STATE OF ARKANSAS

Arkansas Resources and Development Commission

Wayne C. Fletcher, Executive Director

DIVISION OF GEOLOGY

Harold B. Foxhall, Director

BULLETIN 16

TITANIUM ORE DEPOSITS OF HOT SPRING COUNTY, ARKANSAS

By

Verne C. Fryklund, Jr.

and

Drew F. Holbrook

Little Rock, Arkansas

1950

A. Large single brookite crystal and a cluster of brookite and quartz crystals—half natural size.

B. Rutile crystals with cyclic twinning—about twice natural size.

FRONTISPIECE.—SELECTED SPECIMENS OF BROOKITE AND RUTILE FROM MAGNET COVE, HOT SPRING COUNTY, ARKANSAS.

(Courtesy Harvard University Museum)

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DIVISION OF GEOLOGY

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OF HOT SPRING COUNTY, ARKANSAS

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ABSTRACT

This report embodies the results of three years' field and laboratory studies of the Magnet Cove titanium ore deposits. The Magnet Cove area is a rudely elliptical rim and basin covering about 9 square miles in northern Hot Spring County, Arkansas.

The area is in the Ouachita Mountains near their eastern boundary. These mountains were formed by the uplift, folding, and faulting of Paleozoic sediments near the end of Paleozoic time, and the Magnet Cove intrusives were injected into these folded sediments in Cretaceous time. Subsequent uplifts, depressions, and erosion developed the present configuration of the region.

The sedimentary rocks of the region are exposed in the rim of the Cove and the surrounding Ouachita Mountains. These sediments are sandstones, shales, chert, and novaculite that range in age from Ordovician to Pennsylvanian. In the Ouachita Mountains the sandstones and novaculite form the ridges, and the shales underlie the valleys.

The igneous rocks of Magnet Cove are alkalic in composition and are both fine and coarse-grained. The intrusives form an ellipsoidal mass composed of several incomplete but concentric rings of igneous and metamorphic rocks which are cut by numerous dikes. The intrusion is believed to have taken place in three distinct periods. The most basic intrusives are the earliest and occupy the Cove basin, and the youngest rocks are the light-colored syenites of the Cove rim.

The metamorphic rocks of Magnet Cove are of two general types: the contact metamorphosed sediments of the Cove rim, and the hornfels found principally within the igneous mass.

The titanium deposits of Magnet Cove include both rutile and brookite ores. All of the deposits that were mapped during this study had been previously recognized and explored and one of them has produced commercial rutile concentrates; however, none of them is active at the present time.

The largest known titanium deposit at Magnet Cove is the rutile deposit of the Magnet Cove Rutile Company located in Sec. 18, T. 3S, R. 17W, in the northern part of the Cove basin. Approximately 10 million pounds of rutile concentrates were produced from the open pits at this deposit during the period 1932-1944. The country rock is an aegirine phonolite porphyry which varies from a hard, black, fine-grained rock to a soft green clay, depending on the degree of alteration. The phonolite is exposed in the pit walls, in knobs on the pit floors and at the base of the Cove rim north of the pits. In some of the knobs the phonolite contains abundant inclusions of both igneous and metamorphic rocks. Numerous rutile-bearing feldspar-carbonate veins and vein masses cut the aegirine phonolite porphyry, apparently along a major joint set paralleling the Cove rim. These veins are the rutile ore of the deposit. They are, however, poorly defined in the pits because of the irregular shapes of the larger masses and the intense clay alteration of some of the vein types as well as the enclosing phonolite. The rutile in the feldspar-carbonate veins ranges in size from minute needles to veinlets 5 cm in width. The larger masses of rutile, particularly, have an alteration fringe of leucoxene. The small percentage of vanadium present in the ore is probably in the rutile. Small amounts of molybdenite and an unknown radioactive mineral or minerals were found in the ore. The maximum uranium content

reported in chemical analyses of a series of radioactive samples from the deposit was 0.012 U_3O_8. Some of the radioactivity reported in radiometric analyses of these samples was apparently due to thorium. Drilling projects of the U. S. Bureau of Mines have extended the depth of the deposit (to 188 feet in one drill hole) particularly in the West Pit, and extended it 450 feet south and 400 feet west of the West Pit. The best possibilities for further extensions seem to be at depth. Assays of core samples from the drilling projects varied from less than 1 per cent to 16 per cent TiO_2 with an average of about 3 per cent TiO_2. The problem of calculating rutile reserves is complicated by the fact that the igneous rocks in the deposit, even though they contain no rutile, frequently assay from three to four per cent TiO_2 due to the presence of other titanium minerals. It is believed that the deposit was formed by the introduction of rutile-bearing feldspar-carbonate veins into fractures in aegirine phonolite prophyry accompanied by hydrothermal alteration of both the igneous rock and some of the vein types. Volcanic activity, if it occurred at all, was probably a subordinate feature.

The Hardy-Walsh brookite deposit lies on the east rim of the Cove one mile north of Magnet community. Some trenching has been done here but there has been no commercial production of brookite. The deposit lies along the crest of a quartzite (metamorphosed Arkansas novaculite) ridge that is truncated at its west end by the intrusives of the Magnet Cove basin. The ridge crest has an east-west trend and is comprised of three quartzite knobs separated by two saddles. The quartzite knobs, although cut by scattered brookite-rich veins, are essentially barren. The first, or easternmost saddle has been extensively trenched and is essentially the orebody of the deposit. The ore in this saddle is a residual clay composed of quartz, kaolinite, and taeniolite (lithium mica) through which are scattered quartzite pebbles, sand, and very fine-grained (1 mm) brookite. Primary ore, exposed in only one test pit, consists of light and dark quartzites (recrystallized novaculite) which contain subordinate amounts of taeniolite, fine-grained brookite, rutile needles, and leucoxene. Titania assays of channel samples of the residual ore in this saddle range from 5.0 to 8.4 per cent TiO_2 and the deepest test pit sampled was 14 feet. Future explorations should seek extensions of the trenched area in the first saddle to the north and south and at depth. The second saddle should also be tested. The deposit is believed to have been formed by titanium-rich solutions emanating from the Magnet Cove intrusives and mineralizing the metamorphosed Arkansas novaculite, followed by erosion and weathering of the mineralized novaculite.

The Christy brookite deposit is located on the east rim of Magnet Cove about half a mile north of Magnet community. The deposit has been drilled and trenched but has not produced commercial brookite concentrates. The deposit lies on the top and partly on the south slope of an east-west ridge of metamorphosed Arkansas novaculite. This ridge is the south limb of the Chamberlain Creek syncline, which has been overturned so that the sediments dip about 45° to the south. Just a few hundred feet west of the deposit the syncline is truncated by a coarse-grained nepheline syenite intrusive. The ore at the surface at the Christy deposit is mainly residual and varies from 15 to 20 feet in thickness. The residual ore is comprised of masses of porous quartzite and sand size particles in a matrix of red clay. Brookite occurs in the residual ore as small crystals in the quartzite fragments and as free crystals disseminated in the clay. The primary orebody consists mainly of primary quartzite ore and barren clay horizons. Most of the ore developed by the U. S. Bureau of Mines drilling project was oxidized primary quartzite ore. This quartzite which is similar to the quartzite fragments in the residual ore is a dark, fine-grained, porous quartz rock containing rutile needles, altered taeniolite, limonite and fine-grained brookite. Unoxidized primary quartzite ore containing abundant clay minerals in the interstices between quartz grains and some pyrite was encountered in one drill hole. The titanium minerals occurring in both the residual and primary ore are brookite, rutile, leucoxene, and taeniolite, of which the brookite is probably the only recoverable mineral. Analyses of core samples from the U. S. Bureau of Mines drilling project varied from less than 1 per cent to a maximum of 26 per cent TiO_2 with an average for the orebody of about 5 per cent. Appreciable percentages (1 to 2 per cent V_2O_5) of vanadium, which probably occurs in the brookite, were reported for several core samples. The known orebody is restricted to the lower division of the Arkansas novaculite formation and thus pitches steeply to the southwest. The available drill hole data on the thickness of the orebody is limited, but brookite ore was encountered the full depth (141 feet) of the deepest U. S. Bureau of Mines drill hole. Future exploration at this deposit should check possible extensions of the primary orebody to the south. Probably the Christy deposit was formed by the introduction of mineralizing solutions from the Magnet Cove intrusives into the folded and metamorphosed Arkansas novaculite formation, and the subsequent erosion and weathering of the mineralized rock.

The Mo-Ti Corporation molybdenum-titanium prospect is a small open pit located on the south bank of Cove Creek near the northern edge of the Cove basin. A series of steeply dipping feldspar-pyrite veins with small amounts of brookite and molybdenite are exposed in the igneous rock of the pit walls and floor. There has been no commercial production from the pit.

In addition to the known deposits, there are several other untested occurrences of rutile and brookite at Magnet Cove indicating the widespread occurrence of titanium mineralization in the Cove area.

The problems in the beneficiation of the Magnet Cove titanium ores have been studied by both commercial and government laboratories. The Christy brookite ore has been successfully concentrated by a commercial laboratory, and the U. S. Bureau of Mines Metallurgical Division has prepared commercial-grade rutile concentrates with a reasonable recovery of rutile, from the deposit of the Magnet Cove Rutile Company.

Ilmenite and rutile are the two principal economic minerals of titanium. Of these, ilmenite is consumed in the largest tonnages, principally in the manufacture of white titanium oxide pigment for the paint, paper, rubber, and many other industries. Rutile is used principally in welding rod coatings and also in the manufacture of titanium alloys and carbide and in the ceramic industry. Arkansas rutile and brookite have not yet been accepted in the trade as welding rod coating raw material, the principal market for rutile. However, it is possible that current research on the use of Arkansas rutile and brookite in welding rod coatings may result in the development of an acceptable rod coating. Rutile from the Magnet Cove Rutile Company deposit has been used in the manufacture of titanium alloys and carbide, and it is possible that brookite from Magnet Cove would also be acceptable for this application. Titanium metal has recently been given wide publicity in both popular and technical publications. Although the current production of the metal is insignificant, it shows promise of becoming a large scale structural raw material because of its unique combination of properties—light weight, strength, and corrosion resistance. When an economical method of producing this metal is developed, the demand for titanium ores should substantially increase and rutile ores will be important at least so long as the production of the metal is accomplished by first making titanium chloride. It is believed, therefore, that the most promising potential market for the Arkansas rutile and brookite ores is in the production of titanium metal.

INTRODUCTION

PURPOSE AND SCOPE OF THE INVESTIGATION

In 1946 the shortage of rutile concentrates in the United States resulted in the classification of rutile as a strategic mineral and the purchase of rutile concentrates for government stockpiles. As there had been no previous detailed geological study of the Magnet Cove rutile and brookite deposits, the Division of Geology of the Arkansas Resources and Development Commission sponsored a preliminary geologic study (Holbrook, 1947) of the Christy brookite deposit at Magnet Cove, Arkansas, in 1946 in the hope of encouraging its development into a producer of titania concentrates.

Later the Division of Geology expanded this investigation to include all the known titanium ore deposits in the Magnet Cove area. Mr. Verne C. Fryklund, Jr., then a graduate student at the University of Minnesota, undertook this investigation as a thesis problem for the Ph.D. degree. The main purpose of this broader study was to determine the geologic nature of the known rutile and brookite deposits. As two of the deposits, the Magnet Cove Rutile Company property and the Hardy-Walsh brookite property, had been previously described (Ross, 1941) (Ross and Hendricks, 1945) as a volcanic neck and associated with a volcanic breccia, respectively, it was desirable to know what bearing the possible volcanic activity would have on the extent and character of the ore deposits. A secondary aim was a study of the mineralogical composition of the rutile and brookite ores, since a knowledge of the complex mineralogy of these ores would be an invaluable aid to the metallurgist in solving the problems involved in beneficiating the ores and in making use of the contained titanium minerals. As the study of these deposits progressed, interest was stimulated in all the known and prospective titanium ore deposits in the United States by the anticipated future demand for titanium metal, and in the fall of 1947 the Mining Branch of the U. S. Bureau of Mines began preliminary examinations of the Magnet Cove deposits. By this time sufficient progress had been made in the field work at Magnet Cove that the writers were able to furnish the Bureau of Mines drilling recommendations both for the known deposits and for other potential deposits of rutile and brookite in the area. On the basis of these recommendations, two deposits, the rutile deposit of the Magnet Cove Rutile Company and the Christy brookite deposit, were drilled by the U. S. Bureau of Mines in 1948. In order to incorporate in this report the subsurface information afforded by the drilling of these two deposits, all the recovered cores from the two projects were logged by the writers and correlated with the surface data.

METHODS OF INVESTIGATION

Both the mapping of the three known titanium deposits and the laboratory studies of the rock and vein types associated with these deposits were done by Fryklund. During the summer of 1947, Fryklund completed the plane-table mapping of all the deposits and the collection of samples for laboratory study.

These laboratory studies which were principally petrographic but also included some X-ray and chemical analyses, were mainly completed by Fryklund during the 1947-48 school year at the Department of Geology of the University of Minnesota under the guidance of Dr. F. F. Grout. All of the drill cores from the U. S. Bureau of Mines drilling projects at the Christy deposit and the Magnet Cove Rutile Company deposit were logged by Holbrook while the drilling was in progress (January, 1948, through November, 1948), and the nomenclature for the various rock and vein types established by Fryklund as a result of his laboratory work was used in logging the cores.

PREVIOUS STUDY OF MAGNET COVE

Magnet Cove first came to the attention of a geologist in 1806 (Joseph Macrary, M. D.), but it was not until 1834 that A. W. Featherstonhaugh made the first scientific investigation of the igneous rocks of the area. From that time until 1891, when Williams published his remarkable monograph, there were a large number of papers published concerning the interesting mineralogy of the region. Williams (1891) summarized the work of these earlier students and contributed a study of the igneous rocks which is considered to be one of the classic studies in igneous petrography of this country. Williams' report also contains the only detailed geologic map of the igneous rocks of the Magnet Cove area that has been published. In 1900 Washington published a simplified and revised geologic map which corrected some rather serious errors made in the printing of Williams' map. Washington in a later paper (1901) redefined several of the Magnet Cove rock names. This paper also contains the largest amount of quantitative data on the Cove igneous rocks. The Hot Springs Folio (Purdue, A. H., and Miser, H. D., 1923) contains the most complete description of the sedimentary rocks of the region. The igneous rocks described in the Folio are very similar to the Magnet Cove types. Landes (1931) published a paper containing a list of most of the Magnet Cove minerals. He also considered the structure of the intrusive mass and suggested a possible origin for the large calcite masses lying in the Cove basin. The only geologic map of the Magnet Cove area which differentiates the sedimentary sequence immediately around the Magnet Cove intrusive mass is contained in a report by Parks and Branner (1933) on the barite deposits near Magnet Cove. Miser and Stevens (1938) first mentioned the occurrence of the lithium mica, taeniolite, at Magnet Cove in a paper that describes the area now known as the Hardy brookite deposit. C. S. Ross in 1941 presented the first published account of the Magnet Cove rutile and brookite orebodies. Ross and Hendricks (1945) in a later paper gave the only detailed account of the clay mineralization at the deposit of the Magnet Cove Rutile Company. A paper by Spencer (1946) records the drill hole data obtained from the U. S. Bureau of Mines exploration of the Magnet Cove Rutile Company deposit in 1944. The information in this paper is important though fragmentary due to lack of surface geology. Holbrook in 1947 presented the first report on the geology of the Christy brookite deposit. In this report the association of the brookite deposits with the Arkansas novaculite formation and the character of the residual ore were described. In 1949 the U. S. Geological Survey released a report by D. M. Kinney on the geology of the Magnet Cove Rutile Company deposit. This paper was based on the geologic mapping of the open pits in conjunction with the U. S. Bureau of Mines drilling in 1944. The U. S. Bureau of Mines has published a Report of Investigation (Reed, 1949) on each of the two 1948 titanium exploration projects at Magnet Cove. These two reports are significant since they contain assay data on the core and sludge samples recovered during the drilling, and they also describe the drilling and sampling methods employed.

ACKNOWLEDGMENTS

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In Fryklund's laboratory studies which were facilitated by the Longyear fellowship in Economic Geology, the members of the geology faculty of the University of Minnesota, particularly Frank F. Grout, George M. Schwartz, and Lynn Gardiner, were most generous with advice and assistance. Fryklund was assisted in the mapping of the deposits by Willis Graham. Thanks are expressed also to G. A. Cooper of the National Museum for the tentative identification of a brachiopod fragment. The receipt of a specimen of taeniolite for X-ray comparison purposes from George Switzer, of the National Museum, is also gratefully acknowledged. The photographs of the hand specimens were taken by Charles Reilly.

The cooperation of Leon Dupuy, then Chief of the Mining Division, Rolla Branch, U. S. Bureau of Mines, in permitting the examination of drill cores and furnishing analytical data on the cores has been an invaluable contribution to the study. Thanks are due R. G. Knickerbocker, Acting Chief of the U. S. Bureau of Mines, Minerals Technology Division Region VI, and his staff, for their review of the sections on beneficiation and economic geology and for information on the Titanium Corporation of America operation at Magnet Cove. The excellent cooperation of Mr. Donald Reed, Project Engineer for the Bureau of Mines at Magnet Cove, facilitated the logging of the cores and the mapping of drill holes.

The patience and careful work of Katherine Headrick in typing the manuscript and J. L. McDonnell in drafting the accompanying maps are sincerely appreciated.

For historical data on the district the writers are indebted to the Titanium Alloy and Manufacturing Division of the National Lead Company; Wynn O. Christy of Magnet Cove, Arkansas; Percy C. Upton of the Magnet Cove Rutile Company; and Joe W. Kimzey of Magnet Cove, Arkansas.

