarse gravels several feet in thickness, and in many places firmly cemented by iron into a conglomerate. This waterworn material probably belongs to the same period of deposition as the rest of the gravels.

The Paleozoic rocks of the area belong to the series overlying the novaculites. The sandstones immediately above the novaculites are more argillaceous and less quartzose than they are farther east and south of east; they dip deep down with the novaculites, for they do not appear conspicuously in the basin. The shales overlying the sandstones are the rocks commonly seen; they are considerably twisted and contorted, though the dips are usually low. Among these shales some black bituminous beds have a greater development than they have farther east. They outcrop more frequently than the yellow and red shales with which they occur. They are easily recognized by their greasy lustre and feeling, which are characteristic.

THE MAZARN BASIN.

The Mazarn basin forms a great synclinal depression in the Ouachita uplift. If that portion of the syncline between the gorge of the Ouachita in Mill Mountain in township 3 S., 18 W., section 31, and the head of the South Fork of Caddo be regarded as comprising the basin, then its length is sixty miles and its greatest breadth ten miles. The name Mazarn has been applied to this basin because the Mazarn Creeks are the only large streams entirely belonging to this area. Through the Mazarn Creeks and others fully three-fourths of the area drains directly into the Ouachita River. The western end drains through the Caddo to the Ouachita. The divides between the two systems are generally flat and swampy, though well elevated. Gravel beds are not common away from the stream valleys, and other indications of a Pleistocene submergence are not very clear. At Hot Springs on the south side of West Mountain, and near its western end there is the semblance of a sea bench. From the Bear-Hot Springs road the slope north to the base of the mountain is gradual and rounded pebbles and small boulders abound. At the base of the mountain, however, there is no well-defined scarp. The extensive benching noted in the Ouachita basin would naturally be looked for in the Mazarn basin; but the general level in the latter is lower, so that such a bench would be cut high in the mountain sides; the hard novaculites show no noticeable evidence of shore line erosion.

In the character of its rocks the Mazarn Basin resembles the Dallas Basin, both of them containing the strata that overlie the novaculites. The sandstones of the Mazarn Basin, however, are much thicker than those at Dallas and were apparently thrown into higher folds so that there are numerous ridges throughout the basin, some of which are from 200 to 300 feet in height. The red, yellow, and black bituminous shales also occur in the Mazarn Basin. The rocks are much crushed, and there are many small anticlines and synclines, though a general dip in one direction is a common feature of the region. In the section exposed along the roads from Hot Springs to the Trap Mountains a steep south dip prevails for almost the whole distance. It is certain, however, that there is no such thickness of rocks present as the constant dip would signify, and the frequent repetition of red sandstone and shale beds indicates a reduplication by folds; thus the constant south dip in the instance cited shows a general overthrow of the folds in that part of the basin between Hot Springs and the Trap Mountains. Farther east, along the track of the Hot Springs Railroad, the folds are more open, and the successive anticlines and synclines can be seen from the windows of a passing train.

Pigeon Roost Mountain.—The prominent features of the Mazarn basin are Mazarn Ridge and Pigeon Roost Mountain situated in the west central part of the region. Of these Pigeon Roost Mountain is a much more prominent topographic feature, while Mazarn Ridge has a greater length. The mountain extends in township 4 S., 23 W., from section 11, northeast quarter to section 20, southwest quarter, a distance of about five miles. It is a novaculite ridge having a crescent-shaped curve, and five peaks which vary considerably in height. In structure it is an anticline rising abruptly from the overlying sandstones. At either end the first dips seen are nearly vertical, the radiating dips of an anticlinal nose not being seen at all. At the northeast end the anticline is split into two parts for a short distance. The northern one of these divisions shows first a vertical dip which changes to south as one ascends the ridge; the south arm has a dip of 37° south. The strike of the rocks in the north arm is east-west, on the south arm 5° north of east; thus there is an indication of an anticlinal nose which soon becomes overthrown. The first peak occurs at the junction of the two arms. The next and highest peak of the ridge is about a mile away in a direction a little south of west. The ridge between the peaks shows south dips varying between 54° and 70°. This is clearly the overthrown dip of the north side of the anticline, since the ridge connects the north sides of the two peaks, the south side of the anticline being worn away. It is indicated, however, by a tongue reaching eastward from the high peak on the south side of Pigeon Roost. There seem to be many different dips about this high peak and its ridges, so that the top of the peak looks like a syncline. The southeast dip of 60° on the north side, however, shows that the structure is still an overthrown anticline and that the other planes which are so very prominent in the ledges of this peak are joint planes. A lower peak lies south of west from the high one; again the connecting ridge runs into the north side of the peak, and again a spur from the south side extends eastward, indicating as before that the south side of the anticline has been worn away. The location of the latter peak is about at the corners of sections 9, 10, 15, and 16. The dip remains about 70° southeast. From this peak the ridge continues from the south side and only a spur projects westward on the north side. This spur shows a north dip of 64° which changes to the vertical nearer the west end. Following the ridge southwest the dip becomes vertical and sharp, jagged ledges form the crest of the mountain. Then the ridge top broadens as the two sides of the anticline are both represented in the ridge; the dip is again southeast as the whole mass rises in the fourth peak. The direction of the ridge has now changed to S. 20° W. The fifth peak shows an easterly dip of 33° on the east side, and 66° W. on the west side. Another dip taken farther south was 65° southeast. The dips at the south end of the ridges are steep, but show the two sides of the anticline which disappears very suddenly below the overlying rocks. As a continuation of the Pigeon Roost axis a short low ridge of novaculite rises on the west side of Caney Creek in the northeast quarter of section 30.

There are several remarkable points about Pigeon Roost Mountain. First, its isolated position and abrupt rise from the basin of geologically higher rocks. In other places novaculites crop out in isolated patches but they are not pressed into a high mountain ridge. The highest peak of Pigeon Roost

must approach 900 feet in height. Second, the curve in the anticlinal axis of at least 70° is noteworthy. Third, the relation of the axis of this ridge to the axes of the greater mountain ranges is of interest. Pigeon Roost is much nearer the mountains of the Caddo Range than to the Trap Mountains, yet the general trend of the ridge corresponds with that of the Trap Mountain system. On the other hand the axis of the ridge is more nearly parallel with the axis of the Caddo Range northwest of Pigeon Roost. Thus it seems that the direction of the strike of Pigeon Roost Mountain depends upon that of the Caddo Range and consequently that the anticlinal fold of Pigeon Roost is relatively later than the folds of the Caddo Range. But the shearing movement which seems to have affected part of the Trap Mountains as well as the Zigzags is also manifested in the direction of the Pigeon Roost axis. In this way it seems to be indicated that the shearing movement took place late in the general movements accompanying the folding of the Ouachita uplift. The same conclusion was previously reached* from evidence of another sort concerning the relative ages of the east-west and northeast-southwest folds of the Trap Mountains. By itself either proof is, perhaps, weak, but together they form a strong argument in favor of the view that about the Mazarn Basin the later, perhaps the latest, movements were those producing the northeast-southwest folds, or at least giving the northeast-southwest trend to former east-west folds. It seems entirely possible that such shearing movements may take place about a resisting area, such as the Mazarn syncline evidently was, without any change in the general direction of the pressure.

At one other locality in the Mazarn Basin the novaculite comes to the surface; this is at a place a little over a mile southeast of Pigeon Roost Mountain and about in the southeast quarter of section 14. No ledges of novaculite in place were seen, but the angular fragments found over a small area indicate that the upper beds reach the surface at this place.

The Mazarn Ridge.—The Mazarn Ridge is the second

*Pages 240, 248.

prominent topographic feature of the Mazarn basin. It is formed of the sandstones that overlie the novaculite, and it is practically through the rocks that form the Mazarn Ridge that the Pigeon Roost Mountain breaks. It might be expected that the anticlinal fold of Pigeon Roost would be manifest in the Mazarn Ridge sandstones. In reality the Mazarn Ridge sandstones continue in a prominent ridge on the north side of Pigeon Roost Mountain and parallel with it, but on the south side they have been completely eroded away. West of the southwest end of Pigeon Roost the sandstones lose their topographic prominence and become part of a generally flat elevated region. At the northeast end of Pigeon Roost the Mazarn Ridge is broad; on top of the ridge toward the south side, the dip of the sandstones is 43° south, and the south slope is comparatively gentle. The north slope is steep, and on the extreme north side the dip is 40° south, showing that the anticline is much overthrown. The gentle south slope and the abrupt north one is a persistent feature with this ridge; on the line between townships 3 S., 21 and 22 W., it is even more marked. In this latter locality the dip on the south side is nearly vertical, while on the north side it is 45° south, so the overthrow is also persistent. It seems probable that there is some connection between the overthrow and the steep slope on the north side; and it would seem that Big Mazarn Creek found a line of weakness along the overthrown side immediately at the north base of the ridge for a number of miles. The ridge is said to be continuous eastward to the Ouachita River, but it becomes less prominent in township 3 S., 21 W., and farther east.

Quartz crystals.—Although there is considerable resemblance between certain of the strata in the Mazarn basin and those of the great northern basin the development of quartz in the overlying strata of the Mazarn basin is much feebler both in sandstones and shales than in the great basin. In one locality of the Mazarn basin, however, there is a very peculiar development of quartz. This is in townships 4 and 5 S., 23 W., southeast and northeast parts respectively. The rocks are chiefly

shales with some sandstones. In them at various places in the district quartz is developed sometimes in small, perfect, doubly terminated crystals having a bright lustre, but more commonly in irregular masses bounded by plane surfaces. These masses often contain fluid drops, with bubbles, which can be seen to move within the mass of quartz. Both varieties are known as water-gems, and are sold at Hot Springs for the manufacture or jewelry or as curiosities. In the quartz of the great northern basin fluid inclusions are rarely found, but the occurrence may be considered common in the water-gem district.

CHAPTER XVIII.

ECONOMIC FEATURES OF THE NOVACULITE AREA.

NOVACULITES.

Location of the whetstone beds.—Stone suitable for manufacture into whetstones has been found in quantity in two distinct horizons in the novaculite series of rocks. Both of these are now being worked. The chief one is situated at the base of the massive white novaculites of the Hot Springs region. The sediments composing these beds are uniform in character, the size of the grains of silica and the relative quantities of the silica and other minerals remaining constant. A small variation in the amount of lime, however, has caused a wide difference in the uses for the stones from different parts of the same strata. As explained previously* the abrasive qualities of these stones depend in a large measure upon the existence of rhombic cavities caused by the leaching out of the calcite which had crystallized from the lime of the original sediments. Thus the presence of many cavities indicates a relatively large supply of lime in the original sediments, of few cavities a small supply.

The great body of the stone of the massive white novaculites throughout this area is hard and dense and belongs to the grade known as Arkansas stone. In it, however, it is always possible to find some rhombic cavities, and within a limited region northeast of Hot Springs they are sufficiently numerous to change the character of the stone to the grade known commercially as Ouachita.

The other whetstone stratum lies near the top of series and, like the first mentioned, has a wide extent. Unlike the first, however, it tends rather toward a soft rock than a hard and dense one. It is in this stratum that the iron and manganese ores occur. As shown by the microscope the cavities made

*Page 103.

by the leaching out of lime are large and abundant, so that the stone is softer than the Ouachita now quarried; in several localities the stone has been rendered so rotten that it crumbles to powder when exposed to the air. The iron and manganese oxides present often stain this stone yellowish, brownish, or reddish. The stratum seems to promise considerable rock that will be available for whetstones when well prospected.

Prospecting.—Whetstone quarries have been located hitherto in a haphazard way by finding somewhere on the novaculite ridges promising surface exposures, by making small openings into the bed thus located, and extending the observations on this bed along its strike until the quality of the stone warranted a more extensive opening. With the present knowledge of the occurrence of the stone and the general structure of the ridges it is possible to give more general rules and also more particular ones for the discovery and development of good whetstone. In the region about Hot Springs, the lower stratum is a short distance above a chocolate-colored or red shale which is found sometimes as low as the bases of the ridges though it is generally about half way up the slope. Thus it is only necessary to determine in a given ridge which side represents the top and which side the bottom of the geologic series and the bed may be located immediately and with certainty. The dip of the rocks cannot alone be taken as indicative of the geologic position of a bed in this region on account of the folds being so generally underthrown; hence the simplest way to determine the structure at a given locality is to refer to the maps published with this report. If this method is not convenient, a stratigraphic section across the ridge will decide the matter.

The Ridges.

Anticlinal ridges.—There are three kinds of ridges in the Hot Springs region, so that all sections are by no means alike.* The first kind is that of the simple anticlinal ridge in which the strata lowest in the geologic section are at the top of the ridge

*The reader should refer to the plate showing the anticlinal fold in Chapter XVII.

with the rocks higher in the geologic section on either slope and in the valleys on either side. The end or "nose" of the anticlinal ridge has the higher rocks completely surrounding the harder ridge forming rocks of the lower groups. Thus the ordinary succession of strata from the top of a novaculite anticline to the valley will be massive novaculite, thin beds of novaculite and siliceous shales, massive sandstones, and gray, black, yellow, and red shales with some sandstones in the valleys.

The synclinal ridge.—The synclinal ridge is the second variety. As in the anticline the same strata are repeated on either side of the ridge, but unlike it they are in reverse order, or as the succession of strata from top to bottom of the anticlinal ridge is abnormal when considered as a matter of altitude alone, so the succession in the syncline is a natural one, the higher rocks in the geologic series being at the top of the ridge and the lower strata at the bottom. The same groups of strata, however, are not involved in the two kinds of ridges. The crests of the synclinal ridges are generally composed of the massive sandstones that immediately overlie the novaculites; sometimes these ridge crests are of novaculite; below the novaculites are red and gray shales often containg siliceous layers; black graptolite bearing shales with siliceous layers are next found in the valleys or at the bases of the ridges; below these are blue limestones generally in thin beds. On account of the similarity of the red, gray, and black shales the sections above and below the novaculites are difficult to determine when some of the beds are not exposed. The massive sandstones, however, can generally be located with reference to the novaculites and if the sandstones are wanting the limestones can usually be found in the valleys.