GEOGRAPHY OF THE MAGNET COVE AREA

LOCATION AND CULTURE

The Magnet Cove area includes a roughly elliptical basin two by three miles in extent almost completely surrounded by a ridge or rim that rises 200 to 300 feet above the general level of the basin (Plate I). The area is located just southwest of the center of Arkansas in northern Hot Spring County (see Figure 1). U. S. Highway 270, a paved road which connects Malvern, 7 miles to the southeast and Hot Springs, 12 miles to the west, passes approximately through the center of the Cove.

The Magnet Cove area is sparsely populated and the community of Magnet itself, which lies on the east boundary of the Cove on Highway 270, consists only of a few houses and stores. With the exception of the Cove basin, the soil of the area is rather poor, thus, farming is small-scale and restricted to the Cove basin and the more level valley floors of the region surrounding the Cove. The ridges and more rugged valleys are suited only for timber growth. Many of the inhabitants in the area are employed at the Jones Mill aluminum plant of the Reynolds Metals Company on the Ouachita River just south of the Cove, and in the barite mines and mills of the Baroid Sales Division of the National Lead Company and the Magnet Cove Barium Corporation in Chamberlain Creek valley, 2 miles east of the Cove.

The area is served by the Hot Springs branch of the Chicago, Rock Island and Pacific railroad which passes immediately south of the Cove. A spur of this railroad to the barite mines passes a mile east of the community of Magnet. U. S. Highway 270 is the only paved road in the area, but several good gravel roads are maintained both within the Cove basin and in the valleys of the surrounding region.

REGIONAL TOPOGRAPHY*

The Magnet Cove rim and basin lie at the eastern edge of the Ouachita Mountain physiographic province just two miles northwest of the adjacent Gulf Coastal Plain province. This particular section of the Ouachita Mountains is comprised of parts of the Zig Zag Mountains, the Trap Mountains and the Mazarn Basin. The Zig Zag Mountains, lying north and east of the Cove, received their name from the peculiar course of the ridges which have a northeastern trend. The intervening valleys like the ridges are narrow and rough and contain very little level land. The Trap Mountains, immediately south of the Cove, are composed of a series of long narrow ridges that have an eastward trend and are separated by deep, narrow valleys. The eastern part of the Mazarn Basin, which terminates at the west rim of the Cove, has been greatly dissected by erosion, so that its surface is undulating and consists of narrow parallel valleys and low, even-crested ridges and hills.

The Ouachita Mountains were formed by the uplift, folding, faulting and erosion of Paleozoic sediments. The most intensive crustal movements in the

* The topographic features of the Magnet Cove region are well displayed on the Malvern Quadrangle recently published by the U. S. Geological Survey.

formation of these mountains are believed to have taken place near the end of the Paleozoic era (Miser and Purdue, 1929). The region was then reduced by erosion during Permian, Triassic, and Jurassic time to a southward sloping peneplain. In Cretaceous time this comparatively flat erosion surface was submerged and tilted southeastward and sediments were deposited along its southern and eastern flanks. Probably the Magnet Cove intrusives were injected into the folded sediments at about this same time. At the end of Cretaceous time the peneplain was uplifted, and the accelerated erosion that followed lowered the belts of soft rocks, leaving the harder rocks as ridges, the crests of which were all that remained of the old erosion surface. In the Magnet Cove region this erosion surface consists of the crests of the Zig Zag and Trap Mountains and the Magnet Cove rim. The southeasterly dip of this surface is indicated by the gradual decrease in elevation of the mountain crests to the southeast. Thus the Zig Zag Mountains northwest of Magnet Cove have crest elevations of more than 800 feet, while the Trap Mountains have crest elevations of 500 feet where they pass under the Tertiary sediments of the Gulf Coastal Plain two miles southeast of the Cove. Inasmuch as the two brookite deposits described in the section on ore deposits are in part residual ore developed near this upper erosion surface, the influence of this surface both on the origin of these known deposits and the exploration for placer deposits is of considerable importance. The erosion which destroyed the first peneplain or upper erosion surface in the Ouachita Mountains developed a second incomplete peneplain or lower erosion surface in the larger areas of soft rocks of the region. Near Magnet Cove this lower erosion surface is indicated by the tops of the fairly even-crested hills and ridges along the Ouachita River in the Mazarn Basin immediately west of the Cove. The crests of these ridges and hills now have an elevation of about 450 feet above sea level. Much of the interior basin of Magnet Cove was eroded during the development of this lower or 450-foot erosion level, since gravel deposits abut on the interior of the Cove rim at about the 450-foot contour. In early Tertiary time the Ouachita Mountain region was again depressed and sediments of Eocene age were deposited on the lower erosion surface in a sea that extended at least to within a mile of the southeast rim of the Cove. Evidence of this transgression may be seen in a railroad cut near the community of Butterfield, 2½ miles southeast of the Cove, where Tertiary sands and clays lie below and between ridges of Arkansas novaculite at the approximate elevation of the lower erosion surface. Following the deposition of the Tertiary sediments, a succession of uplifts renewed erosional processes and the lower erosion level was greatly dissected, giving the region its present configuration. The Magnet Cove basin was further reduced at this time so that much of it now lies below the 400-foot contour some 250 feet lower than the Cove rim.

The Ouachita River, which is the principal stream of the region, traverses part of the Mazarn Basin to the west, skirts the south rim of Magnet Cove and turns south across the Trap Mountains flowing out on the Coastal Plain. The Cove basin is drained by Cove Creek, which originates to the northwest in the Zig Zag Mountains, cuts through the north and south ridges of the Cove and enters the Ouachita River immediately to the south of the Cove. This stream, as well as the Ouachita River itself, has apparently been superimposed from the upper erosion surface. Chamberlain Creek enters Magnet Cove from the east, where it flows through a valley excavated in shale. It enters Cove Creek in the northeast corner of the Cove.

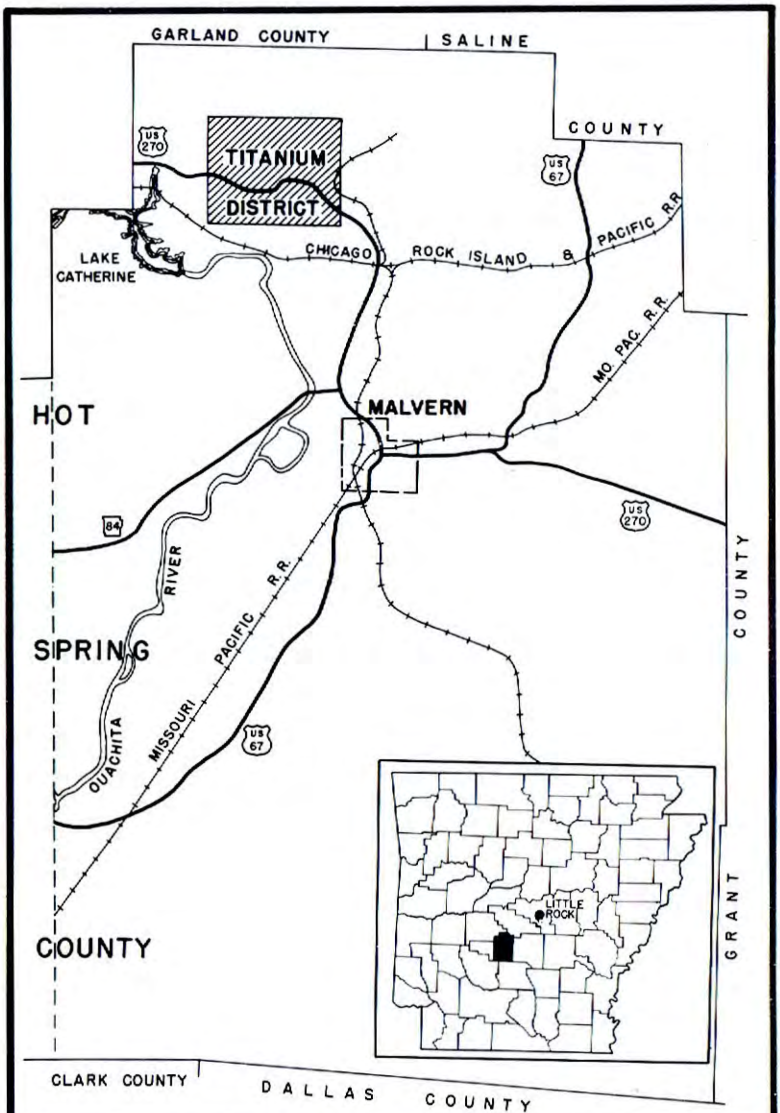

Figure 1. Index map showing location of the Hot Spring County titanium district.

GENERAL GEOLOGY OF THE MAGNET COVE AREA

GENERAL SUMMARY

The Magnet Cove igneous rocks are a group of alkalic rocks which intrude sedimentary rocks ranging in age from Ordovician to Pennsylvanian. These sedimentary rocks are folded into tight northeast-southwest trending anticlines and synclines. Within the Cove proper the intrusives form incomplete rings which are in places separated by rocks mapped by Williams (1891, Map I) as metamorphosed sediments. The relationships of the general region are shown on Plate VIII.

SEDIMENTARY ROCKS

The sedimentary section of the Magnet Cove area has been described by Parks (1930, p. 15) and more complete descriptions of the formations exposed in the Ouachita Mountains are available in the publications of Miser and Purdue (1923, 1929).

The following descriptions are taken from Parks (1930, p. 16 ff.):

Pennsylvanian

Stanley shale 300 feet. "Bluish-black and black, fissile clay shale and fine-grained, compact gray sandstone in thin and thick layers. In the Chamberlain Creek area (half mile east of Magnet Cove) the sandstone is best developed near the base of the formation. Immediately adjacent to Magnet Cove, the Stanley shale has been metamorphosed to a dark compact rock resembling hornstone. Numerous joints occur in the shale and sandstone."

Hot Springs sandstone 50 feet. "Hard gray, massive quartzitic sandstone. The fresh rock has a glazed appearance, but weathered specimens are soft and porous and often tinted with iron-oxides. Adjacent to Magnet Cove the standstone has altered to a white, coarse-grained, porous sandstone."

Mississippian (?)—Devonian (?)

Arkansas novaculite 500 feet. "Middle novaculite is 200 feet thick. Thin bedded novaculite with much siliceous shale, generally black, but contains beds of red flinty shale, some of which is high in iron oxides." Lower part is 300 feet thick. "Massive white novaculite some of it tinted red, gray, green, yellow, and brown. Easily identified by its smooth, compact appearance, conchoidal fracture, and by sharp angular fragments. Novaculite adjacent to Magnet Cove has metamorphosed to a dark, fine-grained rock, composed of small clear crystals of quartz, some of which have a smoky appearance."

Silurian

Missouri Mountain shale 50-100 feet. "Mostly black, clay shale which in places has developed slaty cleavage. Weathers light gray to white and forms light colored clay."

Blaylock sandstone 0-500 feet. "Thin-bedded, fine-grained, gray sandstone, separated by layers of dark shale. The sandstone beds are prominently jointed, the smaller joint cracks being usually filled with quartz. Quartz crystals occur in larger cavities. Some of the beds are hard and quartzitic."

Ordovician

Polk Creek shale 50-100 feet. "Black, fissile shale, rather easily identified by the presence of graptolites. In a few places has developed slaty cleavage."

Big Fork chert 300 feet. "A dense textured, dark siliceous rock which is usually chert. The rock is highly jointed. Many of the joints are invisible. Fresh specimens are hard to obtain because of the ease with which the rock breaks down into small smooth sided, angular pieces. Some of the rock has the appearance of dense quartzite."

Womble shale 250 feet. "Black and green clay shale."

Concerning Parks' geologic section, it should be noted that the Hot Springs sandstone is probably missing from the sedimentary sequence adjacent to the east rim of the Cove. This relationship, however, is considered in detail in the discussion of the Christy brookite deposit. On the question of the age of the Arkansas novaculite formation, Miser (1948) has stated that the lower division is Devonian, but the middle division is doubtfully placed in the Devonian system as there is a possibility that it may be of Mississippian age.

IGNEOUS ROCKS

The Magnet Cove igneous rocks are characterized by the abundance of feldspathoids, the most important being nepheline. Both nepheline syenite types containing orthoclase, and rocks of the Nephelinite-Ijolite-Missourite clan (Grout, 1932, p. 105), lacking in feldspar, are present. In addition there are a large number of lamprophyres. Both aphanitic and phaneritic rocks occur and the size of the intrusive has no influence on the grain size. Complete descriptions of the igneous rocks have been made by Williams (1891) and Washington (1900, 1901) so only those igneous rocks occurring within the areas of the individual deposits mapped by Fryklund are described in this report. For greater clarity in reading the report the pethrographic studies of the igneous rocks have been included in the description of the particular deposit at which these rocks occur. Since the rutile deposit of the Magnet Cove Rutile Company is the only significant titanium deposit at Magnet Cove that lies entirely within igneous rock, most of the detailed petrography is to be found in the description of that deposit.

METAMORPHIC ROCKS

The metamorphic rocks of Magnet Cove were briefly described by Williams (1891, p. 297 ff.) and separated into obvious contact-metamorphic rocks which are restricted to the periphery of the intrusive mass, and a second group found within the Cove which he called hornstones. Only metamorphosed novaculite was present in the areas mapped for this report. This is the dominant rock at the Hardy-Walsh and the Christy properties. Several different quartzite types were recognized and will be discussed in the descriptions of the individual deposits.

The metamorphic rocks of the interior of the Cove present several problems. Williams (1891, p. 177, p. 296) refers to them collectively as hornstones, and expresses doubt as to whether they are actually metamorphic rocks or are igneous rocks of unusual types. For instance, Williams (1891, p. 262) presents several analyses of his "eleolite porphyry" and while commenting on the field resemblance to a metamorphic rock, justified his igneous classification by comparing an analysis of the rock with those of several shales found in Arkansas.

SEDIMENTARY STRUCTURE

The structure of the sedimentary rocks of the Magnet Cove area has been mapped by Parks (1932, Plate I). Immediately east of Magnet Cove the sediments have been tightly folded into isoclinal folds which are overturned to the north. The folds are truncated by the Magnet Cove intrusive mass. The sediments to the north of the area are also tightly folded but apparently not overturned. Sandstones and the Arkansas novaculite form the ridges while the valleys are in the Stanley shale. There is no evidence of major faulting in the district. Exposures in the pit of the Baroid Sales Company and in cuts along Highway 270 indicate some minor faulting, but the lack of surface exposures in the general area would prevent recognition of minor faults. No faulting was recognized during the detailed mapping of the ore areas.

IGNEOUS STRUCTURE

The igneous intrusives of Magnet Cove comprise an ellipsoidal mass with the long axis trending northwest. As mapped by Williams (1891) the mass is composed of a number of incomplete but concentric rings of igneous and metamorphic rocks. Williams (1891, p. 342) believed the igneous rocks could be divided into three distinct age groups: first, basic nepheline rocks; second, monchiquitic rocks; third, a group of nepheline and leucite rocks which form the outer rings of the igneous mass. Washington (1900, p. 392) believed the igneous mass to be a laccolith which had differentiated in place to produce the various igneous rock types. Landes (1931) presented evidence showing that the igneous mass was not a concordant body but cut across the structure of the sedimentary rocks. He, therefore, believed the igneous mass to be a stock which had differentiated in place. Ross (1941) has stated that the Magnet Cove Rutile Company pit is in a volcanic neck. The authors believe that, in part, the noncommittal conclusions of Williams are at present most acceptable.

WEATHERING

Weathering from the lower erosion surface which formed the Cove basin has penetrated to about 20 feet below the surface in the north portion of the Cove basin and to an even deeper but unknown depth in the south part of the Cove basin. The hillsides which rim the Cove basin provide the most outcrops, but even here the surface is usually covered with very heavy float, rather than true outcrops. The determination of the attitude of joints, for example, depends almost wholly on rare outcrops at the crests of the hills or

BULLETIN 16

PLATE VIII

GENERALIZED GEOLOGIC MAP

of the

MAGNET COVE AREA

in the beds of the small creeks and intermittent streams. Cove Creek and Chamberlain Creek flow in channels developed in recent gravel deposits, so that outcrops in the beds of these two streams are rare.

THE MAGNET COVE RUTILE COMPANY DEPOSIT

LOCATION

The largest known titanium ore deposit in the Magnet Cove area is the Magnet Cove Rutile Company rutile deposit in the northern part of the Cove basin. (See Plate I). The deposit is partially exposed by two large abandoned open pits that lie mainly in the east central part of Section 18, T. 3 S., R. 17 W. The remainder of the deposit which was developed by the recent drilling projects (Spencer, 1946) (Reed, 1949) of the U. S. Bureau of Mines, lies south and west of the West Pit. The property may be reached by an access road that joins U. S. Highway 270 about ¾ of a mile to the southwest.

HISTORY OF EXPLORATION AND PRODUCTION

The first investigation of the economic possibilities of the rutile deposits in the northern part of the Cove basin was made by H. A. Perkins for the Titanium Alloy Company of Maine in 1913. At that time Perkins prospected the rutile area with an auger drill and sunk a shaft about 60 feet deep. Probably this shaft is located in the present open pit of the Magnet Cove Rutile Company. The results of this early prospecting apparently were not encouraging, since there was no production or further exploration in the area until 1931. Early in the summer of 1931, Mr. J. W. Kimzey of Magnet Cove interested Mr. H. R. McKnight in the possibilities of the deposits. Subsequent prospecting by Mr. McKnight and his associates resulted in the incorporation of the Titanium Corporation of America in 1931, and immediate commercial development was begun. A mill capable of handling from 30 to 40 tons of ore per hour was built and the first carload of rutile concentrates was shipped in 1932. The rutile ore mined was from the open pits that are now controlled by the Magnet Cove Rutile Company. The first ore treated was the alluvial and residual rutile in the soil, but unoxidized ores were also mined later as the open pits were deepened to bedrock. The rutile operations of the Titanium Corporation of America extended over the period 1932-1942, but were intermittent due to the shortage of water supply in the summer months and the variable market conditions. It is reported that from 200 to 600 tons of concentrates were produced (see Table I) annually during this period, the bulk of which was exported to Europe.

In 1935 the Titanium Alloy Manufacturing Company of Maine made arrangements with Messrs. Nichols and Campbell to produce rutile from residual deposits near the southwest corner of Section 18 about half a mile southwest of the Titanium Corporation operation. This operation was unsuccessful and the company, through a subsidiary, the Arkansas Mining Corporation, took over the operation. Although the Arkansas Mining Corporation did produce some rutile in 1936, this operation also proved unsuccessful and was abandoned. In 1942, the Titanium Alloy Manufacturing Company of Maine, through a subsidiary, the Titanium Alloy Manufacturing Company of Arkansas, acquired the facilities and properties of the Titanium Corporation of America. The subsidiary Arkansas corporation installed additional facilities and equipment and produced approximately ten cars of rutile concentrates during 1943. These concentrates were used entirely in the manufacture of metallurgical alloys of titanium at the plant of the parent company in Niagara Falls, New York, since no method of making them suitable for use in welding rod coatings was determined. Because of insufficient demand for the rutile in the production of alloys, the operation was abandoned and the properties sold in December, 1943, to the Magnet Cove Rutile Company. This company operated the open pit mine and the mill in 1944 and produced rutile concentrates. This operation, however, was shut down in the fall of 1944. There have been no producing operations in this area since that time.

Table 1. Production of Rutile Concentrates from the Magnet Cove Area, Arkansas

(Data from Severance Tax Records of the State of Arkansas)

Year	Producing Company	Production (Short Tons)
1934*	Titanium Corporation of America	39.05
1935	Titanium Corporation of America	295.55
1936	Titanium Corporation of America	282.22
	Arkansas Mining Corporation	100.72
1937	Titanium Corporation of America	947.60
1938	Titanium Corporation of America	441.63
1939	Titanium Corporation of America	456.15
1940	Titanium Corporation of America	792.40
1941	Titanium Corporation of America	895.50
1942	Titanium Corporation of America	12.80
1943	Titanium Alloy Manufacturing Co. of Arkansas	600.00**
1944	Magnet Cove Rutile Company	325.00***
	Total	5,188.62

* Although producing operations began in 1932, apparently no severance tax report was filed prior to 1934.

** Estimate furnished by the Titanium Alloy and Manufacturing Division of the National Lead Company.

*** Estimate furnished by Mr. P. C. Upton of the Magnet Cove Rutile Company.

In 1945 the United States Bureau of Mines conducted an exploration project (Spencer, 1946) on the properties of the Magnet Cove Rutile Company; both churn and core drills were used in drilling a total of 1,252 feet with a maximum depth of hole of 150 feet. The rutile reserves of the deposit were increased appreciably as a result of this investigation. A more extensive core drilling project (Reed, 1949) at this deposit was completed in 1948. Since much of the geologic interpretation of the deposit is based on the 1948 drilling, a more detailed discussion of this project will follow. There has been no activity in the area since the recent drilling project.

PREVIOUS STUDIES

The rutile mineralization of the Magnet Cove Rutile Company deposit has previously been described by Ross (1941) as due to the hydrothermal alteration of a volcanic breccia by titanium-bearing solutions. In a later report based on the geologic mapping of the open pits in 1944, Kinney (1949) stated that the pits were excavated in highly weathered and altered volcanic agglomerate composed of altered mafic igneous rocks in a matrix of clay (highly altered tuff) and that the rutile seemed to be concentrated in a narrow zone in the clay beneath the igneous blocks of the agglomerate.

TOPOGRAPHY

The pit areas of the Magnet Cove Rutile Company's deposit, as well as the extensions developed by the drilling, lie in a belt of gently sloping ground between Cove Creek and the Cove rim in the north part of the Cove basin (See Plate II).

The break at the foot of the Cove rim north of the pits is about at the 450 contour. Outcrops are abundant in the rim north of the 450-foot contour, but they are rare south of the contour, the bedrock being obscured by residual and alluvial soils which in some places contain gravel deposits. East of the 200 E coordinate (Plate II) 5-foot thick terrace gravels are exposed in the pit walls. These gravels are also present at the end of the aegirine phonolite porphyry outcrop near the head of the intermittent stream east of the West Pit. The pits, therefore, occupy a slightly dissected area which probably represents the lower or 450-foot erosion level of the region.

Figure 2. View of the West Pit of the Magnet Cove Rutile Company, looking north.

The depth of weathering is apparently not related to the present topography but is related to the 450-foot terrace, so that the weathering is deeper the greater the elevation of the present surface. In general, the bottom of the pits represents the limit of weathering. On the surface in the immediate vicinity of the two pits, and most particularly in the field at the southeast corner of the mapped area, there is abundant float rutile.

PHYSICAL ASPECT OF THE PIT AREAS

The last mining in the West Pit (Figure 2) was in 1944, while the East Pit was abandoned some time before. The abundant clays of hydrothermal and weathering origin present in the pits have been reworked by rainwash, resulting in poor pit exposures. Some of the clay areas are partially covered with grass and small willows. The best exposures in the pits are "knobs" of relatively unaltered igneous rock that project from the pit floor as a result of selective mining operations. Several of the lower sections of the West Pit are under water the year round.

Because of the extensive clay alteration of both igneous rocks and veins, and lack of both well defined igneous rock-vein contacts and continuous exposures, it was necessary to use the non-committal unit "clay-hydrothermal and weathered" in mapping much of the pit areas. This "clay" as shown on Plate II, together with the few feldspar-carbonate veins mapped as such, constitute the rutile ore of the deposit. In order to obtain a clearer picture of the relationship and character of the altered igneous rocks and vein types present in the pits, a small area in the West Pit was mapped on a 10-foot scale (Plate IX, page 30) after the reworked clays had been removed by hand from contacts and other critical spots.

IGNEOUS GEOLOGY

Nomenclature

Even though the petrography of the Magnet Cove igneous rocks has been the subject of papers by two eminent petrographers, their nomenclature has been slightly revised in this report. In certain respects Williams (1891) used a more modern method of nomenclature than Washington in that he prefixed rock clan names by mineralogic qualifiers. As certain rock types, such as the ijolites, are no longer considered to belong in the clans in which Williams placed them, his nomenclature could not be followed in its entirety. On the other hand, Washington (1900) (1901) used many special names, some of them like "arkite" having only local significance. The rock names used, with the exception of aegirine phonolite porphyry, which is described for the first time in this report, are in part those of Washington and in part those of Williams. The use of each rock name is explained in the description of that rock type, and the characteristic minerals of the different rock types are shown in Table 2.

Table 2. Characteristic Minerals of the Igneous Rocks, Magnet Cove Rutile Co. Area.

Rock	Feldspar	Feldspathoid	Ferro-magnesian
Aegirine phonolite porphyry	orthoclase	nepheline	aegirine
Nepheline syenite (fine grained type)	orthoclase	nepheline cancrinite	diopside aegirine
Nepheline syenite (Diamond Jo type)	orthoclase	nepheline cancrinite	diopside aegirine
"Leucite" nepheline syenite	orthoclase	nepheline	aegirine
Nepheline tinguaite dikes	orthoclase	nepheline	aegirine
Monchiquite dikes	plagioclase	analcime (?)	titanaugite barkevikite biotite olivine (?)
Fourchite dikes		analcime (?)	titanaugite
Amphibole fourchite dikes		analcime (?)	titanaugite barkevikite

Distribution

The country rock of the Magnet Cove Rutile Company deposit is mainly an aegirine phonolite porphyry, the principal rock occurring below the 450-foot contour. There are almost continuous exposures of this rock at the foot of the Cove rim in the mapped area (see Plate II). It is again exposed in a small outcrop in the bed of the central intermittent stream just east of the West Pit. These two areas are in contact with the nepheline syenite (fine-grained type) which forms most of the hill slope to the north. The knob into which the East Pit was dug is also composed of aegirine phonolite porphyry. In the West Pit there are a number of exposures of the aegirine phonolite porphyry which are apparently in place. The extent of this rock beneath the flat to the west and to the south of the pit area is unknown as there are no exposures. Recent drill holes show the aegirine phonolite porphyry extends at least 400 feet south and 700 feet west of the West Pit.

The hillside to the north of the aegirine phonolite porphyry is composed of nepheline syenite (fine-grained type) in the center of which there is a mass of "leucite" nepheline syenite. The nepheline syenite (fine-grained type) intrudes the aegirine phonolite porphyry.

Just north of the East Pit there is a small oval outcrop of nepheline syenite (Diamond Jo type). This rock is probably related to the nepheline syenite (fine-grained type) and therefore younger than the aegirine phonolite porphyry.

In the northeast part of the West Pit there is a monchiquite mass which strikes east-west. There are no exposures to the west of the pit or contacts with the aegirine phonolite porphyry in the West Pit. In the East Pit, however, there is a small exposure of monchiquite which cuts the aegirine phonolite porphyry. A monchiquite dike was also encountered in drill hole N-1. Monchiquitic and leucite tinguaite dikes cut the aegirine phonolite porphyry.

As the various dikes cannot be traced in the "clay" of the pits, nor do any dikes cut the various vein types, the igneous activity was apparently concluded by the time the veins were introduced. In the northwest corner of the West Pit a fourchite dike in the phonolite served as the locus of a vein, as its entire length is now impregnated by carbonate, feldspar, and rutile.

Aegirine Phonolite Porphyry

The aegirine phonolite porphyry was not described by Williams. The area where it fringes the hill rim at the Magnet Cove Rutile Company property was mapped by him as sedimentary rock which passes under alluvial covering to the south.

The aegirine phonolite porphyry occurs in the West Pit as a group of elongate masses (Figure 3) that project above the pit floor. In the west end of this pit these blocks are separated from the main phonolite mass only by thin feldspar-carbonate veins. To the east in the pit they become more and more separated from the main mass and finally occur as isolated knobs surrounded by clay and vein material, well separated from the main igneous body. These phonolite blocks are essentially massive and the general strike of each is roughly N. 60°-70°E., paralleling one of the major joint trends of the nepheline syenite that outcrops in the Cove rim north of the pit. Because these isolated masses have the same elongate shape and trend, even those clearly separated from the main phonolite mass by only thin veins, it is assumed that all of them are remnants of a larger mass of phonolite which was differentially replaced and hydrothermally altered along what was probably a major joint set. A similar conclusion was reached by W. H. Lacey (Vogel, 1944, p. 4) who mapped the pits while mining was in progress. Lacey stated that the orebody appeared to be localized along a zone of en echelon faults which follows an arcuate pattern parallel to the Cove rim.

In the field two general types of phonolite may be distinguished: (1) an "unaltered" phonolite that is hard, dark brown, to almost black in color, very fine-grained and is well exposed in the numerous "knobs" of the West Pit; and (2) an "altered" phonolite that is soft, clayey, gray green to dark green in color, very fine-grained and is the predominant rock exposed in the walls of both the East and West Pits. The phonolite encountered in the drilling was differentiated into these two types (see drill logs, pp. 97-129). On the maps and sections (Plates II, III, IX), however, the phonolite was mapped as a single unit. In some areas in the fresher rock there are a few feldspar or nepheline phenocrysts, which rarely exceed 1 mm in diameter and occasionally an isolated pyroxene phenocryst can be seen. Usually, however, the porphyritic nature of the rock must be determined in thin section. In all exposed areas there are abundant small pyrite cubes.

In thin section the phonolite has considerable mineralogic variety as a result of deuteric alteration and later hydrothermal alteration as well as primary differences. Petrographically three types of phonolite may be recognized: 1. "Fresh" phonolite. 2. Hydrothermally altered, but still hard, phonolite. 3. Phonolite so hydrothermally altered it can be cut with a knife. Types

Figure 3. An aegirine phonolite porphyry knob in the West Pit of the Magnet Cove Rutile Company.

The upper half of the knob is hard, massive phonolite, which is separated from a large feldspar-carbonate vein at the base by an interval of soft, altered phonolite. The vein-phonolite contact is approximately horizontal and is marked by the point of the shovel. (Photo by John Blundell).

1 and 2 correspond in general to the hand specimen rock described as "unaltered" phonolite and Type 3 is the same as the "altered phonolite" hand specimen material.

In the "fresh" phonolite (Type 1) phenocrysts which are pseudomorphs after nepheline (Plate X-A, page 155) a feldspar (?) and a ferromagnesian mineral in that order of abundance compose about two per cent of the rock. The replacing material consists of biotite; a carbonate, probably calcite; apatite; epidote; and chlorite. The groundmass of the "fresh" phonolite is very fine-grained, averaging less than .02 mm in grain size. Aegirine needles composing about 20 per cent of the rock, form a rudely tinguaitic texture (Plate XI-A, page 156). Anhedral orthoclase grains and green biotite grains are present in equal amounts (25-30 per cent) in the rock. A black opaque mineral, probably ilmenite, in grains less than .04 mm in diameter composes about 3-5 per cent of the rock. Other accessory minerals are titanite and diopside. Even the freshest rock contains abundant carbonate, epidote, and lesser amounts of leucoxene, kaolinite,* analcime, allophane, and noselite, indicating alteration.

Table 3 is an analysis of the freshest appearing aegirine phonolite porphyry.

Table 3. Chemical Analysis of Aegirine Phonolite Porphyry.**

SiO_2	38.40
Al_2O_3	15.37
Fe_2O_3	2.42
FeO	6.20
MgO	3.20
CaO	9.30
Na_2O	5.55
K_2O	4.77
H_2O	1.81
H_2O	.36
CO_2	6.68
TiO_2	3.51
P_2O_5	.90
SO_3	.37
S	.57
MnO	.27
	99.68
Less O for S	.14
	99.54

* The clay minerals in most of the igneous rocks occurred in such small quantities that samples could not be taken for X-ray analysis. The preliminary chart for the identification of the secondary minerals compiled by Lovering (Preliminary U.S.G.S. chart) was used for the determination of the clay minerals in thin section.

** R. Chadbourn, analyst, Rock Analysis Laboratory, Department of Geology and Mineralogy, University of Minnesota.

The more altered phonolite (Type 2) while still hard and appearing no different from the freshest rock in hand specimen has a greater mineralogic variety. The aegirine has been in large measure substituted for by epidote, with some thin sections containing less than 5 per cent aegirine. The percentage of green biotite is increased only slightly. The more altered sections are accompanied by considerable amounts of a montmorillonite-like mineral (Plate XI-B, page 156). Apparently kaolinite was not formed. Apatite appears in the groundmass of the more highly altered rocks. Leucoxene is usually present also, as an alteration products of the ilmenite and sphene.

Along the borders of each phonolite "knob" there is a zone in which the phonolite has been altered to a dark green clay-like rock (Type 3) which can be easily cut by a knife. The contact between soft green rock and hard, dark brown, solid rock is gradational. Thin sections of this green rock show that the orthoclase is still identifiable and composes about 30 per cent of the rock; however, only one per cent of the aegirine remains. There is about 30 per cent of green biotite present, roughly the same as the more fresh phonolite. The remainder of the rock is composed of fine-grained masses of epidote, chlorite (?) kaolinite, montmorillonite, carbonate, and leucoxene.

From the dark green clay alteration of the phonolite there is further gradation to a white or gray bleached clay. In some cases this gradation may represent contacts of a feldspar-carbonate vein with the phonolite with subsequent alteration of the feldspar-carbonate rock. There is evidence that at least some of the white and gray clay material was originally phonolite.

Inclusions in Aegirine Phonolite Porphyry

The aegirine phonolite porphyry contains a large number of inclusions of both igneous and metamorphic rock types. In the west end of the West Pit the inclusions in each phonolite block become more abundant. The phonolite mass centering around 10,340 E., 10,240 N. (Plate II) contains inclusions of several different rock types, the largest of which seemed to be a 4-foot block of a metamorphosed sediment. The inclusions are more abundant than the phonolite and this mass could best be described as a breccia. This small area is the best evidence for postulating a volcanic neck that could be found. While many of these inclusions are readily recognized as foreign bodies, many of the inclusions have reacted with the phonolite magma and have much the same appearance as the surrounding phonolite. For instance, what was believed to be an epidotized portion of the phonolite proved in thin section to be a shale inclusion. Because dikes were known to occur in the pit, the larger inclusions were outlined by shovelling, if necessary, to show that they were irregular shaped bodies with closed perimeters. Many of the inclusions were greater than 1.5 feet in diameter, and one, a true breccia itself, was six feet long and varied from one to two feet in width.

Large blocks, up to three feet in diameter, of a biotite nepheline syenite occur in the west end of the West Pit. This rock type is apparently not the same as the nepheline mica syenite described by Williams (1891, p. 208), but because of the characteristic large biotite phenocrysts visible in the hand specimen, it was so named. In hand specimen it is a coarse grained, porphyritic rock containing large biotite phenocrysts, some of which are an inch in diameter.

A very unusual igneous breccia occurs as several inclusions, one of which was the 6-foot long inclusion previously mentioned. The freshest inclusions of this breccia are dark green in color, while one inclusion at the base of the pit wall in well weathered aegirine phonolite porphyry was dark gray, almost black, and decidedly porous due to the leaching of the carbonate. The component rock fragments are angular to subrounded in shape. The largest rock fragment was 40 mm in greatest dimension but 5-6 mm is the average. The groundmass, or cement, composes about 20 per cent of the rock. The included fragments are shale, chert, chert containing pyrite, fairly fresh trachytic aegirine syenite, and highly altered igneous rocks. The igneous fragments are the most angular and the sedimentary rocks are the most rounded. There is a roughly equal division between the number of igneous and sedimentary fragments but the igneous fragments are larger. The cement contains abundant carbonate, large apatite grains, leucoxene masses, orthoclase, green biotite, and possibly some quartz. The origin of such a breccia is uncertain, particularly in view of the nature of the cement, but the essential fact is that such a rock type is present as inclusions.