The monoclinal ridge.—The third kind of ridge is the monocline; this variety constitutes more than half the total length of the ridges in the Hot Springs region. Unlike the anticlinal and synclinal ridges the strata are not repeated on either side of the ridge; instead, one side of the ridge presents half the anticlinal section or the rocks above the novaculites, the other

side presents half the synclinal section or the rocks below the novaculites, so the complete section of a novaculite monoclinal ridge is a complete section of the strata involved in the folds of this region. There should be no difficulty in determining which is the top and which is the bottom in a monoclinal section, even though the dip is so underthrown that the lower rocks seem to be lying upon higher ones as the novaculites often appear to be on the sandstones.

There have been no whetstone quarries located in anticlinal ridges because the lower novaculite stratum is not often well exposed in these ridges; also because the idea is prevalent that good whetstone rock is found only on the sides of the ridges. In synclinal ridges the lower whetstone stratum is always well exposed and several quarries have been opened; thus both Whittington's and Sutton's Arkansas quarries, and Sutton's quarry No. I, are in synclinal ridges. All the other quarries now worked are in monoclinal ridges.

When the relations of the various beds have been determined by the methods mentioned above, to find the lower novaculite stratum it is only necessary to locate the contact with the red shales and then to allow from thirty to forty feet vertical thickness of poor novaculites above which one may prospect for good stone. The Ouachita stone being considerably softer and more easily eroded than the other beds seldom outcrops and the softer portions are sure to be covered by detrital material. Prospecting, therefore, involves the labor of uncovering the ledges of rock. Such is the general character of the Ouachita stone, however, that there is but little change in the texture of the stone belonging to the same stratum within short distances, so that if a lead of good stone becomes useless on account of joint planes it may be expected that if in following along the lead the joint planes disappear, the stone will again be suitable for use. This fact has been illustrated many times in the numerous openings in the Indian Mountain ridge. It is probable that much more of the stone along this lead is suitable for quarrying than is now believed.

Pockets.—Many quarries could undoubtedly be opened farther along the strike line of beds with profit. The idea prevails among quarrymen that good stone occurs only in "pockets" which are sharply defined by joint planes at right angles to the strike of the beds. This idea, however, is not supported by the observations of the Geological Survey. Any change in the character of the stone along the strike of the beds, except those caused by an increase in the number of joint planes, can scarcely be other than a gradual one or an extremely local one; in the latter case the defects consist of small spots of harder or softer stone destroying the homogeneity of the rock.

Use of diamond drills.—The present method of making a small opening with pick and shovel, with perhaps a blast or two to determine the quality of the stone is not entirely satisfactory, since surface stone furnishes but a local and untrustworthy criterion. Surface stone is liable to undergo considerable changes which disappear a short distance below the surface; then, too, local change in the character of the stone may cause surface indications to be entirely misleading. In prospecting for stone, therefore, the diamond drill would be of great service; it would show whether stone appearing good at the surface became poor immediately below, or whether poor surface stone was underlain by good stone in sufficient quantity and near enough to the surface to pay for exploitation. This method of prospecting would be cheaper also in the end because much useless labor would be saved. Prospecting in this way could only be advantageously undertaken by a combination of the quarry owners; the first cost of a hand-drill, the only kind practicable in prospecting for whetstone, would be several hundred dollars.*

North and south exposure of whetstones.—There is a belief among quarrymen that the good whetstone is found on the north sides of the ridges rather than on the south sides; there is some foundation for this belief in the fact that the south arms of the anticlinal noses have a somewhat longer reach than

*The broken condition of many of the novaculite beds may render the use of the diamond drill impracticable.—J. C. BRANNER.

the northern arm, and the south arms are the ones having the lower novaculite stratum on the north sides. There is much more whetstone on the south sides of the ridges than is generally believed, though it is possible that the greater extremes of temperature which the surface stone on the south sides of the ridges undergoes, as well as the greater drying which it suffers in the summer may cause some changes in the character of the surface rock which render it unserviceable. Indeed, the fragments found in the most exposed situations are commonly tough and flinty or porcelanous. Whetstones have been extensively quarried on the south side of a ridge in township 2 S., 18 W., sections 30 and 29, so that there really are no sound reasons why a southern exposure should affect the quality of the stone at a considerable depth beneath the surface. It is noticeable in the instance just cited that the quarries are on the south side of a south arm of an anticline; whereas, it would ordinarily be expected that the whetstone would be found on the north side. Quarries have been worked on the north side of this ridge farther west in sections 30 and 31. The two leads of stone do not connect, so that we have in this ridge quarries in the lower stratum on the north side, and in the upper stratum on the south side. Before describing the trend of this upper stratum there is another point connected with the lower stratum the explanation of which will perhaps assist prospectors.

Continuity of the whetstone beds.—In the great monocline composing the Zigzags the leads of whetstone should be continuous throughout, except where interrupted by stream cuttings; or if not continuous as beds of whetstone they should be represented by beds of a nearly similar nature. This fact should aid prospectors, for once on the whetstone beds with compass and hammer they may follow them for many miles. The difficulties in following a lead are caused by ravines and by the anticlinal and synclinal turns at the ends of the ridges.

Ravines.—The ravines should not give much trouble, for by sighting in the direction of the strike as determined by the compass the bed can be located approximately, or if the work is done in more detail, by taking note of the dip of the beds they may be traced entirely across the ravine.

Synclines.—The anticlinal and synclinal turns also need give no difficulty; at present, however, it does not seem to be generally known by the quarrymen that in the synclinal ridge the whetstone strata pass completely under the ridge from side to side and can also be traced around the end of it. The great whetstone lead of Indian Mountain in township 2 S., 18 W., sections 7 and 8, shows the synclinal structure well. In section 8, at Barnes' and Whittington's quarries, the dip of the beds is low southward into the ridge. Eastward from this locality the dip swings to the southwest, and in Sutton's quarry No. 1 the dip is north of west. The stratum continues on the southeast side of the ridge with northwest dip, and has been prospected for a short distance, but there it has been abandoned, as it is believed that it ends. But such is not the case; the stratum continues southeastward to the Dripping Springs and connects with the beds worked for curbstone in township 2 S., 19 W., section 36, northeast quarter.

The cause of the apparent disappearance of the whetstone stratum in section 8 is found in the existence of a large ravine which has cut back into the syncline on the south side, nearly separating the two arms which compose it. It is noticeable also that in either direction from Sutton's quarry No. 1 the whetstone strata descend rapidly to a lower elevation, so that Sutton's quarry No. 1 must be in the neighborhood of 200 feet higher than Barnes' big quarry. This descent of the strata is due to the plunge of the synclinal spoon southwestward; and such a plunge is characteristic of all the synclines, though it varies much in steepness; sometimes the axes are almost vertical, at others nearly horizontal.

There is one abnormal syncline in the Hot Springs region which needs special mention; this is the syncline composing the northeastern end of Quarry Mountain and the continuation of that mountain across the west fork of Gulpha Creek.* In Quarry Mountain, on the northwest side, at an elevation of

*See figures and descriptions in Chapter XV., p. 305.

about 900 feet above sea level is the whetstone lead on which Whittington's Arkansas quarry is located. The syncline plunges southwest at a low angle. Northeast from Whittington's quarry and across Gulpha Creek is Sutton's Arkansas quarry, at an elevation of 700 feet above sea level. The two whetstone beds are identical in their relation to the underlying red shales, so it is very evident that they should show a natural connection; yet if the dip and strike of the rocks at Whittington's quarry should be prolonged in imagination toward the northwest, the whetstone bed would be considerably more than two hundred feet above the level of Sutton's quarry. As explained on page 305 the Quarry Mountain syncline has been jammed up in such a manner that a slip fault has taken place in the novaculites, and the thickness of the novaculites in the syncline has become doubled. Whittington's quarry is situated in the higher portion, that is, the one that slipped over the other, and Sutton's in the lower part. The numerous openings in these particular ridges made it possible to detect this fault slip. It is possible that similar faults exist at some of the other synclines, though it is not probable in the Hot Springs region, as there are no other synclines so sharply jammed as this one. If they do exist they will give trouble to the prospector, but from the explanation of this case they should be quickly detected.

Anticlines.—The anticlinal turns give trouble to the prospector in a different way. The lower novaculite stratum, which is the one of most importance in the Hot Springs region, is found on that side of the ridge which borders the basin formed by the breaching of every anticline. The anticlinal noses always form high peaks, and as the ridges merge into these peaks the strata are generally much crushed and confused, so that the whetstone stratum is easily lost. It can be followed approximately, however, if the prospector continues his observations at about the same distance from the top of the ridge, climbing upward as the ridge rises into the peak. When the other arm of the anticline descends from the peak the prospector should descend also; and as a rule the whetstone stratum will be found continuing about parallel with the crest of the ridge and from 100 to 150 feet below the crest. Of course, the same stratum, if followed continuously for miles, will pass through both anticlinal and synclinal curves alternately, so that when a beginning has once been made the structure can be anticipated and the prospector can readily follow it.

The upper novaculite stratum.—It has been stated that whetstone quarries have been opened in the upper whetstone stratum in one locality, 2 S., 18 W., sections 29 and 30. There is no reason why good stone should not be obtained from the same stratum elsewhere. As a rule this stratum is lower down the ridge than the other better known stratum on the opposite side of it. It may be called the outside stratum as it lies outside the limits of the great basin defined by the monocline and marked directly by the massive beds of novaculite lying between the two softer strata and forming the ridge crests. In the Hot Springs region, however, the overlying quartzose sandstones frequently form the ridge tops and then this upper novaculite stratum even crosses to the inside position with relation to the ridge crest. It can always be easily located by the prospector, because it is between the massive novaculites and the sandstones and close to the novaculite conglomerate. Being as a rule a softer stratum than the lower one it is less often exposed in outcrops, and must be sought by uncovering the ledges in promising localities. The fact that it is so generally covered makes it a difficult stratum for the prospector to follow closely, and it is as a rule exposed only in ravines and gullies. This stratum is more easily followed about the anticlinal and synclinal turns owing to the two strongly marked massive beds on either side of it, and once its position is found in the series of rocks the general location of the lead is readily kept.

Effect of elevation on quality.—The quality of the whetstone of both of the novaculite beds depends to a certain extent upon the elevation of the beds above the valleys.

The quality of the Ouachita stones depends upon the number and even distribution of minute rhombic cavities, and these cavities have been formed by the leaching out of calcite.

If the calcite is not leached out the rock is not suitable for whetstone. Stone still containing the calcite rhombs in abundance is found in the valleys. The existence of the calcite rhombs in the valley rock and of the cavities in the high mountain rock leads to the obvious conclusion that erosion by the streams is a more rapid process than the leaching, so that thoroughly leached stone will be found only at considerable elevations above the streams. The quality of the stone in the whetstone leads seems to depend largely upon elevation, for at quarries that have been opened low down on the ridges the stone becomes dense and hard a short distance below the surface. In the same way and for the same reasons, in ravines and gullies the good stone is but thin. Ouachita stone in large quantity must therefore be generally sought where the lead is well above the valley. It is doubtful, however, if a very high position on the ridge is favorable, for in such cases the supply of water necessary to dissolve the calcite is intermittent, as most of the rain falling on the ridge tops runs off directly, while farther down the sides the water supply is more constant. The quarries on the southeast side of the south arm of Cutter's Mountain in township 2 S., 18 W., sections 30 and 29, give good support to this theory; at this place in the southwest of southwest of section 29, where the ridge is lower and the quarries come near the crest, the stone becomes dense but a short distance below the surface. In either direction, however, from this place where the ridge rises higher quarries have been worked to a considerable depth. From these actual tests, then, it appears that a middle position on the ridge side is most favorable for the leaching of the rock and so most deserving of careful examination by the prospector.

Arkansas stone.—Prospecting for Arkansas stone is a different matter from prospecting for Ouachita. The greater part of the whole thickness of the Arkansas novaculites is made up of dense stone of the "Arkansas" type, but to be of economic value it must be homogeneous, as well as dense, and free from flaws and quartz veins. On account of the extremely fractured condition of this brittle rock even when free from other imperfections, good stone is rarely found in quantity sufficient to warrant quarrying. It is not possible to identify single beds of promising Arkansas stone as continuous over wide areas, and it can only be stated in a very general way that the massive novaculites of the lower group offer the greatest amount of outcrop of white stone. It is in these beds in strata adjoining the lower whetstone beds that the two present quarries are located. As already explained (see page 97), outcrops of this rock are liable to be much fractured by the action of the frost and the real quality of the stone cannot be ascertained without getting below the fractured portion.

Clay seams.—The "Arkansas" stone is permeable by water as is shown by its containing cavities like those in the Ouachita stone. It seems probable that the ferruginous clay commonly found in thin layers along the joint planes and bedding planes, was deposited by permeating waters, the material having been taken from the massive stone. A comparison by means of the chemical analyses of the ratios of iron and alumina in these clays with the ratios in the neighboring rock show a similarity between them, and this fact supports the theory above proposed for the origin of clays. If this theory has any value, the presence of abundant clay seams may be taken as a promising indication of good whetstone of either variety, since they denote that the stone has been well leached. A significant fact bearing upon this point is the existence of a clay seam several inches thick at the bottom wall of Sutton's quarry No. 7, just underlying a bed of very porous and rotten Ouachita stone.*

Possible localities of available whetstone.—In chapter VII. of this volume some specimens are described which promise whetstones of good quality, and their localities are given.