A single light green, dense, banded inclusion proved to be fine-grained metamorphosed sandstone composed of well rounded quartz grains in a cement of very fine grained amphibole and chlorite. The amphibole and chlorite was originally the clay fraction of the sandstone. The inclusion is presumably a sample of the underlying Pre-Cambrian rocks.

Age Relations

The contact between the aegirine phonolite porphyry and the nepheline syenite (fine-grained type) crops out at several places along the base of the hill at the Magnet Cove Rutile Company property. An outcrop in the bed of an intermittent stream exhibits a mutual interfingering of the two rocks and a reduction in grain size near the contact of the nepheline syenite. As the field evidence was none too conclusive as to the relative ages, thin sections of the contact were examined. The relationships of the two rocks in thin section indicated that the nepheline syenite is the younger. (Plate X-B, page 155). The contact effects on the phonolite seem to be restricted to a thin zone of epidote at the contact.

Monchiquite Dikes

The monchiquite dikes were considered by Williams (1891, p. 342) to have been intruded during the second period of igneous activity and prior to the intrusion of the "eleolitic and leucitic rocks of the 'Cove Ring'."

A large monchiquite dike, 60-100 feet wide, is exposed in the northeast portion of the West Pit. A smaller exposure of the same rock type is present in the East Pit. Here it definitely cuts the aegirine phonolite porphyry and apparently is the parent of three much smaller monchiquite dikes, 6 inches to a foot wide, which cut the phonolite. There are no exposed contacts between the large monchiquite dike and the aegirine phonolite porphyry in the West Pit. The dike is probably an extension of one mapped by Williams (1891) in the northwest quadrant of Magnet Cove. A monchiquite dike was also encountered in drill hole N-1. In hand specimen the monchiquite is coarse grained, and dark green to almost black in color, giving a pilitic appearance to the rock.

In thin section (Plate XII-A, p. 157) the rock is porphyritic with a medium-grained groundmass. An approximate mode is as follows:

Titanaugite	40
Biotite	5
Barkevikite	10
Plagioclase An (?)	20
Apatite	2
Magnetite-ilmenite	3
Chlorite (?)	20
	100

The thin sections examined gave no indication of the analcime which is supposedly characteristic of the monchiquites.

In the northeast corner of the West Pit the large monchiquite mass has also been hydrothermally altered. There is a gradation from the freshest monchiquite through a bleached zone of variable thickness but on the order of 10-20 feet, to "clay." In thin section the bleached monchiquite retains the coarse-grained texture of the fresh monchiquite and even a few patches of recognizable plagioclase but the ferro-magnesian minerals have been altered to epidote, chloritic minerals, green biotite, and iron oxides. Clay minerals are present but greatly masked by the iron oxides. Orthoclase, carbonate, and rutile have been introduced.

Three small monchiquite dikes have been observed in the East Pit of the Magnet Cove Rutile Company. Their width ranged from 6 inches to a foot. A relatively fresh, hard, black monchiquite dike was encountered in drill hole N-1. The dike extended over the depth interval 28.4′ to 43.6′ and was bounded above and below by coarse-grained albite-perthite carbonate rock. The contact relationships, however, were not preserved in the core.

Fourchite Dikes

The fourchite dikes were considered by Williams (1891, p. 110) as being olivine-free monchiquites. Two fourchite dike exposures each 1 foot wide and about 8 feet long are present in the West Pit of the Magnet Cove Rutile Company. In each case the dikes cut the aegirine phonolite porphyry. In hand specimen the dikes are dark green in color, with very abundant large pyroxene phenocrysts some of which reach 12 mm in length.

Amphibole Fourchite Dikes

In Williams' (1891, p. 110) classification the amphibole fourchites are amphibole-bearing, olivine-free monchiquites. Dikes of this rock cut the aegirine phonolite porphyry in the Magnet Cove Rutile Company pit, and also occur in the prospect pit of the Mo-Ti Corporation. In hand specimen the rock is coarse grained, porphyritic, dull gray green in color, with trachitic textures produced by oriented pyroxene needles.

Nepheline Syenite (Fine-Grained Type)

The name given by Williams (1891) to this rock has been retained. It should be noted that the nepheline syenite (fine-grained) is actually coarse-grained but is finer grained than the Diamond Jo type with which Williams was comparing it. The nepheline syenite (fine-grained type) forms the hill-side immediately north of the Magnet Cove Rutile Company pit, and also occurs at the Christy brookite property on the east rim of the Cove. It is younger than the aegirine phonolite porphyry as previously noted. Through the center of the nepheline syenite (fine-grained type) there is a band of "leucite"-nepheline syenite. The "leucite"-nepheline syenite was described by Williams (1891, p. 277) as a differentiate of the nepheline syenite because of a gradation from type nepheline syenite (fine-grained type) to "leucite"-nepheline syenite. The latter rock is dark, fine-grained, and contains abundant pseudo-leucite phenocrysts while the nepheline syenite is a coarse-grained rock which usually has no phenocrysts; however, along the contact there is a development of pseudo-leucite in the nepheline syenite. The position of the line marking gradational contacts on Plate II is tentative.

The major jointing of the nepheline syenite strikes N. 65° E. and dips 40° N. in the northwest corner of the mapped area. In the gully of the central intermittent stream just beyond the Magnet Cove Rutile Company pits the jointing is well exposed and here the major joint system strikes N. 85° E. and is vertical. The major joints, striking N. 85° E., in the central area are frequently filled by thin, less than 1-inch thick, lamprophyre dikes.

In the field the nepheline syenite is coarse-grained, light gray in color, and appears to be largely composed of feldspar and nepheline grains which reach a maximum of 4 mm in length.

Thin sections show that the rock is composed mainly of orthoclase, nepheline, cancrinite, aegirine and diopside, with garnet, biotite, magnetite, apatite and titanaugite as accessory minerals.

Nepheline Syenite (Diamond Jo Type)

This is the foyaite of Washington (1900, p. 398). The rock in thin section appeared to the senior author to be identical with the "fine-grained type." In the field, however, the nepheline of the Diamond Jo type is pinkish orange while that of the "fine-grained type" is colorless. This difference in color makes an easy field distinction. A small isolated outcrop of the Diamond Jo type occurs in the Magnet Cove Rutile Company pit area. Presumably an extension of this intrusive was encountered in drill hole O-3 as the main igneous rock type in this hole was the Diamond Jo nepheline syenite that has been hydrothermally altered to a gray green rock. There are no indications as to age relationships with the other igneous rocks. The rock is presumably closely related in age to the "fine-grained type."

"Leucite"-Nepheline Syenite

This rock type is the leucite syenite dike rock of Williams (1891, p. 267) and the leucite porphyry of Washington (1900, p. 399). The contact between the "leucite"-nepheline syenite and the nepheline syenite "fine-grained type" in the Magnet Cove Rutile Company pit area is gradational. In the field the most typical "leucite"-nepheline syenite is a dark green porphyritic rock containing a few scattered phenocrysts of pyroxene up to 6 mm in length and more abundant feldspar phenocrysts reaching a maximum length of 8 mm lying in a fine-grained groundmass. The characteristic feature is the presence of large, up to 2 cm in diameter, euhedral phenocrysts of pseudo-leucite. The pseudo-leucite phenocrysts are composed of intergrowths of orthoclase and albite, small euhedral crystals of nepheline, cancrinite, and small aegirine needles. Williams (1891, p. 269) has described the pseudo-leucite phenocrysts in great detail.

Nepheline Tinguaite Dikes

The nepheline tinguaite dikes shown on the geologic map of the Magnet Cove Rutile Company property (Plate II) correspond to the dikes mapped and described in that area by Williams (1891, p. 281) as leucite tinguaite dikes. It was necessary to change Williams' nomenclature since thin-section examination of these tinguaitic dikes revealed that nepheline is a common phenocryst in these rocks while pseudoleucite is absent. (Plate XII-B, p. 157). Two varieties of nepheline tinguaite rocks occur in the West Pit. One variety contains augite, as well as feldspar and feldspathoid phenocrysts, while the other variety, which is the largest tinguaite dike and is exposed in the pit wall near the mill contains only feldspar and feldspathoid phenocrysts. In hand specimen the largest tinguaite dike is a rich dark green in color, with a very fine-grained groundmass in which are scattered abundant orthoclase and nepheline phenocrysts. The other leucite tinguaite variety occurs in a foot-wide dike in the northwest corner of the West Pit where the intermittent stream enters the main part of the pit. There is another exposure 200 feet south along the intermittent stream.

VEINS

Summary

In the pit exposures and most of the drill holes the aegirine phonolite porphyry and the monchiquite are cut by numerous veins and vein masses. These veins are not conspicuous in the pit, however, because of the irregular shape of the larger masses and the intense clay alteration of both the enclosing phonolite and some of the vein types. In a few places these veins also cut the nepheline syenite (fine-grained type) and the nepheline syenite (Diamond Jo type). The great majority of these are rutile-bearing feldspar-carbonate veins, four types of which have been recognized. They are: 1. Sugary-textured albite-dolomite veins. 2. Microcline-calcite veins. 3. Coarse-grained albite-perthite-carbonate veins. 4. Albite-ankerite veins. In addition, calcite-rutile veins and coarse-grained calcite veins, as well as several other types of carbonate veins, are known. One small veinlet of fluorite was seen.

The sugary-textured albite-dolomite veins and the microcline calcite veins are the most widely distributed and attain the largest size of all the vein types in the deposit. The albite-ankerite veins, although widely distributed and comparatively rich in rutile, seldom exceed 8 mm in thickness. The coarse-grained albite-perthite-carbonate veins and calcite-rutile veins, though relatively large, are very limited in distribution. The coarse-grained calcite veins are characteristically large, but their rutile content is negligible.

The coarse-grained albite-perthite-carbonate veins, the albite-ankerite veins, the smaller microcline-calcite veins, and minor carbonate veins are at least veins in form. Although the sugary-textured albite-dolomite veins and the larger masses of the microcline-calcite veins are not linear features, the senior author believes that they, as well as the other vein types, are true veins.

Alteration of the two principal vein types, the sugary-coated albite-dolomite and the microcline-calcite, has yielded much of the clay which now covers the pit floors. Hydrothermal alteration, primarily, developed the clay in the sugary-textured albite-dolomite veins, while weathering formed the clay that is associated with some exposures of the microcline-calcite veins. These clays are mainly of the montmorillonite type.

The sugary-textured albite-dolomite veins are the oldest. They are cut by the microcline-calcite veins, which are in turn cut by the albite-ankerite veins. Coarse-grained calcite is cut by albite-ankerite veins, but the relationships with the other vein types are not as yet known. The relative ages of the coarse-grained albite-perthite-carbonate veins, the calcite-rutile veins, and the minor vein types are also unknown.

Rutile occurs in the altered and unaltered phases of all the feldspar-carbonate vein types but only the sugary-textured albite-dolomite, the microcline-calcite, and the albite-ankerite types are important for their rutile content. Rutile occurs in these veins as single acicular grains, nests of acicular rutile, irregular blebs which are really very compact masses of acicular rutile, and as veins and veinlets. The maximum length of acicular rutile was .5 mm and ranged downward so that rutile needles were just barely visible at 360 diameters. The average length was certainly less than .1 mm. Irregular blebs of rutile reached a maximum diameter of 1 mm in only one thin section; in the other thin sections the blebs were smaller than .1 mm in diameter. While the observed rutile veinlets varied from .1 mm in width to 5 cm, some are apparently much larger as indicated by large float rutile. Chemical analyses have shown that the small amount of vanadium present in core samples occurs in the rutile. Leucoxene occurs as small irregular patches and as a coating on the rutile masses. All the larger veins and masses of rutile have a small amount of leucoxene alteration on their edges and rims. The number of rutile patches which are surrounded by much larger leucoxene masses (Plate XVII-A, page 163) indicates that the patches now entirely composed of leucoxene probably were once rutile. The leucoxene formation probably occurred at the same time as the formation of the clay minerals. In even the freshest rock examined, from 15-20 percent of the TiO_2 content is in the form of leucoxene.

In mapping the pit areas the extensive clay alteration of both the vein types and the enclosing igneous rock, and the lack of continuous exposures made it impossible to differentiate these vein types in many sections of the pit floor. Hence, pit areas designated as "Clay, Hydrothermal and Weathered" (Plate II) can be considered to be altered aegirine phonolite porphyry containing numerous feldspar-carbonate veins of the four types listed above, of which the sugary-textured albite-dolomite type is the most common.

In the examination of the drill core, (see drill logs, pp. 97-129) the veins were simply logged either as feldspar-carbonate or as coarse-grained calcite. Most of the feldspar-carbonate vein material examined in the cores was the sugary-textured albite-dolomite type.

Sugary-Textured Albite-Dolomite Veins

The U. S. Bureau of Mines' sample trenching, and their subsequent drilling project at the Magnet Cove Rutile Company deposit in 1948 permitted the recognition of the sugary-textured albite-dolomite vein as the predominant vein type in this deposit. This vein type has been hydrothermally altered to a relatively soft mass containing much clay. Reworking of the clay by rainwash has obscured the albite-dolomite veins throughout most of the pit area. At coordinates 550 N. and 500 E. (Plate II) centering around elevation number "382" this vein type has been exposed in a series of shallow trenches. The vein mass exposed in the sample pits varies from light to dark gray in color, and because of its fine grain size appears to be an altered igneous rock type cut by many carbonate veinlets. It differs considerably in hardness, and even hand specimens appear to contain notable amounts of clay. Three thin sections of material from the sample pits show a surprising uniformity in grain size (Plate XIII-A, B, page 159) but a considerable difference in the dolomite-albite ratio. In one thin section the dolomite-albite ratio was about 60-30, in the second 80-5, and in the third 70-25. The dolomite* is euhedral and averages about .5 mm in

* The carbonates in all the vein types were determined by using the indices of Winchell. (1933, pp. 71-73).

diameter. The albite is also euhedral with some grains approaching 1 mm in length but also averages about .5 mm. About 5 percent of rutile is present. Most of the rutile occurs as acicular needles but some occurs as irregular blebs averaging less than .1 mm in diameter (Plate XIII-A, page 159). Leucoxene is abundant. Fine grained, perfectly fresh pyrite composes from 5-10 percent of the rock.

The most interesting feature of this vein type is the clay* alteration. In one section the albite was fresh containing only a small amount of allophane, but in the other sections the albite was considerably altered to a montmorillonite-like mineral and a minor amount of kaolinite (Plate XIV-A, page 160). An X-ray pattern of the montmorillonite-like mineral showed that it belonged to the montmorillonite group. The montmorillonite has developed along the twinning bands of the albite resulting in elongate montmorillonite masses which have a definite linear structure. The kaolinite lies in and is subordinate to the montmorillonite. As it occurs only in the montmorillonite it is apparently formed from it (see Ross and Hendricks, 1945, p. 68).

It was believed during the field work that much of the pit floor covered by clay was probably underlain by sugary-textured albite-dolomite vein masses. Subsequent drilling in 1948 by the U. S. Bureau of Mines has shown its wide-spread occurrence, and it now appears that this vein type is the most abundant in the West Pit area. The vein material in the drill core varies in hardness and amount of clay alteration, but material from 175 feet below the surface was essentially the same as the more altered rock in the pit.

The clay alteration is considered to be hydrothermal for the following reasons:

1. It is known to extend for at least 200 feet below the present surface.

2. At the present pit surface other feldspar-carbonate vein types have little clay alteration except at the very top of the present exposures, and this clay can be easily removed to expose hard fresh rock. Other weathering effects of the other feldspar-carbonate veins are limited to the leaching of carbonate.

3. The general composition of all the feldspar-carbonate types being essentially the same, it appears doubtful that there would be a selective reaction to weathering which would permit one vein type to be weathered to a depth of 200 feet and the other vein types to a depth of only 10-20 feet.

4. The aegirine phonolite porphyry "knobs" are altered to a clay along their borders only. It appears reasonable, therefore, to assume that the sugary-textured albite-dolomite veins were the earliest veins and that the hydrothermal alteration of the veins and of the aegirine phonolite porphyry "knobs" took place at some later time but before the introduction of the other vein types.

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* The clay minerals in thin sections of the vein types were identified by the methods described as applying to igneous rocks (p. 20). Fortunately larger masses of the clay minerals permitted checking most of them by X-ray analysis.

Drill core (Hole E-8) showed that there is a molybdenite mineralization associated with this vein type. Small veinlets of readily recognizable molybdenite flakes are rare, but areas which were streaked by extremely fine dark particles proved to contain molybdenum. The tests were qualitative, but the amount of molybdenite present is apparently very small.

Microcline-Calcite Veins

The microcline-calcite veins are the most abundant and striking of the veins actually exposed in the pits. This vein type was also present to some extent in most of the drill holes, but it was especially well developed in Hole O-2 where it constituted practically all of the feldspar-carbonate vein material present or 69 feet of the total depth of 91 feet to which the hole was drilled. Small, one-inch wide, veins are very abundant in the weathered walls of the

Figure 4. Network of thin microcline-calcite veins, West Pit, Magnet Cove Rutile Company.

pit (Figure 4). The larger veins of this type are very irregular masses which look more like intrusives than veins. The presence of a few inclusions of the aegirine phonolite porphyry and definite contact zones greatly increases the appearance of true intrusive masses. The presence of abundant carbonate, however, would require more than a simple differentiation of the original magma. Therefore, it is believed that these, as well as the other feldspar-carbonate vein types, are true veins.

Figure 5. Hand specimen of microcline-calcite vein cut by rutile veinlets, West Pit, Magnet Cove Rutile Company.

The porous appearance of the vein is a result of leaching of the calcite. P—pyrite; R—rutile. Natural size.

Unweathered veins are creamy yellow in color, hard, medium-to-fine grained and characterized by very abundant pyrite cubes (Figure 5). In the pit exposures the pyrite content of this vein type reached 20 per cent in a few places, while all the larger masses contain about 10 per cent pyrite. The smaller veins contain about 5 per cent pyrite. The pyrite cubes vary in the same mass from 5 mm on an edge to 2 cm on an edge.

In thin section (Plate XV-A, B, page 161) the fresh vein material is composed almost entirely of microcline, calcite, and pyrite with minor amounts of clay minerals, apatite, rutile, a few quartz grains, leucoxene, and a meager amount of sphene. A small amount of albite is probably introduced. The microcline is very fine-grained, averaging less than .04 mm in diameter, and occurs as anhedral grains. In all thin sections this microcline is the most abundant mineral, composing from 50-70 per cent of the rock. Rather evenly scattered in the microcline groundmass are calcite grains which generally range between 1 mm and .5 mm in diameter, although a minor amount is much smaller. Large, euhedral pyrite grains are abundant. In some cases these calcite grains contain euhedral albite grains averaging about .2 mm in length. A small amount of quartz, less than .5 per cent, was present in three thin sections. Euhedral and subhedral grains of apatite are usually present; one thin section containing about 1 per cent apatite.* The rutile in the microcline-calcite veins occurs as a cementing mineral in fractured pyrite as scattered clumps of acicular grains, and as a component of veinlets that cut the microcline-calcite veins. The clumps of acicular rutile (Plate XVI-A, B, page 162) are largely associated with the calcite grains and frequently lie either within or on the edge of the calcite grains. The density of the rutile aggregates varies from 3-4 needles, to masses that may be almost completely solid. Few rutile aggregates reach 1 mm in diameter and average half this. While the majority of rutile needles are in aggregates, the groundmass contains disseminated rutile needles of variable size among which are fine hairs barely visible at 360 diameters. The average amount of acicular rutile is probably one to two per cent. The rutile in the veinlets is usually associated with albite and ankerite but veinlets composed entirely of rutile are known (Figure 5). The acicular rutile and the rutile aggregates are probably older than the rutile veinlets.

Thin sections show that alteration products compose about 10 per cent of the freshest appearing vein material. These alteration products are uniformly fine-grained and not in masses large enough to separate for X-ray analysis. Most of the alteration products, which include halloysite, montmorillonite, allophane, kaolinite, a beidellite-like mineral, and sericite have been derived from the microcline. Rutile grains, however, commonly have an alteration fringe of leucoxene. (Plate XVII-A, page 163).

The exposures of the microcline-calcite rock in the pit show that the major clay alteration of this vein type is due to weathering, rather than hydrothermal alteration. The vein shown in the northwest corner of Plate IX is typical. Here a portion of the rock at the greatest elevation is weathering to a montmorillonite clay. At the south edge of this mass, 20 feet away and only 3 feet lower in elevation, the rock is hard and firm. At the extreme southwest corner of this same mass the carbonate has been completely leached, leaving a porous rock composed mainly of feldspar and pyrite.

Albite-Ankerite Veins

These veins are thin, varying from 1 mm to 7.5 cm, but their rutile contribution is very important. Albite-ankerite veinlets are very abundant in the microcline-calcite vein type and account for much of the rutile in that vein type. In some places albite-ankerite veinlets also occur in the aegirine-phonolite porphyry in great number, confusing the interpretation of the TiO_2 assays of the phonolite. Drill cores show that albite-ankerite veins also cut the sugary-textured albite-dolomite and coarse-grained calcite veins. The attitude of these veins varies considerably; usually no one strike direction is constant for more than 2-3 feet. Where the aegirine phonolite porphyry is cut by these veinlets, there is usually no visible contact effect.

* In the general study of apatite types made by McConnel and Gruner (1940) apatite from this property was examined. They concluded that while fluor-apatite was the most common apatite a second apatite, carbonate-apatite, occurs as a replacement of the fluor-apatite and presumably as single grains. The occurrence of partially replaced apatite grains is apparently rare as only two large apatite grains showed rims of higher birefringent apatite.

These veins appear to be the main source of large rutile masses. One vein cutting a microcline-calcite mass with several changes in strike contained a one-inch wide streak of rutile over a distance of six feet. Rutile masses two inches in diameter occur as float in the soil surrounding the pit, and even larger masses weighing up to 60 pounds were present in the early days of mining. As the albite-ankerite veins now contain the largest visible rutile masses, it is assumed that larger albite-ankerite veins do occur in the ore areas.

In hand specimen (Figure 6), although there is variation in grain size according to the width of the vein, the texture of the albite-ankerite veins remains constant. Minor weathering of pyrite gives them a yellow-brown color. Abundant rutile is common and pyrite occurs in varying amounts.

In thin section the proportion of ankerite to albite varies considerably but averages 70 per cent ankerite to 20 per cent albite. The ankerite is euhedral with grain size in the smaller veinlets averaging 1 mm. Albite is usually euhedral and well dusted with allophane. In a few places albite replaces ankerite. A beidellite-like mineral and kaolinite-like mineral are abundant. As in the hand specimen rutile is abundant, and it usually has a film of leucoxene on its edges. The albite-ankerite veins are the only veins in which

Figure 6. Hand specimen of albite-ankerite vein, West Pit, Magnet Cove Rutile Company.

The white is albite; dull gray is carbonate; shiny black is rutile; small black squares are pyrite. Natural size.

there are clear indications of a mineral sequence. The sequence is as follows: ankerite, pyrite, albite, rutile. The albite and rutile apparently overlapped.

Coarse-Grained Albite-Perthite-Carbonate Veins

This rock type has been recognized in only three places in the pits where it occurs as vertical veins in the pit walls. The largest vein, about 6 feet wide, is in the north wall of the West Pit, near the 800 E. and 1,000 N. coordinates (Plate II), where its strike is about N. 10° W. The second is at 550 N., 2,170 E. coordinates in the East Pit; the third in the small cut next to the road northwest of the East Pit. The occurrence at 550 N., 2,170 E. coordinates in the East Pit is at the actual top of the vein. The vein near the top of the cut divides into several shoots at right angles so that the main vein does not reach the top of the cut. The other two occurrences are dike-like. In the drill cores this rock was the principal vein type found in drill holes N-1 and O-3.

In the field the rock is creamy white, coarse-grained, porous, and is composed mainly of euhedral feldspar grains, reaching 5 mm in length but averaging about 2 mm. What is presumed to have been originally carbonate has been leached, leaving various-sized cavities.

Figure 7. Hand specimen of calcite-rutile vein type, West Pit, Magnet Cove Rutile Company.

Gray areas are calcite; black areas are rutile; small white grains are albite. One and one-half times natural size.

The minerals visible in thin section (Plate XVIII-A, page 164) are albite, perthitic microcline, clay minerals, hydromica, quartz, rutile, and leucoxene.

Calcite-Rutile Veins

At two places in the West Pit there are masses of calcite with a grain size averaging 5-6 mm which contain very abundant rutile and a small amount of albite (Fig. 7). Both occurrences were in small pits; and the size, shape, and relationships with the other vein types were undeterminable. Rutile occurs as distinct grains, averaging 2 mm. in diameter, which at first glance appear to be rather evenly disseminated through the calcite. Closer inspection shows the rutile grains frequently form linear patterns, but as the individual grains are not connected with each other they cannot be called veinlets. A small amount of finer-grained albite frequently, but not invariably, occurs in these trains. Albite also fills interstices between calcite grains well away from rutile. Calcite was the earliest mineral followed by rutile then albite.

Coarse-Grained Calcite Veins

No large coarse-grained calcite veins were exposed in the pits, but recent (1948) Bureau of Mines drill holes show that in the area immediately south of the pit they are common. These veins are massive, and the appearance of a coarse grain size is brought out by the cleavage. Individual cleavage fragments average about 8 mm with some much larger. The calcite in places contains wollastonite (?) needles and a black biotite altering to chlorite. Very thin veinlets containing rutile and pyrite, as well as pyrite alone, cut the calcite veins. In drill core south of the pit these veins cut a dark green clay, originally the aegirine phonolite porphyry, and a second altered porphyritic rock.

While as a source of rutile these calcite veins are of little interest, their relationships to other aspects of the Cove geology are quite significant. Landes (1931) has described the mineralogy and discussed the origin of several large calcite masses which occur one-half mile to the south. At the time of Landes' visit one mass had just been exposed in a roadside cut along Highway 270 just west of the bridge crossing Cove Creek. At the present time there is an abandoned quarry in the calcite mass nearest the road. Silicate minerals, including wollastonite, monticellite, and biotite are present in the calcite. As exposed in this quarry, the calcite mass is cut by finer-grained calcite veins of much the same mineralogy, as well as much smaller veins containing pyrite and in a few places molybdenite. Landes (1931) and Williams (1891, p. 181) have suggested that the calcite masses represent large fragments of some limestone horizon which lies at depth and which were emplaced by the Magnet Cove intrusions. Inasmuch as similar calcite containing the same silicate minerals occurs as definite veins; the origin of the large calcite masses to the south of the pit should be reconsidered.

Miscellaneous Types of Veinlets

The aegirine phonolite porphyry is cut in many places by dense networks of small carbonate-dominant veinlets. In thin section many of these veins prove to be typical albite-ankerite veinlets. In some areas the phonolite is cut by an intricate network of purely dolomite veins. Other mainly carbonate veins in thin section proved to contain such combinations as dolomite and rutile; dolomite and pyrite; dolomite, rutile, and pyrite; dolomite, rutile, pyrite, and green biotite; dolomite and green biotite (Plate XVIII-B, page 164). A single small veinlet of fluorite was found. At two points, both in the clay of the West Pit, large pyrite veins were found. The pyrite was quite fresh, and untarnished, although the veins were disintegrating.

PARAGENESIS OF THE ORE BODY

1. Intrusion of aegirine phonolite porphyry magma which contained abundant inclusions. The magma may have intruded a volcanic agglomerate, or may have intruded a fault zone.

2. Intrusion of the other igneous types.

3. The introduction of sugary-textured albite-dolomite veins probably controlled by the pre-existing joint pattern of the aegirine phonolite porphyry.

4. Hydrothermal alteration of the sugary-textured albite-dolomite veins and the aegirine phonolite porphyry where it was in contact with these veins.

5. Introduction of the microcline-calcite veins, followed or accompanied by coarse-grained calcite veins.

6. Introduction of the albite-ankerite veins.

The sequence of introduction of the coarse-grained albite-perthite-carbonate veins and the other veins is uncertain, but they are later than sugary-textured albite dolomite veins.

The presence of molybdenite would indicate at least moderately high temperatures at one time during vein introduction. The high temperature polymorph of TiO_2 (rutile) also indicates such temperatures but too little is known about the stability conditions of rutile to make this a very useful criterion. However, the lack of adularia in any of the veins may be a more useful temperature criterion.

THE QUESTION OF VOLCANIC ACTIVITY

The Magnet Cove intrusives may well represent the roots of a volcano, but much more than a cursory examination of Magnet Cove will be needed to confirm such a hypothesis.

Many of the intrusives are obviously ring dikes, but the extremely coarse-grained rocks of the interior of the Cove present interesting problems. Pegmatites containing aegirine crystals over one foot in length, but no mica, are still to be seen in the Cove interior. In the same general area altered mica books six inches in diameter may be dug out of road cuts indicating a second very coarse-grained rock.

Any hypothesis which explains the Magnet Cove intrusives must also explain the manner of introduction of the Potash Sulphur Springs intrusives which lie about four miles to the west. These intrusives do not have the appearance of ring dikes but obviously came from the same parent magma.

Although the question as to whether or not the Magnet Cove intrusives were formed in a volcanic neck cannot be settled in this paper, the writer does not believe the Magnet Cove Rutile Company ore should be described as a volcanic agglomerate. Geology exposed in the pit, and which was not available to Ross, indicates a much more complex history and places such volcanic activity, if it occurred at all, in a subordinate position with respect to the present ore body.

The large number of inclusions in the aegirine phonolite porphyry may be the result of incorporation of a volcanic agglomerate, but the rutile is associated with the previously mentioned vein types which now cut the phonolite, and each other, and represent a period of hydrothermal activity later than any possible volcanic activity.

SUMMARY OF THE OCCURRENCE OF TITANIUM MINERALS IN MAGNET COVE RUTILE COMPANY DEPOSIT

In the discussion of veins (p. 26) it was pointed out that rutile occurs in this deposit as scattered acicular grains, masses of acicular grains, veins, and veinlets in feldspar-carbonate rock. Most of this rutile has at least a film of leucoxene and some of the rutile has been almost completely altered to leucoxene. Perhaps 15 to 20 per cent of the TiO_2 present in the feldspar-carbonate veins occurs in the form of leucoxene.

A study of the assays and descriptive logs (see logs, pp. 97-129) of the cores recovered during the 1948 U. S. Bureau of Mines drilling project reveals that all the igneous rocks cored as well as the feldspar-carbonate-rutile veins contain some titanium. Therefore, the form in which the titanium occurs in the igneous rocks of the deposit is of interest. The TiO_2 in the "altered" and "unaltered phonolite" is mainly in fine-grained ilmenite which appears to be a primary mineral. This ilmenite is uniformly disseminated through the rock and is of such concentration and so fine-grained that it probably could not be economically recovered using current beneficiation methods. The titanium that occurs in the other igneous rocks is sparingly present as silicate minerals, magnetite-ilmenite, and ilmenite. Included in this category is the TiO_2 of the nepheline syenite (fine-grained type), the nepheline syenite (Diamond Jo type), and the monchiquite. Thus, despite the relatively high percentage of TiO_2 in many of the igneous rocks of this deposit, the titanium ore of the deposit is restricted to the rutile-bearing feldspar-carbonate veins.

RADIOACTIVITY IN THE WEST PIT AND AT TUFA HILL

On March 3, 1949, a short time after the completion of the U. S. Bureau of Mines titanium drilling projects at Magnet Cove, a preliminary Geiger counter examination of the drill cores and sludges from the projects was made by Mr. H. B. Foxhall, State Geologist, and Mr. Eugene Brewster of the Geology Division, to check the possible occurrence of radioactive minerals in the titanium ores. Since this preliminary work showed that some of the cores (Holes No. E-8, G-2, B-2, C-2, D-3, and I-1) from the Magnet Cove Rutile Company deposit were radioactive, all of the cores from this deposit were carefully checked both by Mr. Brewster and by the U. S. Bureau of Mines at Rolla, Missouri. At about this same time Mr. Percy Upton, of the Magnet Cove Rutile Company had independently detected radioactivity at the property. Mr. Brewster and Mr. Foxhall in cooperation with Mr. Upton then made a Geiger counter survey of the Magnet Cove Rutile Company's deposit and collected a suite of eight surface samples from the most radioactive spots and two additional surface samples from the center of the SW¼ SW¼ of Section 18, T. 3S, R. 17W, half a mile southwest of the Magnet Cove Rutile Company deposit. These samples were shipped to the Raw Materials Division of the Atomic Energy Commission for analysis. The samples varied somewhat in character, but in general the microcline-calcite vein type previously described predominated. Both chemical and radiometric assays were made by the Atomic Energy Commission laboratories and the results obtained by them on the ten samples submitted are shown on Table 4.

Table 4. Radiometric and Chemical Assays of Radioactive Samples from the Magnet Cove Rutile Company Deposit.

Sample No.	Coordinates* of Sample Location		Percent U_3O_8 Equivalent (Radiometric)	Percent U_3O_8 (chemical)
	N	E		
1501 H	640	232	0.018	0.009
1501 I	668	492	0.018	0.012
1501 J	540	247	0.022	--------
1501 K	481	1430	0.046	0.012
1501 L	945	1248	0.021	--------
1501 M	135	262	0.018	--------
1501 N	968	1272	0.024	0.005
1501 O	478	1405	0.002	--------
1501 P	SW SW sec. 18, T. 3S, R. 17W		0.013	--------
1501 Q	" " " "		0.016	--------

* Refers to the location of the sample on Plate II.

In the letter** containing the above analyses, Mr. Nininger made the following interpretation of the laboratory's results:

> Comparison of radiometric and chemical assays indicates that the radioactivity results in considerable part from elements other than

**Letter dated December 8, 1949, from R. D. Nininger, Deputy Assistant Manager, Raw Materials Division, Atomic Energy Commission.

uranium, probably chiefly thorium. This is particularly noticeable in samples 1501 K and 1501 N. It is obvious, therefore, that the actual amount of contained uranium is considerably less than preliminary counter tests may suggest.

We have received several suites of samples from the Magnet Cove area other than those which you submitted and have studied all of these as a unit. The results obtained are generally similar. The samples exhibit small amounts of radioactivity and comparisons between numerous chemical assays for uranium and radiometric assays show that a large part of the radioactivity does not result from uranium. Therefore, we question whether, at the present time, it would be profitable to work such material for its uranium content. . . .

A short time before the Geology Division began the Geiger counter survey of the Magnet Cove Rutile Company property, Mr. Joe Kimzey discovered radioactive minerals on his property in the NW¼ of Section 20, T. 3S, R. 17W, approximately in the center of Magnet Cove. Although this occurrence is not related to a titanium deposit, it is described here because the nature and intensity of its radioactivity is very similar to the radioactivity at the Magnet Cove Rutile Company pit. The discovery was made at the east end of a low hill of siliceous tufa situated about 300 yards due north of Mr. Kimzey's residence. A suite of surface samples was submitted in February, 1949, to the Atomic Energy Commission by Mr. Kimzey and in March, 1949, after some trenching at the property the trenches were sampled by Mr. Foxhall and Mr. Kimzey. Duplicate sets of these trench samples in addition to samples of radioactive tufa float from the S. F. Moore property, half a mile west of Mr. Kimzey's trenches, were sent to the U. S. Geological Survey and the Atomic Energy Commission for analysis. The results* of

Table 5. Radiometric Assays of Radioactive Samples from Tufa Hill, Magnet Cove.