* I am of the opinion that the presence of the clay seams is as Mr. Griswold suggests, a criterion of value in locating novaculite quarries but not altogether for the reason he gives. The clay seams cannot all be accounted for as crevice deposits, for some of them are clearly ordinary sedimentary beds. Their relations to the commercially valuable novaculites is, I believe, purely mechanical; the impermeable clay prevents the downward passage of water which, when turned along an overlying stratum, leaches the soluble material therefrom.—J. C. BRANNER.

There are many other places, however, where specimens or outcrops give indications favorable enough to warrant prospecting. But even the total of all these points do not by any means indicate all the places where whetstone may be found, but show that the beds are continuous over large areas and from the localities given as starting points may be prospected along the strike lines. At present, owing to the distance from railway transportation, it would not pay to work many of these localities, but with the development of the country they may yet become available. A list of the places known is here given.

The easternmost locality noted at which the prospect of obtaining good stone in quantity seems possible is in township 2 N., 15 W., section 31, southwest quarter, on top of the second ridge from the south side of the range. This ridge is the monocline and the stone a soft Ouachita belonging to the upper horizon. Some iron and manganese occur along the top of the ridge and serve to show the exact position of the whetstone bed. This stratum has been noted at other localities along the monocline from this place to the ridge south of the Brazils post-office, and promises a large quantity of good Ouachita stone of a softer kind than any now quarried at Hot Springs. In the ridge just south of Brazils the lead is on the north side of the mountain and the stone is known locally as a white sandstone. It is entirely possible that there is some good stone on this lead further east and also on other ridges of this range. A thin section of the stone from the lead near Brazils is reported upon in chapter VII., slide No. 16.

But one other locality of stone of possible economic value was noted in the northern range; this was in township 2 S., 27 W., the south part of section 21. The stone is a gray Ouachita, resembling quartzite. It is described in the microscopic notes, No. 18.

In the Zigzags both whetstone horizons may be prospected with advantage throughout a large part of the range. Much of the range is already well known to prospectors, but the following places noted by the Geological Survey may be mentioned :

In township 3 S., 17 W., section 9, northwest corner, in the gorge through the south side of Basin Mountain, massive beds of white novaculite seem to offer a good prospect for Arkansas stone.

In the same township, section 27, southeast quarter, about half a mile north of Butterfield Station and in the valley just north of the first ridge, some strata of Ouachita stones are exposed in a little gully beside the road. The stone is of several grades and the quality is somewhat doubtful, but its nearness to the railway makes the locality worth prospecting.

In township 2 S., 19 W., Sugar Loaf Mountain northwest of Hot Springs offers a fair chance for Arkansas stone. Though the surface of the rock is much fractured the stone is white and in thick beds which below the surface would probably yield blocks of good size. The northeast continuation of Sugar Loaf Mountain ridge, in the southwest corner of section 21, where the New Mountain Valley road crosses, shows fair surface indications of Ouachita stone about 100 yards from the top of the ridge down to the northwest side. The east half of section 16 has been prospected considerably and some stone has been quarried here, but the western side of the mountain seems to have been neglected and here the upper stratum shows fair surface indications for Ouachita stone.

The Trap Mountain region has been prospected to some extent, but no quarries have been worked. The upper stratum of Ouachita stone occurs in the eastern part of the region, as shown by No. 19 of the microscopic sections. This part of the region, however, is so generally covered by soil that no outcrops were observed, slide No. 19 being from a drift fragment. The more western part of the region where the ridges are higher offers better chances for obtaining whetstone. White novaculite of better quality is found in Fourche á Loup Mountains, but where seen the beds do not seem to be massive. In township 4 S., 20 W., section 24, southwest quarter(?), beside the eastern Hot Springs–Arkadelphia road, on the south side of the eastern end of Jack Mountain, a gray Ouachita stone is scattered about in considerable quantity. The surface specimens are somewhat quartzose, but it might pay to prospect elsewhere on this lead. A similar stone is found on the crest of the anticlinal nose in township 4 S., 20 W., section 11, southwest quarter, but it has the appearance of a better quality than that previously mentioned. On the south slope of Bear Den Mountain, in about the south part of section 2, or the north part of section 11, the prospect for Arkansas stone is good, and on the crest of the ridge continuing the south side of the mountain toward the west the same beds show promising outcrops. Blocks of fine Ouachita stone are also found in the western part of the region in township 4 S., 21 W., section 30, southeast quarter, on the south side of the divide ridge and on both sides of the Point Cedar-Hot Springs road. These blocks represent the upper stratum, and they occur over a considerable area. The stone more closely resembles that of Sutton's quarry No. 6 than that found in any other locality. It has only been seen in loose fragments; the want of ledges and the wide distribution of the stone seem to indicate that the stratum here is near the surface and bent into low folds. A thin section of this stone was examined under the microscope (see slide No. 17, p. 130). Good whetstone is also reported on the ridge in sections 33 and 34, in township 4 S., 22 W., but no ledges have been discovered.

The eastern end of the Cossatot Range resembles the western end of the Trap Mountains, in showing over the low anticlinal ridges the frequent occurrence of fragments from the soft Ouachita stratum. Beds of the rock were noted by Mr. J. P. Smith as follows: Township 5 S., 24 W., section 9, northeast of southwest quarter, in a stream cutting. Same township, section 7, north half of southwest quarter, on either side of the Chany Trace road gap. On the top of the ridge which runs through the centres of sections 4, 5, and 6 of the same township good whetstone rock is exposed. In township 5 S., 26 W., section 12, northwest of southwest, at the Warm Spring, the Ouachita stratum is exposed. The stone seems to be in good quality and quantity at the western end of Warm Spring Mountain, in section 6 of the same township, on the top of the ridge. In section 6, north-central part, on the east side of Hog Pen Branch, in the gap there is a large exposure of hard, white grit, apparently of good quality. Farther west, in township 5 S., 28 W., section 4, northeast quarter, on top of the southern novaculite ridge and west of a large ravine, both hard and soft stones have been observed.

A locality of good Ouachita stone noted still farther west, is on the north slope of the Hannah Mountain ridge, in township 4 S., 29 W., section 8, southeast quarter.

All through the Cossatot Mountains the beds of hard novaculite are massive and can be prospected in many places. These beds are commonly found at the tops of the ridges, but the stream cuttings offer better opportunities for their examination.

The Caddo Range is like the Cossatot in the possession of massive novaculite beds. Both massive black and white novaculites are found in the ridges about State House Mountain, in township 4 S., 27 W., section 1. Some thick beds of Ouachita stone are exposed in township 4 S., 26 W., section 7, southwest of southwest quarter, where the Black Springs road crosses the crest of the ridge. These beds vary, however, in hardness and purity. In township 4 S., 25 W., section 18, northwest quarter, on the south arm of Fodder Stack Mountain, and about a quarter of a mile west of the peak, Ouachita stone is found on the top of the ridge. The surface fragments are rather poor, but the stone may be better below. The ridges east of Caddo Gap offer some fair prospects. A hard Ouachita stone is found in township 4 S., 24 W., north part of section 22, and south part of section 15, on the tops of both ridges; for this kind of stone the quality and quantity both seem good. There is an excellent prospect for softer Ouachita stone in township 3 S., 23 W., section 22, northeast quarter, on the south side of an east and west ridge. This stone has been used a little locally. A thin section of this stone was examined under the microscope. (See slide number 15, page 130.)

NEW USES SUGGESTED FOR THE NOVACULITE.

The purity of composition of the novaculites, as shown by chemical analyses* suggests that the crushed stone may be used as a glass-making material. Its purity would make it superior to many glass sands and equal to quartz. As it would require crushing it could not compete with glass sands as a cheap material, but it could be crushed more easily than quartz.

"Ground flint," which is no more than ground quartz, was used in the manufacture of pottery in this country in 1888 to the amount of 16,250 tons, valued at $138,125.† The soft Ouachita stone could easily compete with quartz in this use, provided freight rates were not too high. Since the above figures represent the annual consumption, the importance of the industry is apparent.

White novaculite is said to have been used formerly at Hot Springs‡ for the manufacture of small ornaments. The annual value of the product was estimated at $100. There is now no lapidary at Hot Springs, and this use of novaculite has ceased. The stone, however, the colored as well as the white varieties, might well be used for ornamental purposes. It certainly surpasses the purest marble in beauty, its texture being quite as delicate, while its translucent character adds a charm not possessed by marble. It would be a beautiful stone for statuary or for ornamental purposes, but it is seldom obtained in pieces large enough or free from flaws; it would also be very difficult to work on account of its hardness. Ornaments made from it could not be handled, for even the oil exuding from the skin is sufficient to produce finger marks upon its smooth surface in consequence of its absorption by the stone. As quartz veins are not particularly detrimental in such uses, slabs of considerable size may be obtained for table tops, and similar articles. The difficulty of sawing the stone would make it expensive, but it is more easily sawed than the agatized wood which is used for these purposes.

*See page 161.

†Mineral Resources of the United States, 1888, page 571.

‡Mineral Resources of the United States, 1883, page 494.

The porous Ouachita stone could be used for water filters, just as similar stones are manufactured at Seneca, Missouri.

One quarry has been opened by Mr. J. J. Sutton, near Hot Springs, from which is obtained a hard Ouachita stone of a quality too poor for whetstones; it comes out in large slabs, and is trimmed into shape for curbstones. The pure white color of the stone would make it a very ornamental one for building purposes. In this quarry dimension stone of large size can be obtained.

POLISHING POWDERS.

Deposits.—It township 4 S., 26 W., in either the northwest quarter of section 13 or the southwest quarter of 12, on the west fork of a small branch of Mill Creek draining the synclinal basin of Fodder Stack Mountain, the upper Ouachita stratum, in several places where it is exposed, has the character of a soft, friable stone. This stone, when exposed to the air, crumbles to a fine powder, which in its natural state is suitable for ordinary polishing purposes, and after sifting through a fine bolt it may be used for the finest jeweler's work. There are some harder lumps in the bed which require crushing to reduce to powder, and there are also some hard cherty nodules which should be rejected. The chief exposure shows the bed to be at least three feet thick, and it is very probably several times that thickness. It is crushed at this point into what appears to be a small anticlinal fold plunging slightly toward the east. The bed is exposed again farther west up the ravine, so the supply at this point is large. The locality, however, is difficult of access, for the gorge through which the stream flows is steep and narrow. Another disadvantage is that the beds lie at a steep angle, and all are so weak that it would be necessary to remove a large amount of cap material in order to mine the powder in large quantities. Thin sections of the two hard varieties from this bed were examined under the microscope, and are reported upon in the chapter on microscopy. (See Nos. 22 and 23, p. 132.)

A specimen of the same powder, furnished the Survey by

Mr. J. D. Hollyfield, of Fancy Hill, came from the New Grover shaft in township 4 S., 26 W., section 33, south half of the northeast quarter. This sample came from a depth of forty feet and was penetrated for twelve feet without reaching the bottom of the stratum. The dip of the beds at this locality is low. The stratum contains lumps and nodules like those found at the last locality. If the dip were carefully noted at this locality and a calculation made to determine at what point on the surface the bed should outcrop and the outcrop found, it might prove a profitable place to work, since it would be more accessible in a surface exposure than where it is cut in the shaft.

"Tripoli" in Missouri.—A stone which has been worked extensively in southwestern Missouri, at Seneca and Dalton, closely resembles this rotten Ouachita stone. It is very porous with rhombic cavities, but since it does not disintegrate in the air, it requires grinding to reduce it to the form of a polishing powder. No. 51 of the thin sections examined under the microscope is from this rock. (See p. 143.) Its cohesion is sufficient to make its use possible in solid form for those purposes where porosity is desirable; thus water-filters, blotters and fire-kindlers are made from it. These articles are patented. Powder is made from the stone by crushing, grinding in a common mill between buhrstones, and then sifting through bolts similar to those used for bolting flour.* The finer powder is used for the finest polishing purposes, for tooth-powder, and in the manufacture of soap. It is employed also as a substitute for white lead used for the first coat in painting.

Prices and qualities of polishing powders.—The Missouri supply of stone used for making polishing powders is large, and it is obtained at small expense. In color it is white, yellowish or pinkish. The white stone brings the highest price when powdered. The qualities of the powder are excellent and it commands a high price in the market, though it is comparatively little known. Other polishing powders sold at retail are

*The American Tripoli Company at Seneca use two bolts of 70 and 120 mesh respectively.

"Tripoli" at \$.25, "Rouge" \$.50, "Rottenstone" \$.10, and "Arkansas powder"* \$.30 per pound. The Missouri "Tripoli" brings higher prices than the manufactured Arkansas powder, though the former could be put on the retail market at nearly the price of the rottenstone. The wholesale price of the Arkansas powder is only 10 cents per pound, and it could not be manufactured at a much lower cost. Rottenstone (powdered) is quoted wholesale at 3¼ to 3½ cents per pound.

Miscroscopic examinations of these four powders made to determine their comparative merits gave the following results:

The Arkansas powder contains quartz grains varying from .01 to less than .001 millimeter in diameter, the average being less than .005 mm.

In the Tripoli the quartz grains vary from .05 mm. to .001 mm. in diameter, many of them being about .02 to .03 mm. Besides the quartz it contains much dust and a little iron in red powder.

The rottenstone contains the quartz grains similar in size to those in the Tripoli. It also contains rhombs of lime carbonate from .03 mm. to .005 mm. in diameter. A greenish earthy material probably gives the grayish brown color to the powder.

The rouge consists of a red dust having no grit when tested between the teeth. There are a few grains of silica present about .05 mm. in diameter, but these may be accidental. Rouge is clearly different from the other powders. Of the three whose virtues depend upon the silica the Arkansas powder is evidently the best since it contains no impurities to hinder abrasive action or produce stains, and contains no coarse grains that might scratch the object polished. The Missouri Tripoli and the manufactured Arkansas powder are identical as far as abrasive qualities are concerned, but the Missouri powder can be produced more cheaply, while Arkansas powder has the advantage in appearance, being much whiter.

The chemical analyses made by the Geological Survey of these two powders show their similarity in composition:

*For manufacture see p. 102.

Analysis of Polishing Powder.—Sample pure white freed from a few flakes of brown clay found through it and passed through a sieve of 150 meshes to the inch; most of it went through without powdering. Specimen dried at 110-115° C. (From 4 S., 26 W., S. E., of S. W. of section 12.)

Silica. ($Si O_2$)	97.32 per cent.
Alumina. ($Al_2 O_3$)	1.61 "
Ferric oxide. $Fe_2 O_3$)	0.35 "
Lime. ($Ca O$)	Trace.
Magnesia. ($Mg O$)	Slight trace.
Potash. ($K_2 O$)	0.13 per cent.
Soda. ($Na_2 O$)	0.12 "
Loss on ignition. ($H_2 O$)	0 63 "
Total	100.16 per cent.
Water at 110°-115° C.	0.029 per cent.

Analysis of "Tripoli" from Seneca, Missouri.—Chips broken from a block, most of the material when mashed with the fingers went through a sieve of 150 meshes to the inch without powdering. Cream colored. Specimen dried at 110°-115°C.

Silica. ($Si O_2$)	98.28 per cent.
Alumina. ($Al_2 O_3$)	0.17 "
Ferric oxide. ($Fe_2 O_3$)	0.53 "
Lime. ($Ca O$)	Very slight trace.
Magnesia. ($Mg O$)	Extremely slight trace.
Potash. ($K_2 O$)	0.17 per cent.
Soda. ($Na_2 O$)	0.27 "
Loss on ignition. ($H_2 O$)	0-50 "
Total	99.92 per cent.
Water at 110°-115° C	0.21 per cent.

Two other analyses of the Missouri stone show over 98 per cent. of silica. The slightly lower percentage of silica in the Arkansas polishing powder than in the Ouachita stones may be accounted for by the fact that the specimen came from near the surface where the relative amount of impurities was greater.

Possibilities of the Arkansas polishing powder deposits.—It is manifestly a waste of energy to grind Arkansas stone into powder when identically the same powder can be found in a natural state. At present the two Arkansas localities previously mentioned are too far from the railway to make it possible for them to compete with the Missouri product, but with better facilities for transportation and the decreased cost of production, sifting alone being necessary, the more attractive appearance of this powder would give it a leading position in the market. It is possible that this powder can be found in some places along the upper Ouachita stratum at the eastern end of the novaculite area, and that it may become immediately available. Specimen No. 20 described in the chapter on petrography (see p. 131) comes from this stratum and is almost in the condition of powder. The locality from which this specimen was taken is 100 yards northeast from Central Avenue, in the town of Hot Springs, in the first ravine north of Happy Hollow.

A pure white powdered silica is in demand for many purposes besides those mentioned above, so the value of the soft Ouachita stratum may eventually prove to be great. This powdered stone is probably suitable for all purposes for which flint, silex, and ground quartz are used.

Other localities of silica powders in Arkansas.—Outside the novaculite area some deposits of silica powders have been reported to the State Geologist, but neither their extent nor quality are known except by sample. Such a powder is said to occur in abundance in Lee's Mountain three-quarters of a mile north of Yellville, Marion county, and a good sample has been submitted from that locality.

A sample of infusorial earth has also been received, said to have come from a spring eight or nine miles west of Pine Bluff in Jefferson county. The extent of the deposit is not known. Infusorial earths are now used for very many purposes, sixty-one uses being known in 1887.* The price is about the same as that for ground quartz. It may be that the Arkansas deposit is too small to be of economic value, but the possibility is presented that the Ouachita powder may find a market for some of the uses to which infusorial earth has been applied,

*Mineral Resources of the United States, 1888, p. 578.

for the infusorial earths are less pure than the Ouachita powder and some expense of purification attends their use.

MANGANESE.

Associated with the silica of the upper Ouachita stratum manganese and iron oxides are very commonly found in lumps, nodules and veins. In some localities these ores are common, in others the rock is merely stained by the minerals, while in still others they are entirely wanting. Considerable prospecting and some mining have been done for manganese. The quality of the ores, their distribution and probable values have been treated in the report on Manganese by Dr. R. A. F. Penrose, Jr., in Vol. I., of the Annual Report of the Geological Survey of Arkansas for 1890; and persons interested in the manganese are referred to that volume for detailed information. It is sufficient here to state the opinion of Dr. Penrose that many of the ores are of good quality, and while it might be profitable for the farmers to work the surface prospects at times when the farm work is not pressing, these ores do not occur in quantities that will warrant an investment of capital in mining them.

STRUCTURAL MATERIALS.

"*Granites.*"—Within or near the limits of the novaculite area are three small districts where igneous rocks are found; these are Magnet Cove, a district in Saline county near Benton, and the Fourche Mountain district near Little Rock. At the Magnet Cove and Fourche Mountain localities quarries have been opened, and the stone has been used extensively for buildings, bridges, and paving blocks. The qualities and economic values of these rocks are presented in Volume II., of the Annual Report of the Geological Survey of Arkansas for 1890, by Dr. J. Francis Williams.

Sandstones.—At Hot Springs quartzose sandstones have been quarried in several places for use as underpinning. The stone is rather a hard one to work, but the intersection by joint planes helps greatly in getting out blocks. The faces of the joint planes are generally iron-stained, but a fresh surface has a pleasing light-gray color which would be attractive in a building stone. The chemical analysis of this stone by the Geological Survey (see p. 161) shows that it is a remarkably pure sandstone containing very little iron, so that there would be but little danger of discoloration from iron stains. Sandstones of this character are commonly found on the southern side of the area associated with the novaculites. Less closely associated with the novaculites and belonging among the Lower Carboniferous rocks are some olive-green sandstones, also quartzose, which could be used for building purposes. These are found in abundance in the Mazarn basin where they form the higher ridges.

"*Slates.*"—The shales commonly found in the valley parts of the area in different degrees of hardness and in various colors are commonly called slates. These have been quarried in several places west of Little Rock for roofing slates, and near Hot Springs for flagging. They seem to lack the toughness of a good slate and soon wear out. When sheltered from the weather, however, they are fairly durable. The rocks of the area have been so completely crushed that it is often difficult to obtain the stone in large slabs, so the waste in quarrying is great. Some of the red varieties have pretty colors and may find some use where the wear will not be so great as it is in the pavements.

Limestones.—Some curbstones have been quarried from limestone beds nine miles northwest of Hot Springs; lime has been burned at the same locality. In several other localities within the novaculite area lime has been burned for local use. Lime burning at these localities has not always been successful.* The beds are usually thin, rather impure, blue limestones, but in some localities, notably northwest of Cedar Glades on Buckner Creek, and near Blocher post-office the beds reach a thickness of eighteen inches to two feet, and are sometimes crystalline to a large extent. The stone from these

*Information of value to lime burners can be found in Vol. IV., of the Annual Report of the Geological Survey of Arkansas for 1890, the limestones and marbles of Arkansas, by T. C. Hopkins.

localities, and perhaps some others might be used as building stone.

Ouachita stone.—The use of the Ouachita stone for curbing, in Hot Springs, has already been mentioned on page 384, and the possibility is there suggested of its use as a building stone. It would be a very handsome stone for window sills or trimmings.

OTHER MINERAL PRODUCTS.

Rock crystals.—Quartz crystals are found at many localities already mentioned in the account of the detailed geology of the area among the Crystal Mountains or the shales overlying them. Their method of occurrence has been described on pages 340, 357, 366. As they come from the veins or pockets the crystals are generally covered with earth and often stained with iron. The labor of washing and scratching away the earthy matter is considerable. The iron stains are removed with oxalic acid. They are almost exclusively used for ornaments, being sold to the visitors at Hot Springs. The value of the product is about $5000 per year for the natural crystals. This does not include the value of the cut stones, of which many are sold each year in the form of watch charms and other articles of jewelry. Eye-glasses are also made of the pure crystal.

Smoky quartz.—Smoky quartz is found about Magnet Cove in small quantities, and like the rock crystal is sold at Hot Springs both cut and in the natural state. The value of the product can scarcely be more than $100 per year.

Wavellite.—In several localities about Hot Springs wavellite is found in association with the upper novaculite beds. It finds a market in Hot Springs. Perhaps two or three hundred dollars will cover the value of the annual product.

Loadstone.—Magnetic iron ores from Magnet Cove, as well as some other minerals, are sold in Hot Springs, but most of the rare minerals found in this locality are sold to dealers outside the State. For more concerning them see Vol. II., of the Annual Report of this Survey for 1890.

SOILS AND PRODUCTS

According to their mode of origin soils are divided into two groups: First, residuary or sedentary soils, derived in place from the rocks underlying them. Second, transported soils, or those formed of materials coming from rocks situated at a distance and brought together by some transporting agency. Of these two the residuary soils cover the greater part of the novaculite region of Arkansas, though the transported soils are perhaps of equal economic importance. The transported soils are of good quality, though not uniformly so, since as a rule in this area they have not been transported far, and so oftentimes their characters depend upon the rock formations immediately surrounding them, so that they are not much more heterogeneous in composition than the residuary soils.

The distribution of both kinds of soils in this area, at least to a certain degree in the case of the second variety, is dependant upon the peculiarities of the geological structure. The great sandstone formations bordering the area on the north and south sides have given residuary sandy soils to these regions, and the same strata in the Mazarn basin have given a similar soil to that region; except in the larger stream valleys the transported soils of these districts are also sandy. Between this sandstone region and the novaculites there is commonly a depressed belt seldom less than a mile wide, and generally several miles in width, which is occupied by nearly 1000 feet of much contorted shales, which upon decay yield a clayey soil. This clayey belt is timbered chiefly with the hard woods, while the sandstone region is covered almost exclusively with pine. In cultivation, the farmers say that the sandy soil produces better crops for a few years, but that the clayey soil wears longer. Neither can be called rich soils, and they would be much improved by the use of fertilizers. Some analyses of soils from the shale belt near Dallas, in Polk county* show that the soils there are of very good quality, but as they are transported soils they cannot be taken as criteria for the belt.

*See Owens' Second Geological Survey of Arkansas, page 236.

Better soils as a rule are those found among the novaculite ridges, and in particular those lying within the limits of breached anticlines. The novaculites themselves contain the elements of a good soil though in small quantity. The strata exposed below the novaculites in the breached anticlines contain limestones, and the superior quality of the soils within the confines of the great anticlines is probably due in a large measure to the presence of these limestone beds. The timber growing upon the novaculite soils is chiefly hardwood, the oak, ash, hickory and gum prevailing; and on the larger streams walnut was formerly common. A peculiar distribution of the timber on the higher ridges is worthy of mention; on the south sides nearly to the crests pines grow, about the crests are scrub oaks and small hickories, while on the north slopes the hardwoods grow to larger size and pines are seldom seen. There can scarcely be any difference in fertility on the two sides of the ridges, so the difference in tree growth must be due to the differences of temperature and moisture. Of these it must be that temperature has the greater influence, for both the dryer and colder portions of the ridges, namely, the crests, are covered by the hardwoods.

The residuary soils of the valleys lying between novaculite ridges are very stony but yield good crops of corn, while small patches of land free from stones are good farming lands. With ordinary cultivation they produce half a bale of cotton to the acre. Fruits grow finely in this area, particularly grapes and peaches, the grapes in several varieties growing wild in all situations from the bottom lands in the valleys to the mountain tops. Vineyards and orchards are now being cultivated. They do particularly well when situated at the base of the north slope of a novaculite ridge for here the temperature and water supply are more even. Vegetables of all kinds grow well, and if there were direct railway communication with the northern markets, gardening would be a profitable business on account of the early spring. Clover and many varieties of grasses grow luxuriantly; stock-raising might become a paying industry.

Timber.—The lumber industry is already a large one along the lines of a railway which touch this area, and as the country becomes more generally accessible this industry will increase. Already a short railway has been built in the eastern part of the Trap Mountain range solely for lumbering purposes; it is being extended westward as fast as the timber is cut. Temporary narrow-gauge lumber roads have also been extended into the eastern end of the Zigzags, and connect with the St. Louis, Iron Mountain and Southern Railway. Along the line of the Hot Springs Railroad also, and within easy hauling distance of Hot Springs, lumber is manufactured to a considerable extent, outside these places the manufacture is small and for local use only. The lumber manufactured is almost exclusively yellow pine. Fine hard wood timber is abundant, consisting of various kinds of oak, hickory, ash, elm, and gum, some walnut is still left; and in the southern part of the Cossatot range beech is abundant and holly is found of larger size than ordinary. Much hardwood timber is being lost at the present time, for no use is made of it on the newly cleared lands except as a fertilizer in the form of ashes.

WATER POWER.