U.S.G.S. Sample No.	Locality	Nature of Sample	Radioactivity Percent Equivalent Uranium
403-HBF-6	Trench on J. W. Kimzey property SW·NW sec. 20, T. 3S, R. 17W	Yellow-green earthy material	0.063
403-HBF-2	Same as above	Surface tufa	0.012
403-HBF-3	Same as above	Altered syenite dike	0.003
403-HBF-4	Same as above	Limonite and clay	0.037
403-HBF-5	Same as above	Tufa at 5-foot depth	0.019
403-HBF-1	S. F. Moore property NE¼ sec. 19, T. 3S, R. 17W	Siliceous tufa float	0.027

* Letter dated May 20, 1949, from Mr. T. B. Nolan, Acting Director, U. S. Geological Survey.

radioactivity tests on these trench samples obtained by the U. S. Geological Survey, are shown in Table 5.

In his letter transmitting the radiometric assays of the samples, Mr. Nolan furnished the following interpretation of the results:

> Chemical tests on sample HBF-6 indicate that approximately two-thirds of the radioactivity is due to uranium and the remaining activity is probably due largely to thorium.
>
> Mineralogical examination of HBF-6 shows that the material is a mixture of limonite and rare-earth phosphates. Titanium, vanadium, niobium, and iron are also present.
>
> The radioactivity of the samples indicates that the uranium content of this material is too low to be of commercial interest for uranium alone under the current prices paid for uranium ores.

Comparable radiometric and analytical results on samples of the same material were obtained by the Atomic Energy Commission laboratories and by Mr. Troy W. Carney, Arkansas Division of Geology chemist.

THE U. S. BUREAU OF MINES DRILLING PROJECTS

The West Pit area and a few holes in the East Pit were drilled by the U. S. Bureau of Mines in 1945. Twenty-six holes were completed of which 16 were churn-drilled and 10 were core-drilled. The total footage drilled was 1,252 feet, and the deepest hole was 150 feet. Prior to the drilling, a plane table geologic map* of the pit areas was prepared by D. M. Kinney of the U. S. Geological Survey and a potential-drop-ratio survey of the deposit was completed by the Bureau of Mines. The descriptive logs and assays of the drill hole samples, as well as the geologic map and the potential-drop-ratio survey map were published in a report by Spencer (1946). Churn drilling of a complex containing hydrothermally altered igneous rocks, hydrothermally altered vein types and unaltered vein types gave data difficult to interpret. Consequently the logs in Spencer's report lacked much needed descriptive detail. The distribution of the 1945 drill holes made them especially well suited to the construction of cross-sections of the deposit. Thus, the logs of these holes provided most of the subsurface data on which the geologic sections (Plate III) of the deposit are based. In preparing these sections the data from the published logs were correlated as well as possible with the geology of the pits and the surface as mapped by Fryklund. On these geologic sections the "hard, dark rock" from Spencer's logs is shown as phonolite, the "felsite" is shown as feldspar-carbonate and the "clay, pyrite, rutile, calcite, and other minerals" is shown as clay, hydrothermal and weathered. In order to provide as complete data as possible on this deposit, Spencer's logs have been reprinted on pages 82-96 of this report.

During the 1948 drilling project (Reed, 1949) the U. S. Bureau of Mines drilled 27 holes. The total footage drilled was 3,043.8 feet and the deepest hole was 188.5 feet (E-7). The purpose of this project was to obtain representative samples for metallurgical testing both from the previously drilled

* This map accompanied by a brief geologic report was later released by the U. S. Geological Survey (Kinney 1949).

area and from the possible extensions to the south and west. In order to recover acceptable samples, core drilling methods (Dupuy, 1949) were used exclusively and core recovery was good. Most of the holes were drilled south and west of the West Pit or in the West Pit and a few were drilled in the East Pit.

All of the cores* recovered during the 1948 project were logged by Holbrook while the drilling was in progress. In logging the core the distinction between igneous rock and vein material was emphasized. The igneous rocks were either identified as specific rock types, i. e., altered phonolite, monchiquite, and others, or simply called igneous rock where their identity was obscure. With the exception of the coarse-grained calcite veins, which were logged as such, all of the veins and vein masses in the core were usually described as feldspar-carbonate rock. In a few instances, however, where characteristic sections of the different vein types were observed, the vein type (microcline-calcite, albite-dolomite, etc.) was indicated on the log. As a general rule, the soft, altered feldspar-carbonate referred to in the logs is the sugary-textured albite-dolomite vein type, while the hard, light-colored feldspar-carbonate containing coarse pyrite crystals is the microcline-calcite vein type. Since the ore mineral in the deposit is rutile, the abundance and size of the rutile grains visible in the core was recorded in the logs. The descriptive logs, together with the U. S. Bureau of Mines analyses (Reed, 1949, Figs. 4 through 30) of the cores, are on pages 97-129.

Although the 1948 drill holes were too widely scattered over the deposit to permit subsurface correlation, they did afford detailed subsurface geologic information on the deposit. Some of the important features of the deposit that were brought out by the recent drilling are listed below:

1. The sugary-textured albite-dolomite veins represent the largest volume of feldspar-carbonate vein material.
2. There is, in places, low-grade molybdenite mineralization. (Holes E-7 and E-8).
3. The coarse-grained calcite vein type containing some silicates was first recognized in drill core.
4. The coarse-grained calcite vein type is the only significant vein in the southernmost line of drill holes, but it is of no consequence in the drill holes in the pit area.
5. Brookite veins cutting well altered feldspar-carbonate veins occur in a few places in the ore area.
6. The presence of unaltered phonolite in a drill hole does not necessarily indicate a lack of rutile mineralization below. Ribs of unaltered phonolite were often found to lie between sizable feldspar-carbonate veins (Holes C-2, O-2).
7. Many of the drill holes including the deepest one (E-7, 188′) were bottomed in "ore".
8. The significant rutile mineralization is now known to extend about 450 feet south and 400 feet west of the West Pit area.

* Splits of all the cores from this project are on permanent file at the Core Library of the U. S. Bureau of Mines of Rolla, Missouri. This library is open to the public for study of the cores at any time that qualified persons wish to make such a study.

RECOMMENDATIONS FOR FURTHER EXPLORATION

On the map of the Magnet Cove Rutile Company deposit (Plate II) the most favorable ore area is bounded by the broken line described as the "limits of significant rutile mineralization". This boundary is based both on the pit exposures and drill hole data. The ore area as shown on the map is roughly oval in shape with a maximum east-west length of about 2,400 feet and a maximum north-south width of about 1,000 feet, centering around the West Pit. Drill holes outside of the most favorable ore area have encountered rutile-bearing veins in igneous rock but not in significant numbers or thicknesses. Perhaps future pit excavation may indicate extensions of the deposit, but it appears that new drilling in the mapped area would contribute more to the immediately usable ore reserves by attempting to extend the depth of the deposit rather than the length or width. An exception to this is the ore area around drill hole M-5 which might be expanded laterally by drilling.

HARDY-WALSH BROOKITE DEPOSIT

LOCATION

The Hardy-Walsh deposit lies in two adjacent 40-acre tracts in Sections 16 and 17, T. 3S, R. 17W (Plate I), one mile north of the community of Magnet, on the east edge of Magnet Cove. The Hardy portion lies entirely within the SW¼ NW¼ of Sec. 16 and the Walsh portion of the deposit is in the forty immediately to the west (SE¼ NE¼, Sec. 17). The Hardy tract may be reached by following a dirt road north from Highway 270 at Magnet, a distance of a mile and a half and turning east on an obscure access road which enters the east end of the property. The Walsh tract is not accessible by road but may be reached by crossing the Hardy tract on foot.

HISTORY OF EXPLORATION

Exploration on the Hardy property was begun by McCombs Hardy of Little Rock, Arkansas, in the fall of 1941 and continued intermittently during 1942. During this period the deposit was extensively explored by trenches (Plate IV) and core and hand-auger drill holes. The property was examined and sampled by engineers of the U. S. Bureau of Mines in 1942 and 1943, but no report of this work was published. There has never been any commercial production of brookite from the property.

It is not known what individual or company did the test-pitting on the Walsh property, but it is evident that there has been no commercial production of brookite from this part of the deposit.

PREVIOUS STUDY

The ore of the Hardy-Walsh deposit has been briefly described by Ross (1941, p. 25) as being a mineralized volcanic breccia.

TOPOGRAPHY

The prospected area lies along the crest of a quartzite ridge, which is at or near the uppermost erosion surface of the Magnet Cove region. As at the Christy property, weathering and possibly stream activity, have played a part in the formation of the orebodies.

SEDIMENTARY ROCKS

Except for one small outcrop of shale the only rock exposed in the immediate vicinity is a gray quartzite. The outcrops of the quartzite are actually very heavy float areas, and structure determinations depended upon exposures in prospects pits.

As mapped by Parks (1932, Plate II), a ridge is developed along the crest of a tightly folded anticline in the northern part of Secs. 16 and 17. The end of this ridge on which the two properties lie was mapped by Parks as Stanley shale with an area of Hot Springs sandstone occupying the crest of the ridge immediately to the northeast. Arkansas novaculite is shown as occupying the crest of the ridge still further to the northeast beyond the Hot Springs sandstone outcrop. There was some question at the time field work was in progress as to the stratigraphic position of the gray quartzite country rock. As Parks

(1932, p. 16) referred to "Compact layers of gray sandstone in thick and thin layers", in the Stanley shale and had mapped the quartzite ridge on which the brookite properties lie as Stanley shale, it was tentatively assumed that the quartzite was one of these sandstone layers which had been metamorphosed. No sandstone was observed in the Stanley shale in this area, however. Thin section material of known Hot Springs sandstone, the only other sandstone of the region, was then collected for comparison with the gray quartzite.

In thin section the quartz grains of the gray quartzite average between .5 mm and 1 mm in diameter, but the grain size is quite variable (Plate XIX-A, p. 165). The grain boundaries are in general smooth but there is localized interlocking of grain boundaries. The texture as a whole cannot be called sutured. The thin sections have a "dirty" appearance caused by abundant bubbles and very fine inclusions in the quartz. Most of the sections contained some limonite. There were 5 or 6 rounded heavy mineral grains, averaging about .05 mm in diameter, in each thin section. A green amphibole was most abundant and apatite the next abundant. In all the thin sections only three grains of zircon were observed.

A thin section of known Hot Springs sandstone contained abundant heavy minerals, the most important of which were zircon grains. Other heavy minerals present were leucoxene masses, an amphibole, apatite, biotite, and one grain of tourmaline.

Metamorphism would recrystallize the quartz of a sandstone but not remove the heavy minerals. It was assumed, therefore, that the gray quartzite was not metamorphosed Hot Springs sandstone. Because of the character of the primary brookite ore it is thought that the gray quartzite is metamorphosed Arkansas novaculite, and that the few heavy mineral grains present were introduced into the novaculite at the same time as the "detrital quartz and sand grains" referred to by Miser (1943, p. 106).

The shale outcrop (probably of the Stanley shale formation) is an exposure 6 feet in diameter on the edge of the small ravine on the east edge of the mapped area. It's attitude could not be determined.

IGNEOUS ROCKS

The nearest large exposure of igneous rock lies about one-eighth of a mile north of the mapped area. In the ravine south of the quartzite ridge there is one small fourchite dike. There are no igneous rocks in place along the crest of the ridge.

DESCRIPTION OF THE ORE AREAS

The ridge crest can be divided into five separate areas from east to west as follows: (See Plate IV):

1. An essentially barren quartzite knob.
2. A saddle occupied by the best prospected ore areas.
3. A second quartzite knob.
4. A saddle immediately west of the second knob.
5. A third quartzite knob which has been mineralized.

The main prospecting of the Hardy property (Sec. 16) was in the first saddle, while the Walsh property (Sec. 17) was prospected on the third quartzite knob.

First Quartzite Knob

The gray quartzite of this knob, although cut by three types of coarse-grained quartz veins, is essentially barren.

The most common type occurs as narrow veins along joint planes in the quartzite where solution has enlarged shallow cavities. The quartz crystals are gray, terminate on only one end and contain very abundant gas bubbles and inclusions. No brookite was observed accompanying this vein type.

Veins of the second type are well exposed in the two trenches in the northern tip of the knob where they reach a maximum of one foot in width. The veins consist almost entirely of smoky quartz that occurs as poorly formed crystals which average 2 to 3 inches in length and are oriented perpendicular to the vein walls (Fig. 8). The centers of the veins have abundant irregular cavities as well as a few cube-shaped cavities which are now coated with limonite, indicating that pyrite was probably a primary constituent. No brookite was visible in these veins, but a hand specimen of the smoky quartz assayed .5 per cent TiO_2.

The third vein type, a coarse-grained smoky quartz vein with large brookite crystals and clay minerals was exposed in two prospect pits, in the south portion of the knob.

Figure 8. Hand specimen showing smoky quartz vein—gray quartzite contact, Hardy-Walsh brookite deposit. Natural size.

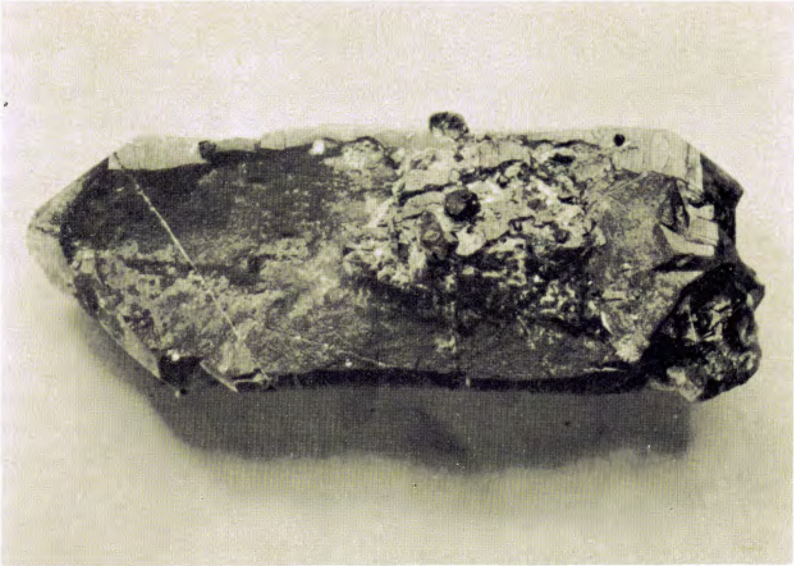


Figure 9. Corroded quartz crystal from a clay seam, Hardy-Walsh brookite deposit.

Brookite crystals (black) are shown within the quartz. Natural size.

In the prospect pit which adjoins the shaft in the south portion of the knob there is a vein 6-8 feet wide of the third type where the quartzite has been recrystallized to almost massive smoky quartz accompanied by the introduction of very abundant, large brookite crystals and clay minerals. This smoky quartz and brookite is similar to massive and coarse-grained quartz *and brookite (see Fig. 11, p. 58), of the Christy property except for the smoky* color of the Hardy quartz. A solid wall of this vuggy, smoky quartz and brookite extends to the bottom of an 8-foot deep prospect pit. The shaft was sunk on the foot wall of the vein and in barren rock. On the hanging wall of the smoky quartz vein there is a seam of clay which is composed mainly of limonite-stained kaolinite and taenolite. Scattered through the clay seam are fragments of smoky quartz and abundant, doubly terminated, coarse gray quartz crystals. On and in these large euhedral quartz crystals are perfect brookite crystals which reach 2 mm. in diameter (see Fig. 9). Since the mound resting on the corroded quartz crystal shown in Figure 9 is actually part of the crystal as shown by remnants of the crystal faces, it is apparent that brookite crystals are visible well within the quartz. Thus, the brookite mineralization probably preceded the recrystallization of the quartz.

One hundred feet due east of this pit there is a smaller pit in which is exposed a second vein of the same general type. The two pits are not on the same vein as shown by an intervening pit in barren quartzite. The veins of this type are important because they indicate the probable source of much of the coarse brookite which occurs as float along the east rim of Magnet Cove.

The First Saddle

General Statement

The first saddle has been rather thoroughly trenched so that the character of the underlying material is known to a depth of about 15 feet below the surface. Presumably the pits were deeper at one time as there is evidence of caving. The pits are so spaced on the hill slopes as to give a 30-foot section of the deposit. This saddle is essentially the principal known "ore body" of the entire deposit. Most of the ore is a clay residual ore through which are scattered sand and silt sizes of various materials as well as pebbles and small cobbles composed mainly of recrystallized quartz types. In the northeast corner of the ore area large angular fragments of various rock types are dominant. Primary ore consisting of recrystallized quartz rock with disseminated rutile needles and brookite is exposed in the prospect pit in the center of the saddle. The country rock contacts with the clay area are sharp and apparently vertical. The strike of the contacts is very irregular in detail but follows a roughly north-south trend.

Residual Ore

The clay in the residual ore of the first saddle is a rich red-brown in color, becoming more yellowish at depth. X-ray analysis of the true clay sizes from several samples* showed that these sizes are composed of quartz, kaolinite, and taeniolite. The relative proportions of each mineral appeared to be variable.