In many places in the novaculite area streams of considerable size furnish good water power. The supply of water is constant though in the smaller streams it may become small in the summer season. There is also danger of freshets in these streams. Many available sites are now occupied by small grist and saw mills; as a rule more power could be obtained at these sites, and many others could be utilized. The largest river of the area, the Ouachita, would furnish water power in many places, but it is actually utilized at but one place at the present time, and that is at Thornton's Mill west of Hot Springs. The fall of the river from the Dallas plain to Rockport near Malvern is 750 feet, and much of this fall is concentrated in swift rapids. Some of these rapids occur where the river cuts across the Trap Mountains, others are west and southwest of Hot Springs in the Mazarn basin. Those in the gorges cut

through the Crystal Mountains are not available; a good site was noted in township 1 S., 24 W., section 26, western part. The slope of the bed of the Saline River is not great, but it is probable that sites for small mills might be found on the Middle and Alum Forks. Small mills might be located also on the Mazarn Creeks, on the Walnut Fork of the Ouachita in township 2 S., 22 W., on the South Fork of the Ouachita in the upper part of its course, and on Big Fork and Board Camp Creeks.

The best sites for water-power are where a stream cuts across the novaculites. This has been illustrated already in the case of the Ouachita River and the Trap Mountains; but a still better power is given by the Caddo River at Caddo Gap. The opportunities of utilizing this power are excellent, while there is a constant supply of water great enough to run the machinery of large mills. Other instances where the novaculites are cut by large streams are found farther west in the gorges of the Little Missouri and Cossatot Rivers. Of these the Little Missouri would give more power but it is surrounded so closely by mountains that it is not easily available except at the southernmost gorge. The "falls of the Little Missouri" where the stream transects the Cogburn Mountain are not available for water power as the stream is too small at this place. The Cossatot flows through a more open country and could be utilized in several places. As a rule the small streams, like the west Saline River where it breaks through the novaculites, and the Brushy Fork of Cossatot are the ones now running mills, the water supply being sufficient and the expense of construction less. The existence of water-powers upon the large streams promises good manufacturing industries to this part of Arkansas.

MINERAL SPRINGS.

Spring waters of well-known medicinal properties are common in the novaculite area. Some of these have become sources of profit to their owners through the sale of the waters and through the boarding of visitors. Several health resorts have been established in the neighborhood of Hot Springs, and fine spring waters and attractive locations are not wanting for the establishment of others.

Judging by the taste alone, it seems possible to divide the spring waters of the area, excluding the hot waters, into six general groups: pure waters, chalybeate, lime, chalybeate and lime, sulphur, and copperas and alum.

Pure waters.—Pure waters are common among the mountains and issue from the novaculites or the overlying sandstones, being the surface waters which have percolated through the rocks of these formations. The purity of the rock material is attested by the water which comes from them. The Happy Hollow Spring at Hot Springs belongs to this class. An analysis of this water made by the Geological Survey of Arkansas, R. N. Brackett, analyst, is as follows:

Analysis of the Water of Happy Hollow Spring.

(Hypothetical Combination.)

Constituents.	Grains per U. S. Gallon.	Per Cent. of Total Solid Material in Solution.
1. Chloride of potassium (KCl)	0.0456	2.76
2. Chloride of sodium (NaCl)	0.2221	13.47
3. Chloride of magnesium ($MgCl_2$)	0.0014	0.08
4. Sulphate of magnesia ($MgSO_4$)	0.0908	5.50
5. Ferrous sulphate ($FeSO_4$)	0.0236	1.43
6. Sulphate of alumina ($Al_2 (SO_4)_3$)	0.234	1.42
7. Carbonate of magnesia ($MgCO_3$)	0.0945	5.73
8. Carbonate of lime ($CaCO_3$)	0.7703	46.68
9. Silica (SiO_2)	0.3784	22.93
Total	1.6501	100.00
Free carbonic acid (CO_2)	4.5464	

This is the purest water that has been analyzed by the Survey, containing but 1.65 grains of solid matter to the gallon. Of this matter nearly half is lime carbonate, which gives a sparkling appearance and a pleasant taste to the water. The other principal ingredients tend to improve the water, and none of the lesser ones injure it as a drinking water. It is probable that other of the clear water springs that come from the novaculites are as pure as this.

Chalybeate waters.—Almost if not quite as common as the pure water springs are those of the chalybeate water. These also are very common among the novaculite mountains, but commonly come from a particular part of the formation, the upper Ouachita horizon, also known as the manganese and iron bed. This porous stratum is a great water channel and the springs issuing from it are much larger than the pure water springs. The iron beds of these springs are probably derived from the limonite of this stratum. Chalybeate springs are also commonly found in the basins of rock underlying the novaculites, but they are not so plentiful in the overlying rocks. Chalybeate springs are noted at many places in the account of the detailed geology. Some are very large, for example the great spring at Crystal Springs, the Big Chalybeate near Hot Springs, and the Warm Spring in the eastern part of the Cossatot Mountains.

Lime waters.—The limestones underlying the novaculites furnish hard waters in the districts where they approach the surface. Since the distribution of the limestone is general (within the area of the great breached anticline) hard spring waters are commonly found in that area.

Chalybeate and lime waters.—Sometimes iron is present in these hard waters in sufficient quantity to produce the red deposit characteristic of chalybeate springs, and to give the taste of an iron water. The big Mountain Valley spring belongs to this class.

Sulphur waters.—Several springs of Sulphur water are kown. The greatest resort is at the Potash Sulphur Springs, near Hot Springs. The strongest water tasted was from the spring at the house of Mr. W. E. Maddox in township 2 S., 27 W., section 32, southeast quarter of northwest quarter. Of nearly equal strength and greater volume is Hutchinson's sulphur spring in township 3 S., 27 W., southeast corner of section 9. Both these springs have a white deposit. In this same vicinity, on the headwaters of the Caddo, another sulphur spring is reported. The sulphur springs in township 1 S., 24 W., section

23, northeast quarter, at the fork of Muddy Creek, also have strongly impregnated waters.

Copperas and alum waters.—The copperas and alum waters come from the black shales of the lower graptolitic horizon. A few springs noted in these shales have sour waters, and wells dug in them are sometimes abandoned; the waters, however, are not always bad. The decomposition of small deposits of pyrites is probably the cause of their peculiarities. The waters flowing from the abandoned Texas Tunnel mine near Crystal Springs furnish the best example of the waters of this class. Incrustations of alum are formed about the walls of the mine.

CHAPTER XIX.

THE FOSSILS OF THE NOVACULITE AREA.

INTRODUCTION.

Until the present work was undertaken, no fossils had been found in the novaculite area, and the previous attempts at correlations of the rocks of this area were made entirely upon a lithologic basis. It is now possible to distinguish two distinct fossiliferous zones, within the area, one characterized by the presence of graptolites and a few other forms regarded by Prof. H. S. Williams as belonging to the upper part* of the Lower Silurian, and the other by the remains of plants probably belonging in the Lower Carboniferous or Mississippian series. The identifications of the plant remains have not been sufficiently positive to alone determine the age of the rocks in which they occur, but the evidence which they give is supplemented by the general knowledge of the stratigraphy of Arkansas possessed by the State Geologist. All the evidence is that the Lower Carboniferous strata overlie conformably the Lower Silurian rocks. No Devonian or Upper Silurian beds have been identified as yet, and the two established horizons are separated by only about two hundred feet of strata.

The paleontologic work upon the Lower Carboniferous horizon, so far as it is treated in this volume, was done by Mr. Charles S. Prosser of the U. S. Geological Survey, and this Survey is particularly indebted to him for his extensive and careful work upon the Silurian as well as the Lower Carboniferous rocks.

In addition to those collected by the writer, fossils have been collected by Mr. J. Perrin Smith of the Arkansas Survey, and by Mr. Charles S. Prosser and Dr. W. P. Jenney of the U. S. Survey. As it did not seem expedient to credit each

*Lower half or lower middle portions. R. R. Gurley.

individual by separate lists of localities, all the work done upon the graptolites has been brought together and the collectors at the various localities have been credited by giving their names after each location. Where more than one person has collected at a locality, the names are placed in the order of time of collecting.

For the specific determinations of fossil forms the Survey is indebted to Prof. H. S. Williams, Mr. C. D. Walcott and Dr. R. R. Gurley. The work of identification upon the graptolites, however, has been done by Dr. Gurley and he is responsible for all determinations of species, but not for opinions relative to the stratigraphic position of the graptolite beds except where specially stated.

Dr. Gurley distinguishes in the graptolite-bearing rocks of Arkansas two horizons, a middle Trenton or Dicellograptus zone and a Calciferous or Dichograptus zone. Stratigraphically the Dicellograptus or Trenton beds are found to be separated into two parts through a large part of the novaculite area by a considerable thickness of barren strata. A brief explanation of the stratigraphy of the region with reference to the Trenton graptolites is as follows: The novaculite rocks form a single continuous horizon throughout the novaculite area, though there are variations in the character and strength of the formation in different localities. With reference to the novaculite monocline which outlines the north side of the great Ouachita anticline, the Trenton graptolites have been found stratigraphically both above and below the massive novaculites; those found above being commonly associated with black siliceous shales. On the south side of the Ouachita anticline and in the Trap and Cossatot Mountain systems the graptolites have only been found below the novaculites. Black siliceous shales and the black novaculites commonly exist above the massive light-colored novaculites in these regions, and must correspond with the graptolite-bearing strata, having the same stratigraphic position on the northern side.

Since the Trenton horizon is thus stratigraphically separated

into two parts, the notes describing the Trenton localities have been grouped to correspond.

The stratigraphic position of the Calciferous graptolites is a peculiar one. Graptolites belonging to this horizon have been found in but two localities, both on the northern side of the Ouachita anticline; but in each case the evidence is very positive that the strata containing these forms are situated above the novaculites. Therefore they occur in the same general horizon with the upper stratigraphic division of the Trenton group, and it would seem that they occur at the base of this group. Thus they occupy a position between the two divisions of the Trenton.

With reference to this peculiar occurrence of the Calciferous the region in question seems to offer no explanation; but the separation of the Trenton group into two parts by a series of barren rocks may be accounted for in this way: It has been previously explained* that the novaculite formation becomes weaker toward the north. It is possible that farther north than the novaculite is found now this barren formation was entirely wanting, and the two divisions of the Trenton group existed as one. Of course, under such a supposition, a return southward, when the conditions became favorable, of forms identical with those found below the novaculites is entirely possible. As shown by the existence of more massive black siliceous beds overlying the novaculites in the south part of the area, the conditions were not favorable for such a great southward extension as the first or lower division possessed.

Besides the graptolites and plants, there have been found a few brachiopods, lamellibranchs, corals, and worm trails. These so far as they furnish evidence, support the conclusions drawn from the graptolite material.

THE GEOLOGICAL AGE OF THE GRAPTOLITE SHALES OF ARKANSAS.

By R. R. Gurley, M. D.

A study of the Arkansas graptolites has shown that two distinct horizons are represented: a Trenton horizon and a Calciferous horizon.

*Chapter IX., page 193.

The fauna of the first horizon is in a general way the same as that yielded by the black graptolitic shales of the Hudson River valley, which form part of the so-called "Hudson River Group." This assemblage of forms is commonly known as the "Norman's Kill fauna."

The horizon of the Norman's Kill shales has been for years a matter of controversy. They have usually been correllated with the Utica or Lorraine shales farther to the west, especially with the former.

Without entering into an extended discussion of this question, I may say that the only view that receives any support from my own studies is the one put forth by Professor Lapworth,* who first suggested that these Hudson Valley black shales are some distance below the Utica shale. The same authority also expresses his belief that these shales crop out unconformably from beneath the Trenton limestone, but this view seems to me hardly probable.

Not improbably, the Hudson Valley beds represent an eastward replacement of the Trenton limestone by shales and grits, and they may ultimately be found to represent several horizons within the limits of the Trenton formation. That these beds are not of Chazy age, is, I think, evident from the fact that I have collected at Schodack Landing, N. Y., at the locality first noted by Mr. Ford,† in the limestone interbedded with the graptolitic black shale carrying the "Norman's Kill" fauna, a series of fossils which cannot be pre-Trenton, and further because there is in the National Museum collections a "tuning fork," *Didymograptus*,‡ collected in Nevada by Mr. C. D. Walcott, from beds which he informs me are positively supra-Calciferous, that is, at least as high as the Chazy. Considering that the *Didymograpti* of that form mark such a definite horizon (in Britain the summit of the Arenig and the base of the Llandeilo) and that they are separated from the beds which carry the "Norman's Kill" fauna by a vast interval (in Britain nearly the entire thickness of the Llandeilo), it seems almost certain that the horizon of the last-named fauna must be placed above the Chazy. That the "Norman's Kill" fauna is entirely different from that of the Utica shale is shown by the fact that (in spite of the assertions to the contrary, based upon incorrect identifications of species,) very few species of graptolites (I know of but two) are common to the two. The place of the "Norman's Kill" fauna is thus by exclusion found in the Trenton period and probably within the lower half of that formation. The Arkansas beds are probably a little higher, their fauna resembling that of the "sub-zone without *Cœnograptus gracilis*" of Professor Lapworth.* The most marked peculiarity of this sub-zone is a negative one, namely: the absence of many species which occur so abundantly in the shales of the age in the Hudson Valley. As one genus is strikingly characteristic of the whole period, I propose the name *Dicellograptus* zone to include the two sub-zones characterized by the "Norman's Kill fauna" and the "zone without *Cœnograptus gracilis*," and the names Lower *Dicellograptus* sub-zone and Upper *Dicellograptus* sub-zone for the two sub-zones respectively.

*Lapworth, Trans. Roy. Soc. Can., V., Sec., IV., 1886, pp. 169-72.

†Ford, S. W., Am. Jour. Sci., XXVIII., 1884, pp. 206-242.

‡Apparently identical with *D, bifidus*, Hall.