Through the clay are scattered lumps of taeniolite, a rare magnesian lithium mica ($KLiMg_2Si_4O_{10}F_2$) which contains a small amount of titanium as an essential constituent (Miser and Stevens, 1938). Presumably the taeniolite was originally introduced into quartzite. Those taeniolite masses observed by the writer were small, reaching 2 to 3 inches in diameter, but larger masses do occur in the clay as Miser and Stevens observed much larger masses of the mineral on the dumps of several pits.

An occasional nodule of unstained kaolinite about the size of a pea can also be found in the red clay. Its original manner of occurrence in this area is not known definitely, although it is a vein component in the third quartzite knob area.

Angular and subrounded pebbles and cobbles of various types of quartz rocks are scattered through the clay. Perhaps 10 per cent of the entire "clay" mass is composed of such fragments. The fragments rarely exceed 2 inches in greatest diameter and average a little over 1 inch in diameter. Subrounded fragments are dominant and most of the fragments are composed of quartz grains of much the same character as the gray quartzite. The quartz rock fragments differ in concentration from pit to pit, but even in pits that reached the lowest elevation below the crest of the saddle these rock fragments were present. Though Ross (1941, p. 25) described fragments of a

* Vertical channel samples were taken from the walls of all the test pits to provide material for assay and for microscopic and X-ray determinations. The assays were made by T. W. Carney, Chemist, Arkansas Division of Geology, and the assay values are plotted on Plate IV.

weathered nepheline syenite rock in the clay of this area or perhaps in the northeast corner of the first saddle, no igneous rock fragments were found in the "clay" samples examined.

During the preparation of the clay sizes for X-ray analysis it was found that about 9 per cent of the "clay" of the first saddle was actually sand. The "clay" was wet seived with the smallest screen being 250-mesh and the screen analysis of the sand-sized material (+ 250-mesh) was as follows:

Mesh	Opening in mm.	Per Cent
Plus 16	.991	0.6
Plus 42	.351	3.1
Plus 60	.246	1.5
Plus 80	.175	0.0
Plus 115	.124	1.3
Plus 250	.062	2.3

The material in each size fraction is as follows:

Plus 16 mesh—All grains are very well rounded, many closely approach sphericity. The identified materials were:

1. Fine-grained sandstone—several grains.
2. Clear recrystallized quartzite aggregates, some containing brookite.
3. Cloudy and almost black recrystallized quartz, some containing brookite—abundant.
4. Clay pellets—abundant.
5. Feldspar grains—common.
6. Taeniolite.
7. Magnetite—minor.
8. Dark brown goethite (determined by X-ray)—abundant.
9. Carbonate—alone and with feldspar—minor.
10. Brookite alone—minor.
11. Novaculite fragments—common.

Plus 42 mesh—All grains are well rounded. Magnetite, both as discrete particles and associated with quartz, is abundant. Brookite is present. The other grains are of the type described above.

Plus 60 mesh—The grains are not as well rounded as the larger sizes. Magnetite is very abundant. Brookite is present. Other grains are of the same types as described before.

Plus 115 mesh—Essentially the same as the 60 mesh fraction.

Plus 250 mesh—Essentially the same as the 60 mesh fraction but less magnetite.

Visible brookite is not common among the sand sizes, and as channel samples averaged about 5 per cent TiO_2, undoubtedly much of the brookite is of silt or clay size.

The subrounded cobbles and pebbles, and the well rounded sand sizes indicate that at least the upper part of the residual ore has been mixed with some water transported sediments. While weathering in place may have produced such rounding the abundant magnetite was transported from some outside source, as neither the primary ore exposed in the pits nor the gray quartzite contains magnetite. The nearest source of fine-grained magnetite is about one-half mile to the northwest and at an elevation 200 feet lower than the deposit. A second possible source is a zone of magnetite mineralization which lies just west of the rim of Magnet Cove.

The character of the material in the northeast corner of the first saddle is quite different from the rest of the residual ore. Immediately adjacent to the gray quartzite contact are large blocks of the gray quartzite, whose presence can be explained by slumping from the parent mass. These blocks extend 10-15 feet from the gray quartzite. Other large blocks farther from the quartzite contact are composed of black, porous quartzite containing rutile and brookite identical with the black porous quartzite occurring at the Christy property, and a light gray quartzite. Several large blocks show a gradation between these two types. The concentration of these blocks decreases toward the center of the saddle. Igneous material may be present but none was recognized. Between the blocks there are a few small quartz and goethite veins. The quartz occurs as irregular masses and as euhedral crystals showing zonal growth (Plate XIX-B, p. 165). The euhedral crystals lie in goethite. The larger irregular quartz masses are cut by goethite. A clay matrix, mineralogically the same as the red clay in the main part of the saddle, is present in varying amounts between all the quartzite blocks. There is evidently an abrupt contact with the main residual clay mass as shown by two pits 20 feet apart. One pit contains abundant large blocks, the other pit, 15 feet deep, is entirely within the red clay with only a very few subrounded cobbles and pebbles.

Primary Ore

As exposed in the prospect pit (coordinates—10,500 N, 9105 E, Plate IV) at the crest of the saddle, the primary ore is composed of light and dark quartzite. The relations in the pit do not indicate their relative ages, but the nature of the light quartzite indicates it is the earlier.

The dark quartzite is recrystallized novaculite with individual quartz grains slightly more than 1 mm in diameter. The dark color is due to rutile and altered taeniolite; brookite is frequently very abundant. A similar quartzite is present at the Christy property, which, because of its importance there, will be described in greater detail in that section.

In the field the light quartzite is creamy white to yellow in color, very fine grained, and with varying degrees of coherence. It has weathered along joints and irregular fractures so that the hardest material occurs in the center of well altered blocks. Thin sections of the rock are composed mainly of quartz with subordinate amounts of taeniolite, rutile, brookite, and leucoxene (Plate XX-A, B, p. 166). Aggregates of coarse quartz grains, similar in texture and grain size to the unmineralized gray quartzite, lie in a matrix of much finer grained quartz which in one thin section averaged less than .01 in diameter. As shown by the occurrence of unaltered taeniolite in the fine-grained quartz areas and altered taeniolite in the coarse-grained quartz areas, the fine-grained quartz has been recrystallized to form the coarser-grained aggregates after the introduction of taeniolite. All stages in the alteration of the taeniolite, from partially altered grains to skeleton grains composed of leucoxene, which retain the shapes of the fresh taeniolite, are present.

The sequence of events in the formation of the light quartzite primary ore appears to have been as follows:

1. The introduction of up to 20 per cent of taeniolite and varying amounts of acicular rutile into very fine-grained quartzite.

2. The later introduction of brookite as shown by rutile inclusions in brookite grains and the interruption of altered taeniolite skeleton grains by brookite (Plate XXI-A, p. 167). Brookite usually occurs as inclusions in large quartz grains but only rarely between large quartz grains indicating recrystallization of the quartz after the brookite introduction.

3. Recrystallization of the quartz along streaks, and, as far as thin section evidence is concerned, also as isolated globular aggregates. During this recrystallization the taeniolite in the areas undergoing reorganization was largely altered to shadow grains.

The Second Quartzite Knob

The second quartzite knob lies entirely within the Hardy deposit. Exploration of this knob is restricted to one prospect pit, in which a single vertical vein of smoky quartz with abundant visible brookite is exposed. The surrounding quartzite is very much coarser-grained and darker than the gray quartzite. It has abundant small cavities and the amount of gossan-like material suggests a sulphide mineralization. Float indicates that similar veins occur in the general vicinity of the pit. The area should not be ignored in any further exploration, but it is not considered particularly favorable.

The Second Saddle

All but the eastern edge of the second saddle is on the Walsh tract. The previous exploration in this area is also restricted to a single pit; however, it is believed that the topographic expression reflects the character of the material in the pit. The single pit is 4 feet deep and isolated from any other pits. The material looks like an iron-stained gravel composed of angular rather than rounded fragments. Individual particles range in size from slightly larger than an inch in length to clay sizes. The larger particles, 9-mesh and larger, are angular to somewhat subrounded in shape. Almost all of the fragments are light and dark quartzite types containing abundant brookite. A few are composed of goethite fragments. The plus 16 mesh sizes are, in general, subrounded quartzite grains, also containing abundant rutile. In sand sizes smaller than 60-mesh the brookite is largely liberated from the quartz. Excellent crystal shapes with fresh, sharp edges characterize the liberated brookite. The sharp crystal edges as well as the angular shapes of the quartzite grains indicate a residual ore. The lack of abundant magnetite indicates no admixture of transported material.

The Third Quartzite Knob

There is probably a gradation from the type of material described in the second saddle to the clay seams which occur in the pits on the east edge of the third quartzite knob. As shown in the prospect pits in the northeast corner of this area the country rock is a quartzite cut by seams of clay up to 8 feet in width. The attitude of these clay seams varies from vertical to dips paralleling possible bedding planes in the quartzite. The clay is in general, a uniform red-brown in color and appears at first glance essentially the same as the red clay of the first saddle. The sand sized particles are less variable and frequently consist only of slightly iron-stained kaolinite and taeniolite. In the heavily iron-stained portions there is abundant brookite; euhedral quartz crystals, both clear and smoky; irregular gray quartzite fragments; and black coarse-grained quartzite. The quartzite on either side of the clay seams is coarse-grained, dark to almost black in color, only slightly porous, and composed of quartz, very abundant altered taeniolite, abundant brookite, rutile needles, and colloform-textured iron oxide masses. Euhedral quartz is rare.

These clay seams probably resulted from weathering of veins similar to those which occur in the quartzite of the prospect pits, (coordinates 10,300N, 8440E), to the southwest, where taeniolite-mineralized but brookite-barren gray quartzite is cut by veins, as much as 6 inches in width, which contain all of the minerals to be found in the clay seams. In the test pit exposures the veins are friable masses composed of very abundant brookite, quartz, and white clay.

Thin sections show that the veins are composed of over 50 per cent of brookite linked together to form cellular-like masses (Plate XXI-B, p. 167) . Be-tween the brookite grains are large, up to 1.5 mm in diameter, euhedral, zoned quartz grains, smaller irregular-shaped quartz grains, fine rutile needles, abundant taeniolite, iron oxide-stained masses of kaolinite, and colloform-textured masses of iron oxide. Some brookite has invaded taeniolite along the taeniolite clevage. There are abundant altered taeniolite shreds in the coarser quartz, showing that some of the coarse-grained quartz is again produced by the recrystallization of finer quartz after the taeniolite mineralization. The kaolinite and iron oxide masses corrode euhedral quartz grains and are the last minerals introduced into the veins.

Much of this quartzite knob must be considered barren as only the black porous quartzite and the clay seams can be considered to be ore. The shaft 28 feet deep in the southern part of the knob was not accessible, but examination of the dump disclosed vein material containing abundant brookite.

PARAGENESIS OF THE HARDY-WALSH DEPOSIT

1. Formation, then folding, and probably regional metamorphism of the Arkansas novaculite at the end of Pennsylvanian time. (Miser, 1943).

2. Intrusive activity in Magnet Cove in Cretaceous time. (Miser, 1943).

3. Mineralization of the novaculite forming the fine-grained yellow quartzite containing taeniolite, rutile, and brookite. As shown by the greater

abundance of altered taeniolite in the barren quartzite of the west end of the property, the mineralizing solutions came from the direction of Magnet Cove.

4. Recrystallization of almost all of the fine-grained quartz, including the barren gray quartzite.

5. A repetition of the initial mineralization accompanied by kaolinite which formed minor veins.

6. Renewed hydrothermal activity, or the end of the last stage, during which smoky quartz veins were introduced into the recrystallized quartzite, as well as some minor recrystallization of the quartzite along preexisting fractures and joints.

7. Erosion of the general area ending in the formation of the upper erosion surface.

8. Intensive weathering to an unknown depth of the brookite and taeniolite mineralized zones. The areas of deep weathering occur mainly where the recrystallized quartzite was fine-grained. It is suggested that the angular blocks lying in the red clay in the northeast corner of the first saddle are talus material.

9. At a later time after the formation of much of the residual ore there was a final period of quartz mineralization accompanied by goethite which formed small veins cutting the residual ore in the northeast corner of the first saddle. The mineralization probably occurred at the same time as the formation of the hot spring deposits in the center of the Cove basin.

SUMMARY OF THE OCCURRENCE OF TITANIUM MINERALS

Considering the Hardy-Walsh deposit as a whole rather than as topographic units, the recognized titanium minerals are brookite, rutile, leucoxene, and taeniolite.

Brookite is probably the only recoverable titanium mineral. In this deposit the largest brookite crystals are restricted to smoky quartz veins where 2 mm is about maximum. In the primary ore, residual clay, and in the veins of the third quartzite knob the brookite is much smaller. In the primary ore the average is about 1 mm with a range from .5 mm to a few reaching .05 mm. Brookite in the residual clay of the first saddle averages the same as in the primary ore. Brookite in the second saddle averages about .15 mm. Brookite in the veins of the third quartzite knob is larger, averaging .5 mm.

Rutile occurs in acicular grains which are in large part altered to leucoxene. Individual grains range from .1 mm to those barely visible at highest magnifications. The average is about .01. While rutile is very abundant, it cannot be considered as an ore mineral because of its size, and alteration. Taeniolite, according to Miser and Stevens (1938, p. 109), contains only a small amount, 0.11 per cent, of titanium.

EXTENT OF THE DEPOSIT AND RECOMMENDATIONS FOR FUTURE EXPLORATION

The known "ore" of the Hardy-Walsh deposit, so far as it has been developed by trenching, is limited to the "clay" of the first saddle. The titania assays on Plate IV show that the material in the test pits, ranged from 5.0 to 8.4 per cent in TiO_2 content. The deepest test pit in the first saddle at the time of sampling (1947) was 14 feet.

In any future exploration program at the Hardy-Walsh brookite deposit possible extensions of the ore in the first saddle both in depth, and to the north and south of the trenched area should be investigated. Because of the similarity in topographic expression of the second saddle to the known "ore" area, (first saddle) and the fact that the only test pit in the second saddle contained residual brookite "ore", this area should be prospected. Although all three quartzite knobs do contain veins that are rich in brookite, the size and distribution of the known veins are such that they would be very costly to mine. These knobs merit consideration in any future exploration, however.

CHRISTY BROOKITE DEPOSIT

LOCATION

The Christy deposit is located on the east edge of Magnet Cove, mainly in the SW¼ SW¼ of Sec. 16, T. 3 S., R. 17 W. (Plate I), on property owned by the Malvern Lumber Company of Perla, Arkansas, M. H. Strauss, President. The same road from Magnet that passes near the Hardy-Walsh deposit crosses the west edge of the Christy deposit about half a mile north of Magnet.

HISTORY OF EXPLORATION

The first exploration of this deposit was directed by H. E. Perkins in 1913, as a part of the survey of the Magnet Cove titanium deposits made for the Titanium Alloy Company of Maine at that time. Perkins had an adit 200 feet long driven into the northeast portion of the deposit from Chamberlain Creek gorge. Upon completion of the adit the project was abandoned and the adit is now caved. No further exploration of any consequence was carried out until Mr. Wynn O. Christy obtained a lease on the property in 1941 Some ore was developed by Christy, and several months later a small plant utilizing dry methods of concentration was placed in operation. No commercial production resulted from this operation as the recovery was too low. In 1942 a development loan was granted by the Reconstruction Finance Corporation. Under the direction of an R.F.C. engineer (Riggs, 1943), 32 test pits, the deepest of which was 45 feet, were sunk during 1942-43, and bulk samples of the test pit material were submitted to several commercial laboratories for ore dressing tests. Despite favorable results from these tests, work at the Christy deposit ceased until January, 1948, when the U. S. Bureau of Mines began its core drilling project (Reed, 1949). During this project 21 holes were drilled with a diamond drill, bucket drill, and a churn drill with Baker coring tools. There has been no activity at the deposit since this drilling project.

PREVIOUS STUDY

Holbrook (1947) has briefly described the nature of the residual ore at the Christy deposit.

TOPOGRAPHY

The Christy deposit lies on the top and partly on the south slope of a ridge at the upper erosion surface of the Magnet Cove region. The crest elevation is about 600 feet and increases to about 700 feet farther east. The character of the ore, both residual and primary, has been affected by weathering processes originating at this erosion surface. There is at least one indication of the admixture of transported material to the residual ore at a time when this upper erosion surface was of greater extent. Undoubtedly much residual ore has been removed from the deposit and may now occur as undiscovered placer deposits on remnants of the upper erosion surface.

SEDIMENTARY ROCKS

At the Christy deposit the country rock is composed of sediments. (Plate VI). Exposed at the surface are the Stanley Shale (Pennsylvanian), the Hot Springs sandstone (?) (Pennsylvanian), and the Arkansas novaculite Devonian (?)-Mississippian (?). Inferred, but not exposed, are the Missouri Mountain shale (Silurian) and the Blaylock sandstone (Silurian). The nearest exposure of the entire section is in a road that cuts diagonally across the ridge about half a mile east of the deposit.

The Stanley shale formation is well exposed in Chamberlain Creek gorge immediately northwest of the deposit. Here, contact metamorphism by the syenite intrusive to the west has altered the shale to a dense, black hornfelsic rock. Unaltered black clay shale of the formation may be seen in the road cut just north of the mapped area of Plate VI.