The Lower *Dicellograptus* sub-zone is characterized by the presence of *Dicellograptus furcatus*, Hall, with *Climacograptus parvus*, Hall (*Mss.*) *Cœnograptus gracilis*, Hall, etc., while the upper zone is marked by the extreme rarity of *Cœnograptus gracilis* and by the entire absence of the other two forms mentioned whose abundance imparts to the lower zone its peculiar facies. The upper may also be readily distinguished by the predominance (in conjunction with *Dicellograptus*) of *diplograptids*, to a great extent, of peculiar species.

Further, the Arkansas beds indicate their slightly higher position by the approximation of the contained fauna to the Utica type notably in the *Dicranograpti* which are generally of the type of *D. ramosus* (Norman's Kill). Also the presence of a *Leptograptus* very similar to if not identical with *L. annectans*, Walcott re-inforces the same view. On the whole I

*Loc. cit., p. 172.

should place these Arkansas black shales as about Mid-Trenton.

Respecting the horizon of the localities which are marked doubtful, the paleontological evidence is uncertain by reason of small collections and imperfect preservation. Relative to these I can only say that taking into consideration the lithologic similarity and the apparent general similarity of the forms, I believe that all the Arkansas black shales examined represent about the same horizon. But for the last named series of localities this is an opinion rather than an absolute demonstration.

The fauna of the second horizon is that found in the Calciferous shales of Pt. Levis, Province of Quebec, Canada, and there can be no question that the beds containing it are of Calciferous age. I am inclined to think that they may be a little more recent than the main zone at Pt. Levis, that is that they are rather high up in the Calciferous. This opinion is based upon the similarity of the graptolite fauna to those found in a limited area of the Levis shale and also to that found in Nevada.

It is interesting to note that this is the first time that this fauna has been recognized within the limits of the United States, it occurs also in the Piñion Range in Nevada.

NOTES ON LOCALITIES OF FOSSILS—TRENTON HORIZON.

Fossils from Rocks Overlying the Novaculites.

Locality No. 1.—Southeast quarter of section 32, 2 N., 14 W. (Griswold, Prosser.) Along the creek just north of the ridge, near the house of Mr. Josiah White.

Identifications by Dr. Gurley, are:

Didymograptus, fragment.

Diplograptus foliaceus, Murch.

Glossograptus ciliatus, Emmons.

Locality No. 2.—2 N., 15 W., section 28, northeast quarter of the southeast quarter of the northeast quarter, near the east line of the section. (Prosser.)

This point is a bluff of bluish black shale on the south bank of the Little Maumelle. The exposure is a quarter of a mile east of the last and a short distance west of Slater Run, which flows into the river from the north. Graptolites occur in the shales and it is the eastward extension of the shales at the last locality.

Locality No. 3.—2 N., 15 W., section 28, southwest corner of the northeast quarter. (Prosser.)

Over the low ridge, in a line nearly south of the locality No. 2, two small runs head, one flowing west and the other east, with a small divide separating them. In the bed of the eastern one, 100 feet below the top of the hill, is a small exposure of gray and blackish flinty shales, and almost immediately above it, five feet of black shales containing graptolites. In the run a little further to the east only the graptolite shale is exposed. In the western run, over the low ridge separating them, the graptolite shales were again found.

Diplograptus.

Locality No. 4.—1 S., 25 W., section 35, southeast quarter of the northeast quarter. (Prosser.)

On the northern side of the novaculite ridges east of the road and on the western bank of the creek, just below a small branch from the west, is a prominent bluff composed of shales alternating with three strata of breccia. The breccia contains large angular fragments of novaculite and flinty rock, together with pieces of black shale. In one of the fragments of black shale are graptolites. The angular fragments of the rock are much coarser in this breccia than in that exposed in Hot Springs.*

Locality No. 5.—2 S., 25 W., near the center of section 5, just below the last ledge of black novaculite that forms the bluff on the south side of the Ouachita River at that place. (Prosser.)

*Graptolites above the novaculites have not been identified on the south side of the Ouachita anticline, but the identification of this layer of breccia on both sides indicates where they might be expected.—L. S. Griswold.

Diplograptus.

Locality No. 6.—2 S., 25 W., near Knight's, in the northwest quarter of Section 5. (Prosser.)

Diplograptus.

Locality No. 7.—In 2 S., 26 W., section 3, southwest quarter of the southeast quarter. (Prosser.)

Small exposure of black shale by roadside containing graptolites. The graptolite shale was traced to the east where it soon runs into the creek and to the west, where it enters the side of the high mountain. This shale is near the top of the entire series of massive and siliceous novaculite rocks.

Diplograptus.

Locality No. 8.—In 2 S., 26 W., section 10, about the center of the northeast quarter. (Prosser.)

Dicellograptus.

Diplograptus.

Locality No. 9.—In 2 S., 26 W., section 10, northwest quarter of the southeast quarter. (Prosser.)

In the gorge at Mr. Young's house, about one-fourth of a mile north of the Dallas road, is slaty, blackish shale and flinty rock, the shale containing graptolites.

Climacograptus.

Diplograptus.

Locality No. 10.—In 2 S., 26 W., section 10, southwest quarter of the southeast quarter. (Prosser.)

Just south of the Dallas road, in the run at the northern end of the short gorge, are poorly preserved graptolites. A single fragment of a shell was found.

Locality No. 11.—In 2 S., 26 W., section 15, northeast quarter. (Prosser.)

In this portion of the northern line of the novaculite on the western side of the road some blackish shale contains poorly preserved graptolites. This locality is north of the so-called novaculite mountain, north of South Fork.

Locality No. 12.—In 2 S., 26 W., section 8, southeast quarter of the northeast quarter. (Prosser.)

On the bank of the creek, north of the road, is an exposure

of black shales in which graptolites are very abundant. This is one of the best localities noted for graptolites along the northern line of the novaculite series. The shales at this point are in the upper part of the novaculite series, although there are still flinty and siliceous shales above the graptolites.

Identifications by Dr. Gurley are:

Dicellograptus.

Diplograptus foliaceus, Murch.

Diplograptus.

Locality No. 13.—From 2 S., 26 W., the southeast quarter of section 8, southwest of Oden. (Smith.)

Diplograptus foliaceus, Murch.

Locality No. 14.—From 2 S., 26 W., section 8, southeast quarter of the northwest quarter. (Prosser.)

A short distance south of the road and to the west of the creek is a low hill, which is formed by a small anticlinal fold. This anticline is to the west and on a line with one noticed at locality No. 13 In the creek, just a little north of the ridge and above its flinty rocks, are blackish shales containing graptolites.

Locality No. 15.—In 2 S., 26 W., section 17, probably the northwest quarter. (Prosser.)

There are some exposures of black slaty shales in the creek on the northern side of the hill, which contain plenty of good graptolites.

Climacograptus antiquus, Lapworth ?

Diplograptus.

Locality No. 16.—West of Fancy Hill in 4 S., 26 W., section 28, northwest quarter. (Griswold.)

Crustacean or annelid trail.*

Fossils from Rocks Underlying the Novaculites.

Locality No. 17.—Township 1 N., 15 W., section 2, northeast quarter of northeast quarter, on east branch of headwaters of McFadden Branch. (Griswold.)

*This fossil may belong to the Lower Carboniferous horizon.—L. S. GRISWOLD.

Dicellograptus.

Climacograptus antiquus, Lapworth var.?

Climacograptus, fragments.

Diplograptus.

Locality No. 18.—In 1 N., 18 W., section 25, southwest corner of southwest quarter. (Griswold, Prosser.)

About a quarter of a mile north of Blocher post-office on the east side of the road where the branch has a fall of three or four feet, are bluish black shales containing graptolites.

Dicellograptus, poorly preserved fragments.

Locality No. 19.—Northwest of Blocher Post-office, in 1 N., 18 W., section 26, the northeast quarter of the southeast quarter, in a small run where there is a fall of about three feet, are blackish shales containing graptolites. (Prosser.) This exposure is about half a mile west of locality No. 18 and is the continuation of the graptolite shale of that place.

Diplograptus, obscure impressions.

Locality No. 20.—1 S., 18 W., section 32, southeast corner of the northwest quarter. (Prosser.)

On both sides of Lockert Creek, just west of the highway and above the house of Mr. Neighbor, are black shales with interstratified layers of limestone. A small excavation on the south side of the creek shows shale alternating with thin layers of limestone. On the south bank, in the black shales just above the excavation, are good specimens of graptolites, and it is a good locality for collecting.

Cœnograptus gracilis, Hall.

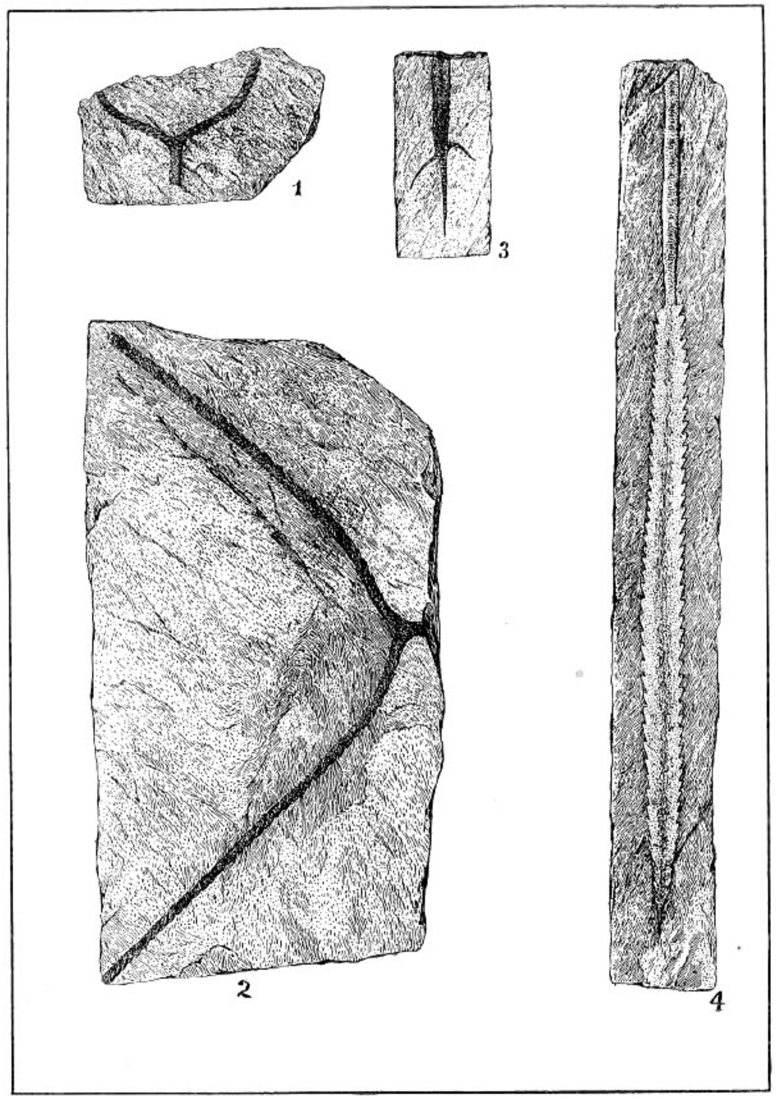
Dicranograptus arkansasensis, sp. n.*

Climacograptus.

Diplograptus foliaceus, Murch.

Locality No. 21.—2 S., 18 W., section 7, probably the southwest quarter of the northwest quarter. This place may possibly be across the line in section 12 of 2 S., 19 W. Where the Hot Springs road crosses the South Fork for the second time going southwestward, there is an exposure of blackish

*See description of this species on p. 416, and plate IX., figures 1 and 2.



NEW SPECIES OF GRAPTOLITES FROM ARKANSAS.

shale on the bank of the creek, which contains graptolites. (Prosser.)

Locality No. 22.—In 3 S., 18 W., section 10, southwest quarter, on the west fork of Boss Allen Creek, or Sulphur Fork, above the "Narrows," are blackish shales with graptolites. (Prosser.) In some of the shales the graptolites are very abundant, and some of them are well preserved.

Diplograptus foliaceus, Murch.

Locality No. 23.—In 3 S., 18 W., section 10, southeast quarter. A quarter of a mile farther up Sulphur Fork, after passing over olive and bluish shales, is another exposure of black shales with graptolites. (Prosser.)

Locality No. 24.—In 3 S., 18 W., section 10, southeast quarter, about a quarter of a mile up the northeast fork of Boss Allen Creek, is black shale with numerous graptolites. (Griswold, Prosser.) This exposure is the northeastern termination of the shale seen on Sulphur Fork at Locality No. 22. Boss Allen Creek forks just above the "Narrows," and near the base of the novaculite.

Dicellograptus.

Diplograptus, two species badly preserved.

Diplograptus trifidus, sp. n.*

Locality No. 25.—In 2 S., 19 W., section 27, southwest quarter of the northeast quarter. (Prosser.) In the northeast fork of "The Gorge" creek, on the western side, are ledges of black shales with graptolites. These black shales continue up the creek for a considerable distance.

Diplograptus.

Locality No. 26.—In 2 S., 19 W., section 27, the southeast quarter of the northwest quarter. (Griswold, Smith, Prosser.)

Near the upper end of the Gorge, at the forks of the creek, the shales become quite black in color and contain graptolites.

Dicellograptus, minute fragments.

Diplograptus.

Locality No. 27.—2 S., 19 W., near the line between the

*See plate IX., figure 3.

northeast quarter of section 28, and the northwest quarter of section 27. (Prosser.)

The graptolite shale at this place is in a small run on the west side of the continuation of Park Avenue, Hot Springs, and on the northern slope of the hill.

Climacograptus bicornis, Hall.

Locality No. 28.—The bluff on the western side of Park Avenue, Hot Springs, above Hotel Hay and a little below the Barnes House, is formed of very black shale which contains numerous specimens of graptolites. (Griswold, Smith, Prosser.) Some of them are well preserved and for collecting it is one of the best localities yet found.

Dr. Gurley's determinations for this locality are:

Dicellograptus divaricatus, Hall.

Dicellograptus, sp. undt.

Climacograptus.

Diplograptus foliaceus, Murch.

Diplograptus, sp. undt.

Locality No. 29.—On Whittington Avenue, Hot Springs, about a quarter of a mile above the head of Central Avenue, where the creek crosses the street, is a considerable exposure of black shales containing graptolites. (Griswold, Smith, Prosser.)

Dicellograptus.

Leptograptus.

Diplograptus.

Locality No. 30.—In a ledge on the north bank of the creek, in the northwest part of Bear, 2 S., 21 W., there is graptolite shale near the centre of section 29. (Prosser.)

Dicellograptus.

Climacograptus.

Locality No. 31.—Region about Crystal Springs, twenty miles west of Hot Springs, in 2 S., 22 W., section 34, southeast quarter of the northeast quarter. (Griswold, Smith, Prosser, Jenney.)

In the lower part of Crystal Springs Village on the creek, is a locality which, according to Dr. Gurley, has furnished the most complete series of graptolites found in this region.

Determinations of graptolites by Dr. Gurley are:

Cœnograptus gracilis, Hall.

Didymograptus sagittarius, Hall (name preoc.)

Didymograptus, sp. undt.

Dicellograptus divaricatus, Hall.

Dicranograptus ramosus, Hall.

Dicranograptus nicholsoni. Hopk.

Dicranograptus nicholsoni, var. parvangulus (var. n.), see p. 417.

Diplograptus foliaceus, Murch.

Diplograptus whitfieldi, Hall.

Diplograptus, sp. undt.

Dendrograptus, sp.

In the limestone, exposed in the small creek just east of Crystal Springs, (SE. of NE. of Section 34, 2 S., 22 W.) Mr. Prosser found graptolites associated with some fairly well preserved specimens of *Conularia*, brachiopods and other fragments of fossils. The *Conularia* is near the well-known *C. trentonensis*, Hall, a brachiopod that is considered a *Leptæna* by some and a *Streptorhyncus* by others. *Zygospira*, sp.? *Trematis*, sp., fragments of trilobite, *Leperditia*, sp., fragments of *Monticuliporidæ* and crinoid segments. (Prosser.)

Locality No. 32.—Crystal Springs. (Jenney.)

Didymograptus serratulus, Hall.

Didymograptus sagittarius, Hall (name preoccupied).

Cœnograptus gracilis, Hall.

Dicellograptus rigidus, Lapworth.

Dicellograptus, (like *D. intortus*, Lapworth).

Dicranograptus nicholsoni, var. *parvangulus* (var. n.) For description of this new variety, see p. 417.

Climacograptus bicornis, Hall.

Diplograptus foliaceus, Murch.

Cryptograptus tricornis, Carr.

Glossograptus spinulosus, Hall.

Dictyonema obovatum, (sp. n.) For description of this species see p. 418.

Thamnograptus barrandii, Hall.

Locality No. 33.—2 S., 22 W., section 34, northwest quarter of southeast quarter. (Smith, Griswold, Prosser.)

From a small gorge in the creek at the western end of Crystal Springs. The rocks are nearly vertical with a strike about southwest and northeast. The rock is principally a very impure, argillaceous limestone, alternating with some blackish shales which contain graptolites.

Locality No. 34.—2 S., 22 W., section 34, the southeast quarter of the southeast quarter. (Prosser.)

On the road south of Crystal Springs is a slight exposure of blackish shales with fragments of graptolites.

Locality No. 35.—2 S., 22 W., section 27, probably the northwest quarter of the southeast quarter. (Prosser.) After crossing the sandstone ridge, north of Crystal Springs, the blackish shales reappear and graptolites occur in the small ledges on the creek bank. Still farther north they are found in loose pieces of blackish shale, in a small run that enters the creek from the west. At about the northwest corner of the quarter section, a small excavation by the road side shows traces of graptolites.

Didymograptus.

Diplograptus.

Locality No. 36.—This locality is north of No. 35 and the material found was in loose fragments. (Prosser.)

Diplograptus foliaceus, Murch.

Locality No. 37.—2 S., 22 W., section 34, southeast quarter of the northeast quarter. (Prosser.)

On the western slope of the main road just east of Crystal Springs are blackish shales alternating with reddish shales, both of which contain graptolites and an occasional specimen of *Lingulops* or possibly *Pholidops*.

Determinations by Dr. Gurley from this locality are:

Dicellograptus.

Diplograptus.

Locality No. 38.—2 S., 22 W., section 34, northwest quarter of the southwest quarter. (Griswold, Prosser.)

On the south side of the valley, half a mile west of Crystal Springs, in the Texas Tunnel mine.

Identifications by Dr. Gurley are:

Dicranograptus nicholsoni, Hopk.

Dicranograptus arkansasensis, (sp. n.)

Climacograptus bicornis, Hall.

Climacograptus, sp. undt.

Diplograptus, trifidus, (sp. n.)

Diplograptus foliaceus, Murch.

Diplograptus, (sp. undt.)

Lasiograptus mucronatus, Hall.

Also a specimen of *Conularia*, sp.

Locality No. 39.—2 S., 22 W., section 33. Shaft on the northern side of the road which was sunk in the black shale one mile west of Crystal Springs. (Prosser.) An occasional graptolite was noticed in the pile of debris from this shaft.

Locality No. 40.—3 S., 23 W., section 17, northeast quarter of the northeast quarter, on Mazarn Creek. (Griswold.)

Diplograptus foliaceus, Murch.

Glossograptus (like *G. spinulosus*, Hall.)

Locality No. 41.—On Carter's Creek, 3 S., 23 W., section 30, northeast quarter of northwest quarter. (Smith.)

Dicellograptus.

Dicranograptus.

Locality No. 42.—2 S., 24 W., section 6, southwest quarter. This locality is in a section across the novaculite ridges to the northeast of Mount Ida. The first and lowest exposures of blackish, flinty rock are in the creek and on the hill west of the road, before reaching the summit. A little higher in the creek, at the ruins of an old building, are thin layers of black shale alternating with the black, flinty layers. The black shales contain poorly preserved fragments of graptolites, and the shales can be traced for some distance along the northern side of the minor ridge. This exposure of graptolite shale is on the southern side of the novaculite ridges and is below the main mass of the novaculite. (Prosser.)

Locality No. 43.—Township 3 S., 24 W., section 27, northwest quarter of the southeast quarter, near the main road from Hot Springs to Dallas, half a mile east of the house of Mr. Johnson, at the crossing of Collier's Creek. The graptolites were found in black shale in the bed of a small creek about one hundred yards south of the road, just south of an unoccupied house. (Jenney.)

Locality No. 44.—Near Caddo Gap, in 4 S., 24 W., section 19 (Griswold.)

Dicranograptus (*ramosus*, Hall ?) } Southwest section 16.
Dicranograptus augustifolius, Hall. } Southwest section 16.
Lingula, sp. undt. } Southwest section 16.
Diplograptus, from west of Caddo Gap.
Diplograptus trifidus (sp. n.,) from Vaut's Mill,

Locality No. 45.—Big Fork and Black Springs road, in 3 S., 26 W., section 30. (Griswold, Smith.)

Dicellograptus divaricatus, Hall.
Dicellograptus, sp. undt.
Dicellograptus.
Dicranograptus ramosus, Hall.

Locality No. 46.—4 S., 26 W., section 31, middle of north half. (Smith.)

Dicellograptus divaricatus, Hall.
Diplograptus.

Locality No. 47.—Southwest of Black Springs, 4 S., 26 W., section 10, southeast quarter. (Smith.)

Dicellograptus.
Dicranograptus.
Diplograptus.
Favosites ? sp. undt.

Locality No. 48.—On Blocher Creek, 4 S., 27 W., section 36, southeast quarter. (Griswold.)

Dicellograptus divaricatus, Hall.
Dicellograptus elegans. Carr.
Dicellograptus, sp. undt.
Diplograptus.
Lingula, sp. undt.

Locality No. 49.—South of Big Fork post-office on the creek,

3 S., 28 W., section 23, southeast quarter of the southeast quarter. (Griswold, Smith.)

Dicranograptus ramosus, Hall.
Dicranograptus arkansasensis, (sp. n.)
Diplograptus trifidus, (sp. n.)
Diplograptus, sp. undt.

Locality No. 50.—On Mack's Creek, 3 S., 29 W., section 15, northeast quarter of southeast quarter. (Smith.)

Leptograptus, like *L. annectans*, Walc.
Dicellograptus divaricatus, Hall.
Diplograptus trifidus, Gurley (sp. n.).
Diplograptus, sp. undt.

CALCIFEROUS HORIZON.

Locality No. 51.—1 N., 14 W., section 11, northwest quarter of the northwest quarter. (Griswold.)

Phyllograptus anna, Hall.
Phyllograptus typus, Hall ?
Schizograptus ?
Dichograptus.
Tetragraptus serra, Brongn.
Didymograptus caduceus, Salter ?
Didymograptus, (sp. n. ?)
Diplograptus dentatus, Brongn.
Cryptograptus antennarius, Hall.
Cryptograptus tricornis, Carr.
Retiograptus tentaculatus, Hall.
Trigonograptus ensiformis, Hall.
Caryocaris wrightii, Salter.*

This find is particularly interesting as it is the first discovery

*1863, Quarterly Journal of the Geological Society, London, XIX., page 139, with figure, p. 137. This form occurs in the Calciferous shale of Point Levis, and also in the Nevada beds, which are Calciferous (probably upper Calciferous). I had described it in Mss., under a new generic and specific name, but am informed by Prof. Lapworth that it is identical with Salter's species, which was supposed by its author to be crustacean. While it is impossible to identify it with Salter's species merely from his descriptions and figure, I have provisionally suppressed my Mss. name in accordance with Prof. Lapworth's advice.

in the United States of the fauna which has become classic through the work of Hall.

Locality No. 52.—2 N., 15 W., section 28, southwest quarter of the northeast quarter, a short distance directly south of the house of Mr. Bresher. (Prosser.)

At the western end of the bluff, on the Little Maumelle River, graptolites were found; they are more abundant a little below the place just mentioned in an exposure of quite black shale. A little farther down the bank is another outcrop of the darkest shale, and in this more graptolites were found than at the other ledges. In addition to the graptolites is a specimen of a linguloid shell, probably *Lingulops*.

NEW SPECIES OF GRAPTOLITES.

BY R. R. GURLEY.

Dicellograptus rigidus, Lapw.

(*D. moffatensis* var. *divaricatus* (Hall) Lapw. 1877 Ann. Rep. and Proc. Belf. Nat. Field Club, I., pt. IV., Appdix, p. 141, t. F. f; *D. divaricatus* var. *rigidus* Lapw. 1880, Ann. Mag. Nat. Hist., p. 163, t. 5, f. 20 a, b.)

This species resembles in angle of divergence and general outlines *D. divaricatus*, Hall, but may be readily distinguished from that species by the great thickness of the branches (about 1.5 mm. or 1-16 inch) and especially by the uniformity of the thickness throughout the whole length. This form also differs markedly from Prof. Hall's species in character of the base, which is much wider, stouter and more rounded. Hydrothecæ about 9 in the space of 10 mm. (22 to the inch). The Arkansas form agrees closely with the diagnosis given by Prof. Lapworth for his var. *rigidus*. As he suggests, this form is entirely distinct from *D. divaricatus*.

Horizon and locality, *Dicellograptus* zone locality No. 32.

Dicranograptus arkansasensis, Gurley, sp. n. See plate IX., figure 1.

Proximal portion 9 mm. in length; branches diverging at a very wide angle (90° to 130°), curving upward at a short distance from their origin; hydrothecæ 8 to 1 cm.

The specimens on which this species is founded are a half dozen in number. Their aspect is very peculiar, being characterized by the very wide angle between the branches, in which it differs from all the other species of the genus. The condition of preservation is very poor; the condition of the cells is therefore largely conjectural.

Horizon and locality, Dicellograptus zone, Arkansas. See plate IX., figure 1, showing proximal portion. See also figure 2, distal portion, showing outline of polipary. The thecæ are shown as distinctly as they occur in the specimen.

Dicranograptus nicholsoni, var. parvangulus, Gurley (var. n.).

Several specimens of this form occur. It differs from the typical form found in Utica slate mainly in the narrow angle between the branches, which is only 35° or 40°, while in the *D. nicholsoni* the angle between the branches is 70° to 80°. The hydrothecæ of the stem and proximal portions of the branches bear short, rigid spines. These I have not seen in the specimens of *D. nicholsoni* from the Utica shale, but they are present in the English form as figured by Prof. Lapworth.* This may prove to be distinct, but with the present material its varietal reference to *D. nicholsoni* seems preferable. Horizon and locality. *Dicellograptus* zone, locality No. 31.

Diplograptus trifidus, Gurley, (sp. n.)

(*D. pristis*, (His.) Nich., 1872, Mon. Brit. Grapt., p. 58, Fig. 26B).

Pristoid in general outline and appearance, greatest length observed (in a somewhat incomplete specimen), exclusive of prolonged axis and proximal spines, 6 cm.; greatest breadth 5 mm.; cells 8 to 10 in the space of 1 cm.; virgula distally prolonged, very broad, especially distally where it approaches in this feature, *D. vesiculosus*, Nich; proximally it terminates in a straight line about 7.5 mm. in length, which is flanked on each side by two curved processes, 4 mm. in length; no disk as in *Climacograptus bicornis*, only a few specimens showing a faint alation of the lateral spines.

*Armstrong, Young and Robertson's Catalogue, West Scottish Fossils, 1876 to 3 (f. 79.)

This species is strikingly distinct from the previously described American forms. It is perhaps identical with the species figured (as above) by Nicholson. In regard to the latter form we have the authority of Tullberg (who made a special study of Hissinger's original material, including the type specimens, with the special object of settling the synonymy) for regarding it as distinct from Hissinger's species.*

Horizon and locality.—Several localities in Arkansas associated with the *Dicellograptus* fauna.

See plate IX., figure 3, *Diplograptus trifidus*, sp. n. Proximal portion showing characteristic basal spines.

See also figure 4 of plate IX. The same, showing the general outline of the polypary and the distal prolongation of the virgula. The lateral basal spines are broken off.

Dictyonema obovatum, Gurley, sp. n.

Polypary small measuring in the single specimen seen 12 mm. (1-2 inch) in length and the same in breadth. Outline broadly rounded at the base, rather rapidly fulling out to its greatest width. Proximal extremity marked by a large sicula 15 mm. (1-16 inch) in length. Branches about 0.5 mm. (1-50 inch) thick dividing several times. Dissepiments filiform. Meshes rhomboidal a little wider than the branches, about as wide as long.

The aspect of this species is characteristic. It resembles the outline of a boy's top, the sicula corresponding to the plug. The two layers of the compressed funnel-shaped polypary are seen separated by a thin film of shale. It is an interesting species, being the second one of the genus to show the sicula.

Horizon and locality, *Dicellograptus zone*, locality No. 32.

THE GEOLOGICAL AGE OF THE ROCKS OF THE NOVACULITE AREA.

By Charles S. Prosser.

One of the earliest references to the age of the geological formations of this region, and one of the most accurate, is that of Prof. Henry D. Rogers. In giving the geological distribution of tha Matinal series, which was Prof. Rogers' name for the Trenton limestone and Hudson group of New York, it was stated that this series is present "encircling the anticlinals of the older metamorphic rocks, the Ozark Mountains in Missouri, the Washita Hills in Arkansas."*

David Dale Owen referred both the novaculite and the quartzose sandstones to the millstone grit of the Carboniferous. It was stated that the "White calcedonic novaculite [of the Hot Springs ridge] belongs, undoubtedly, to the age of the millstone grit;"† the underlying quartzite sandstone of the Crystal Mountains in Montgomery county, was referred to "the same millstone grit formation"‡ as the ridges about Hot Springs; and "the sandstones and shales of the millstone grit," in the middle part of Montgomery county, were mentioned.§

Dr. Theodore B. Comstock examined a considerable part of this area in 1887. In describing Witherspoon's, west of Crystal Mountain, Dr. Comstock stated that "from developments at these points, and observations southward, the relations of this rock have been clearly determined. There is no doubt that it lies in the millstone grit."‖ Again he says "a tough quartzitic rock abundant in the vicinity of Bear City, and traceable for miles east and west of that place, has been selected as the prominent gold ore of the Bear City region, and although this, too, is a bedded formation of Carboniferous age—a member of the grit series—which is exposed in many

*Bihangtil. Sv. Ak. Handl. 1882, VI., No. 13, p. 10.

*The Geology of Pennsylvania, Vol. II., Pt. II., 1858, p. 753.

Rogers gives no reason for this statement and I am at a loss to know whether it is based upon knowledge or is simply an inference. I am unable to learn that he ever visited the region in question, and I know of no fossils ever having been found to show that there were Trenton rocks in the Ouachita region prior to their discovery by Mr. Griswold. It is my opinion that Prof. Rogers simply included the Ouachita hills in his reference to the Ozark region because these hills were generally supposed to be a part of the Ozark uplift.—J. C. Branner.

†Second Report, Geol. Reconnoissance of the Middle and Southern Counties of Arkansas, Philadelphia, 1860, p. 23.

‡Op, cit., p. 25.

§Op. cit., p. 98.

‖Ann. Rep. Geol. Surv. Arkansas, for 1888, Vol. I., p. 109.

places over a wide range of counties from Pulaski to the Indian Territory."*

In 1889, Mr. Griswold first found fossils in the black shales of this series which were identified by Prof. H. S. Williams as graptolites and the rocks consequently considered as belonging to the "upper part of the Lower Silurian"† Later, these with additional specimens were submitted to Dr. R. R. Gurley for study and he has identified a number of species as identical with those of the Norman's Kill graptolite shales of New York.

The precise age of these shales has long been a matter of doubt and the recent statements as to their age will be of interest.

In 1875 Prof. R. P. Whitfield wrote Dr. White as follows: "Your inquiry in regard to the geological age of the graptolite shales of Norman's Kill near Albany, N. Y., involves a question of considerable complexity, and is one to which I have given much thought and labor during several years past. The rocks in that vicinity are so altered and disturbed that their relative position is not easily determined from stratigraphical evidence. I have sought diligently at all points for fossil remains, but with only limited success thus far, except as to Graptolites. From the evidence furnished by these fossils, I have reached the conclusion that the Graptolite-bearing layers there are of the age of the Utica slate."‡ On p. 20 is a section showing the folding and order of these formations, according to Professor Whitfield's interpretation of the region.

February 27, 1891, Professor Whitfield was asked whether he had found any evidence, since his letter to Dr. White, to change his opinion as to the geological age of the Norman's Kill graptolite shales.

In answer Professor Whitfield wrote, March 2nd., that he had

*Op. cit., p. 186.

†Proc. Am. Assn. Adv. Science, Vol. XXXIX., 1891, p. 249.

‡Report upon geographical and geological explorations and surveys west of the one hundredth meridian, in charge of First Lieut. Geo. M. Wheeler. Pt. I., Vol. IV., Paleontology, 1875, p. 19.

no reason for changing his opinion; that, on the contrary, all the evidence he had seen or known of confirmed it.

In 1887 Professor Charles Lapworth published a very able paper on some Graptolites from the lower Paleozoic rocks on the south side of the St. Lawrence. In discussing the geological equivalency of the Norman's Kill and the Marsouin River beds Professor Lapworth says: "There can be no question of the general identity of this Griffin Cove rock, and the Marsouin Cœngraptus zone with that of the Norman's Kill of the Hudson River valley. The New York geologists have always adhered to the opinion that the Norman's Kill beds are of the age of the Hudson River group (Lorraine) or of that of the Utica slate. The best advocacy for the last named view will be found in a letter from Mr. R. P. Whitfield, addressed to Dr. White,* in which it is asserted that *Graptolithus serratulus*, Hall, *Diplograptus pristis* Hall (non His.), *Climacograptus bicornis* Hall, and *Dicranograptus ramosus*, Hall, occur in the Utica slate of the valley of the Mohawk. I have myself referred to the Norman's Kill beds in my paper on the Moffat Series (Quart. Jour. Geol. Soc., 1858, p. 335) as probably rising out unconformably from below the Trenton Limestone, and forming the highest portion of the convoluted rocks of the so-called Quebec Group—a view also held by Dr. Sterry Hunt. At a later date (see "Distribution of Rhabdophora," 1880, pp. 30, 28, etc.), while I refused to allow their equivalency with the Lorraine Shale (Hudson River Group), I reluctantly admitted that it was very probable they might in part be Utica and in part of true Trenton age. But here we have to recollect that with the exception of Whitfield's distinct assertion that *G. serratulus*, Hall, occurs in the Utica Slate of Oxtungo Creek—which may be easily accounted for on the supposition that what Whitfield calls a Didymograptus may possibly be a *Leptograptus*—not a shadow of paleontological evidence has yet been adduced to show that these Norman's Kill or Marsouin rocks are newer than the Trenton.

I will not discuss the evidences further in this place, but will

*Report of the Geological Survey of the 100th Meridian.

merely say that in Great Britain the fossils of the *Cœnograptus* (Norman's Kill) zones occur in the beds immediately succeeding the typical Llandeilo Limestone of Wales, with *Ogygia buchii* and *Asaphus tyrannus*, and in association with the Craighead (Stinchar) Limestone of Scotland, with *Maclurea logani* and *Ophileta compacta, i. e.*, in beds apparently homotaxeous with the Chazy or Lowest Trenton (Bird's Eye and Black River).*

On pp. 182, 183 is a table showing the European formations and graptolitic zones and the American formations and graptolitic zones. In this table the graptolitic shales of Norman's Kill are given in the Black River and Trenton division of the American formations and as equivalent to the Upper Llandeilo of Great Britain.

Mr. Henry M. Ami has also called attention to the "decided lower Trenton facies" of the fauna of these shales.†

Dr. Gurley, who has studied the American graptolites with great care and whose paper upon the Arkansas graptolites appears in another part of this chapter, is inclined to agree with Professor Lapworth as to the approximate age of the Norman's Kill beds, and considers the graptolites of the Arkansas black shales as belonging to the upper zone of the Norman's Kill fauna, which latter he refers to the lower portion of the Trenton series.

As is stated in the detailed notes, along the northern line of the novaculite series the black graptolitic shales are interstratified with the novaculite rocks, occurring to near the top of that series. However, at no place were graptolites found above the last of the flinty rocks. The writer understands Dr. Gurley to say that there are species of graptolites in these upper layers of black shale which are identical with those found in the black shales underlying the novaculite along its southern line. On account of the above data it seems reasonably safe to consider the novaculites as belonging to the upper part of the Lower Silurian, perhaps at about the middle of the Trenton stage.

*Proc. and Trans. of the Royal Soc. of Canada for 1886, Vol. IV., Sec. IV., pp. 170, 171.

†On the Geology of Quebec and Environs, Bull. Amer. Geol. Soc., Vol. II., Apl., '91, pp. 490, 491.

The shales and sandstones above the novaculites contain fragments of fossil plants and there is no evidence yet, so far as the writer is aware, to show that they are not in the Lower Carboniferous.

NOTES ON LOWER CARBONIFEROUS PLANTS FROM THE OUACHITA UPLIFT.

By C. S. Prosser.

Locality No. 1.—Northeast quarter of section 17, 2 N., 14 W. (P.) On the northern slope of the mountain, 300 feet below the summit, in a small run, is an exposure of bluish-black, argillaceous and arenaceous shales, which contain fragments of fossil plants. Some of these are probably fragments of *Calamites* and others fern stipes or possibly *Cordaites*. In places the shale is streaked with red and yellow stripes and it is clearly above the heavy quartzose sandstone.

Locality No. 2.—Northwest quarter of southeast quarter of section 17, 2 N., 14 W. (P.) The western end of Shinall Mountain forms a steep bluff, with the Little Maumelle River at its base. At the northern end of this bluff, and about sixty feet above the river, are bluish black rather arenaceous shales containing fragments of fossil plants.

Locality No. 3.—Northwest quarter of the southeast quarter of section 20, 2 N., 14 W. (P.) On the northern slope of a minor novaculite ridge are two excavations in a bluish-gray, argillaceous shale. The shale is frequently marked by red and yellow streaks. Stems of plants were found, but a microscopic section shows scarcely any structure. This specimen has been examined by Prof. F. H. Knowlton, but owing to the imperfection of its preservation he is able to say very little, except that it is the stem of some plant.

Locality No. 4.—Southwest corner of the southwest quarter of section 31, 2 N., 16 W. (P.) This locality is at the foot of the low hill about one-fourth mile south of Brazils. The fossils were thought possibly to be plants when in the field, but the package of fossils was not received.

Locality No. 5.—In an excavation for a cellar on the western side of Malvern avenue, Hot Springs, three or four numbers north of the Park Hotel, is an exposure of the shales overlying the novaculite and sandstone series, (P.) The shales are of various colors from slaty black, streaked with brownish yellow and red, to a sort of olive. In some of the brownish and olive shales, which are somewhat mealy, are fragments of fossil plants. They were found occasionally in the slaty black shales; but are not so common or well preserved as in the brownish, mealy shales. On one of the olive pieces of shale is a fern pinnule, which is similar to those of *Sphenopteris*. It resembles somewhat the pinnules of *Sphenopteris decomposita*, Kidston* from the Calciferous sandstone (Lower Carboniferous) of Scotland; but nothing could be stated positively of such a fragment. Other fragments resemble *Cordaites*.

Locality No. 6.—Along Ouachita Avenue, Hot Springs, are similar olive colored shales, with arenaceous layers, alternating with slaty black shales streaked with red and yellow (P.) In the olive to brownish shales fragments of fossil plants were found.

Locality No. 7.—Probably section 1, possibly section 2, 3 S., 19 W. (P.) In a railway cut about three miles below Hot Springs, near the place where a prominent stratum of sandstone crosses the railway and creek, are slaty colored shales with somewhat brownish, arenaceous shales, which contain fragments of fossil plants. Also, they occur in a rather friable sandstone changing to arenaceous shales, which is exposed for some distance in the cuts along the railway, alternating with the quartzose sandstones. The arenaceous layers contain the fragments of fossil plants.

Locality No. 8.—Northeast quarter of the northeast quarter of section 4, 2 S., 26 W. (P.) South of the Ouachita River, near Oden, is first the greenish to olive shales with thin sandstones, and in one of these sandstone layers, near the top of the hill, found fragments of plants. Also, fragments of plants were found in the shales on the north bank of the Ouachita River, west of Oden.

*Trans. Roy. Soc. Edinburgh, Vol. XXX., Pt. II., 1882, p. 538, Pl. XXXII., Figs. 1, 4, 5.

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