The sandstone shown on Plate VI as Hot Springs sandstone (?) is exposed at only two points at the Christy deposit, one at the entrance to the caved adit and the other where the sandstone crosses the road just north of the mapped area. At neither of these two localities is the upper contact of the sandstone bed exposed but the gray, quartzitic character of the rock

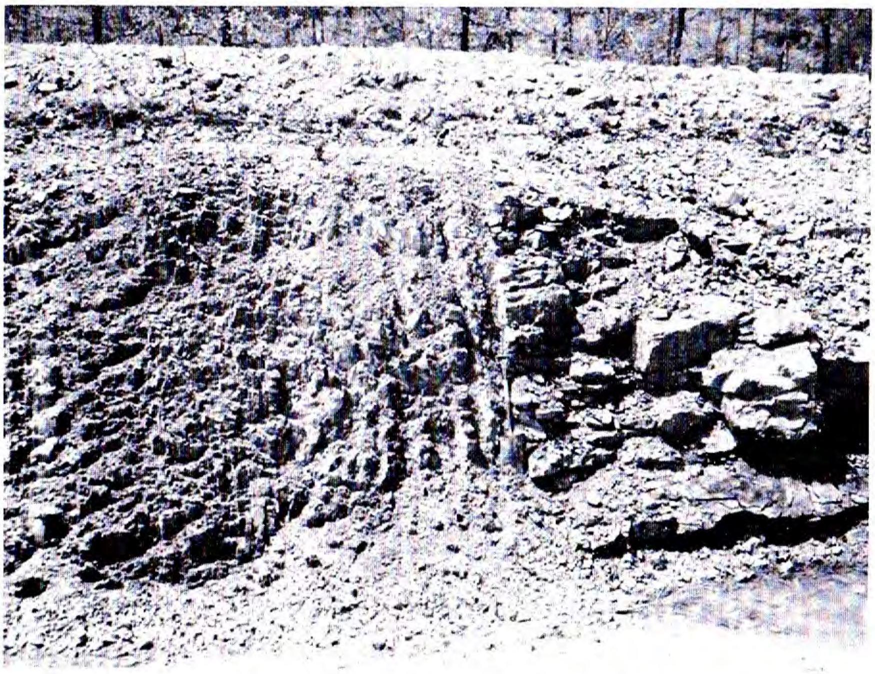


Figure 10. Exposure of the Arkansas novaculite formation in the Rock Island railroad cut one mile east of the Christy deposit.

The shovel marks the contact between the massive novaculite of the lower division (on the right) and the interbedded novaculite and shale of the middle division of the formation. The bedding is approximately vertical. (Photo by John Blundell).

and the position of the sandstone bed in the section were the basis for naming it the Hot Springs sandstone. However, a similar sandstone bed is exposed in the road cut half a mile to the east along the strike of the formations. This sandstone bed is separated from the overlying Stanley shale formation by several feet of thin-bedded white novaculite, indicating that this sandstone is a part of the Arkansas novaculite formation, probably the middle member. Similar relationships may be observed at the sandstone exposure in the slot of the inclined shaft of the Magnet Cove Barium Corporation barite mine, two miles northeast of the Christy deposit. It is possible, therefore, that future excavation may show the sandstone bed at the Christy deposit is also a sandstone member of the Arkansas novaculite formation.

Both the massive novaculite of the lower division and the thin-bedded novaculite and shale of the middle division of the Arkansas novaculite formation are present but poorly exposed at the Christy brookite deposit. The best exposure of the formation in the Magnet Cove area is one mile east of the Christy deposit along the Rock Island railroad's spur to the barite mines (Fig. 10).

All of the primary brookite ore developed by drilling to date is restricted to the massive novaculite of the lower division of the formation. The massive novaculite of the lower division has been recrystallized to some extent in all its exposures at the Christy deposit. This recrystallized novaculite varies from a friable sandstone-like rock composed of clear quartz grains to a hard grey-to-white rock that resembles a very fine-grained quartzite. Where the novaculite has been both recrystallized and mineralized a more porous brookite-bearing quartz rock is developed which will be discussed in more detail in the section on primary ore. The best exposures of the recrystallized massive novaculite are in the road cut which parallels the west section line of Section 21, immediately southwest of the deposit (see Plate VI). Fresh novaculite of the lower division occurs as float on top of the ridge east of the deposit. Thin-bedded novaculite and shale of the middle division of the formation are exposed only in the trench directly above the caved adit in Chamberlain Creek ravine. Drill holes BD-7, BD-8, and BD-9, however, disclosed residual ore lying on hydrothermally altered but unmineralized novaculite and shale of the middle division.

Since neither the Missouri Mountain shale, nor the Blaylock sandstone formations outcrop at the Christy deposit it was necessary to project the boundaries of these formations into the mapped area (Plate VI) from their nearest outcrop in the road cut half a mile to the east. However, drill hole information from hole BD-10 tends to confirm the location of the Missouri Mountain shale formation.

Structurally the sedimentary rocks at the Christy deposit lie on the south limb of an overturned syncline which plunges to the southwest. It is interesting to note that the Hardy brookite deposit previously described is located on the north limb of this same structure where the Arkansas novaculite is truncated by the Magnet Cove intrusives, and also that the extensive barite deposits of the Magnet Cove area lie at the base of the Stanley shale formation in this same syncline, about one mile east of the brookite deposits.

IGNEOUS ROCKS

The synclinal limb in which the brookite deposit lies is truncated by an intrusive mass of nepheline syenite (fine-grained type) which is essentially the same type of rock described at the Magnet Cove Rutile Company deposit (p. 24). On Williams' map (1890, Map IV), however, the syenite at the Christy deposit is shown as leucite syenite. Good exposures of the syenite may be seen in Chamberlain Creek ravine immediately northwest of the deposit.

DESCRIPTION OF THE DEPOSIT

General Statement

The Christy brookite deposit as outlined by the recent U. S. Bureau of Mines drilling project may be divided into two parts: (1) a residual orebody; and (2) an underlying primary orebody which constitutes the bulk of the deposit. The titanium ore mineral in both orebodies is brookite. The distinction between these two portions of the deposit is based entirely on differences in their physical characteristics. The residual orebody, which extends from the surface to depths of as much as 20 feet, has been developed as a result of the reworking, slumping, and selective erosion of the upper part of the primary orebody. It consists of quartzite fragments, free brookite crystals and sand-sized material in a matrix of red clay. The primary orebody has essentially the same structure it had when it was formed from the mineralizing solutions, and it consists of brookite-bearing quartzite layers separated by layers of relatively barren clay. Probably the entire primary orebody as shown on the geologic sections (Plate VII) contained pyrite, as well as quartz and clay minerals as gangue minerals at the time the orebody was originally formed. However, most of the primary orebody has since undergone extensive weathering during which the pyrite has been altered to iron oxides and some interstitial clay has been removed from the quartzite. Thus, only a very small part (the bottom 17 feet of Hole BC-1) of the primary orebody now contains pyritic brookite ore. The term "primary" has, however, been retained to describe the weathered as well as the unweathered portion of the orebody because the weathering processes did not affect either the original titanium ore mineral, brookite, or the original structure of the deposit.

Residual Orebody

Extent

The ore exposed on the surface at the Christy deposit is almost entirely residual but in some places, particularly along the northern boundary of the deposit, it overlies relatively barren rock, indicating some transportation, or at least slumping. In drill holes BD-7, BD-8, and BD-9 (see logs, pp. 131 through 146) a maximum thickness of 15 feet of ore is known to lie on altered but unmineralized thin-bedded novaculite and shale of the middle division of the Arkansas novaculite formation. In hole C-3A, about 10 feet of brookite ore overlies recrystallized massive novaculite of the lower division of the formation. The ore in the above enumerated holes is for the most part very heavily oxidized although clay seams of varying attitudes and thicknesses are not permeated with limonite. This ore has probably slumped into its present position, and, as indicated by a fossil fragment* found in one of the test pits in the northeast corner of the ore area, has apparently been reworked to a certain extent by stream or other water action.

In all the remaining drill holes, except BD-10, the surface ore is a true residual ore in that it overlies primary ore. Because of the condition of the recovered cores, it was difficult to determine the contact between the residual and primary ore, but it is suspected that the residual ore coincides with the heavily oxidized zone in which the clay matrix of the ore is permeated with iron oxide stain. This heavy limonite staining is restricted to about the upper 15 feet in the drill holes although in Hole BD-1 it extended to 20 feet.

Character of the Residual Ore

The residual ore is composed of masses of porous quartzite, dark red clay containing abundant sand-sized particles and thin white to gray kaolinite seams.

Two varieties of quartzite ranging from pebble size to masses 3 and 4 feet in maximum diameter occur as irregular-shaped bodies in the residual ore. One quartzite type is composed of large subhedral and euhedral quartz crystals that are clear or milky white in color. Associated with it are the largest brookite crystals (Fig. 11), some of which reach a maximum diameter of 6-7 mm. The pore spaces of these quartzite masses are now filled with red clay and stained with limonite. Possibly the original material in these pores was the same clay minerals as are present in the unoxidized, dark primary ore. This quartzite is not abundant in the surface ore but is present throughout the area. It comprises most of the dump material at the caved shaft. The second quartzite type forms at least one-third of the residual ore. It is dark gray to almost black and very fine-grained, and some specimens resemble basic igneous rock. The rarely visible brookite averages less than .5 mm in diameter.

In thin section the quartz grains vary from slightly more than 1 mm to .05 mm in diameter. Brookite ** is present in extremely variable amounts. In some thin sections only a few brookite grains were present, in others there was 10 per cent. The dark color of the rock is due to very abundant acicular rutile, (Plate XXII-A, B, p. 168), and altered taeniolite shreds. The rutile, much of which is altered to leucoxene, is somewhat patchy in concentration but always

* According to G. A. Cooper (personal communication) the fossil is a *Strophemena* of Ordovician age, but whether it is of Upper or Middle Ordovician is uncertain. As the nearest Ordovician is over a mile from the Christy deposit, the fossil was presumably transported to this locality by a stream.

** There has been some question as to the actual identity of the brookite in this deposit, and it has been suggested (but never published) that the brookite is actually anatase. X-ray analyses made at both the University of Minnesota and Harvard University of specimens selected at random have invariably indicated brookite.

Figure 11. Coarse white quartz and brookite from residual ore, Christy brookite deposit. Natural size.

present in abundance. Rutile inclusions in brookite show that the early solutions formed rutile and that later solutions formed brookite. Rutile pseudomorphs after brookite are known to occur along the east rim of Magnet Cove but none were identified at the Christy deposit.

No fresh taeniolite was present but skeleton grains, now leucoxene, undoubtedly represent original taeniolite. Iron oxide, presumably goethite, is present to the extent of 2-3 per cent. Pore space averaging at least 15 per cent in all thin sections indicated the loss of some original mineral or minerals. Examination of deep core material from the primary ore showed abundant clay minerals, and without doubt the original clay of this quartzite type has been removed by weathering and the percolation of water.

The quartzite types of the residual ore lie in a "clay" matrix that is a uniform, dark red in color and contains silt, sand, and pebble-sized material. A channel sample of "clay" wet sieved after the large recognizable quartzite fragments were removed showed that almost 47 per cent of the "clay" was actually sand-sized material.

The screen analysis was as follows:

Mesh	Opening in mm.	Per Cent
Plus 9	1.981	22.0
Plus 16	.991	8.6
Plus 42	.351	6.1
Plus 60	.246	4.8
Plus 250	.062	5.2

Descriptions of the individual size fractions are as follows:

Plus 9 mesh—Angular fragments of novaculite; several types of quartzite including: granular recrystallized novaculite; clear, coarse-grained, porous quartzite; black, porous quartzite; quartz crystals, including comminuted crystals as well as euhedral crystals. Brookite is abundant, mainly associated with the quartzite types but some is liberated. Limonite nodules are common.

Plus 16 mesh—Angular fragments of the same materials mentioned above. Liberated brookite is more abundant.

Plus 42 mesh—Angular fragments of the same materials mentioned above. The limonite fragments are subrounded, probably due to weathering.

Plus 60 mesh—Same material. Most of the brookite has been liberated from the quartzite fragments. There were a few magnetite grains.

X-ray analysis of the clay fractions indicated kaolinite is the major mineral. Examination of "clay" samples from other prospect pits gave very similar screen analyses. In none of the size fractions was there any important amount of rounded or subrounded particles, and other than the single fossil fragment and a few magnetite grains there is no indication of admixed material.

An interesting feature of the residual ore is the occurrence of a number of white to gray clay seams. The attitude of these clay seams ranges from 10° to 15° up to 50°. Uniformly the dips are to the south, down the hill slope. The clay is kaolinite essentially free from grit. Possibly these seams are merely altered shale horizons, or altered veins, in the original novaculite which have slumped into place.

Primary Orebody

Extent

The primary orebody as defined in the general statement (p. 56) includes all brookite ore, developed by the recent U. S. Bureau of Mines drilling, that lies beneath the residual orebody. Stratigraphically the known primary ore is located in the lower division of the novaculite formation. The primary orebody is apparently bounded on the north by the interbedded novaculite and shale of the middle division of the formation. The log of drill hole C-3A and the dumps of the test pits at the east end of the deposit indicate that the eastern limit of the deposit is unmineralized, altered novaculite of the lower division of the formation. The southern boundary of the deposit was not positively established by the drilling. It has been assumed, however, on the basis of information from drill hole BD-10, that the Missouri Mountain shale is the southern boundary or footwall of the deposit. Additional drilling south of the present drilled area is needed to confirm this assumption. The numerous ribs of barren novaculite in drill hole C-7 and the relatively barren novaculite exposed in the road along the west boundary of Section 21 (see Plate VI) indicates that there is probably barren novaculite of the lower division between the primary orebody and the nepheline syenite intrusive to the west.

The orebody apparently plunges to the southwest at a steep angle as indicated by a series of holes along the east side of the orebody only. These holes, however, were not so spaced or deep enough at critical points to actually determine the angle. As previously noted, four drill holes (BD-7, 8, 9, and C-3A) did pass through ore into barren rock. The ore encountered in these holes, however, probably slumped into place, and therefore was not considered primary. Only one hole (BD-6) was drilled through the primary orebody into barren rock. It is believed that the remainder of the drill holes that reached the primary ore zone did not pass through it, thus leaving the depth of the primary ore zone untested throughout most of the deposit.

Character of the Primary Orebody

The primary orebody as shown on Plate VII is composed essentially of brookite-bearing quartzite layers separated by relatively barren clay horizons. The orebody locally contains ribs of barren novaculite, unmineralized shale layers, and at least one altered dike is known. Although most of the primary orebody has been thoroughly weathered, the term "primary" has been retained to describe the orebody because the only weathering effects on the original pyritic brookite ore were the removal of some clay minerals and the alteration of pyrite to iron oxides.

Practically all of the ore in the primary orebody was porous brookite-bearing quartzite that was thoroughly oxidized as shown by the abundance of limonite in the drill cores. This oxidized primary quartzite ore resembles dark quartzite of the residual ore in both hand specimen and thin section. This quartzite varies from light to dark gray in color, a feature dependent on the rutile and taeniolite content. As a rule, the quartzite is fine-grained, but in many places in the orebody it is cut by narrow veins of coarsely crystalline quartz. Irregular cavities and small vugs are characteristic and these cavities are frequently coated or partially filled with limonite-stained clay. Brookite occurs in this quartzite as euhedral and subhedral black crystals enveloped by quartz or perched on individual quartz crystals.

Of the holes drilled into the primary orebody, only two, BC-1 and C-1, reached the unoxidized zone. Hole C-1 was bottomed in a pyrite-bearing shale bed in the novaculite formation. In hole BC-1 unoxidized quartzite ore containing a small amount of pyrite and abundant clay minerals was encountered at a depth of 65 feet. The clay minerals, kaolinite and probably nontronite, occur in irregular masses and in the interstices between some quartz grains (Plate XXIII-A, p. 169). Rutile occurs as needles which are altered to leucoxene, but the brookite occurs as small unaltered crystals. Taeniolite is completely altered (Plate XXIII-B, p. 169). As in the Hardy-Walsh ore, the alteration took place during the recrystallization of the novaculite. The sequence of mineralization was: rutile and taeniolite apparently simultaneous, brookite accompanied by a minor amount of magnetite (?), nontronite and kaolinite.

The analyses of the recovered cores and sludges (see logs, pp. 131-151) show appreciable percentages of vanadium in both the residual and primary ore. Qualitative tests indicated that much if not all of the vanadium is present in the brookite crystals themselves. The per cent of vanadium present in the brookite apparently is variable as the V_2O_5 content in a given set of samples is not directly proportional to the TiO_2 content of those samples.

Clay horizons of varying thicknesses are common in the primary orebody. Much of the clay from drill cores was dead white in color, but light green, buff, gray and mottled clays were also recovered. Limonite staining in the clay was restricted to the upper portions of the primary orebody. The texture of the clays varied from massive to an indefinite pisolitic texture. X-ray analyses showed that the clay is composed of kaolinite, and kaolinite mixed with halloysite. The indefinite pisolites were identical in composition with their matrix. Presumably the clay layers and seams found throughout most of the primary orebody represent seams of shale in the lower division of the novaculite that have been hydrothermally altered. The thicker sections of clay encountered in drill holes BC-1 and BD-11, however, cannot be so explained since shale seams are generally thin and sparsely distributed in the lower division of the novaculite formation. Possibly the clay in these holes was formed as a result of extensive clay mineralization of the novaculite itself. The clay seams and lenses in the primary orebody were for the most part lacking in brookite. This is particularly true of the thicker layers. Some brookite occurs in the thinner clay layers as free crystals embedded in the clay and perched on small quartz crystal aggregates that were completely enveloped by clay. It is interesting to note that despite the relatively high TiO_2 assays reported on the thick clay sections from Hole BC-1 (see p. 151), much of the recovered core contained no visible brookite, the values apparently being due to the presence of leucoxene or taeniolite, or both, in the clay.

PARAGENESIS OF THE DEPOSIT

1. Deposition, then folding and regional metamorphism of the Arkansas novaculite at the end of Pennsylvanian time (Miser, 1943).

2. The intrusion of the Magnet Cove igneous rocks during Cretaceous time (Miser, 1943).

3. Introduction of rutile, taeniolite, and brookite, at the time of igneous intrusion.

4. Recrystallization of the novaculite.

5. Introduction of clay minerals.

6. Erosion.

7. Deep weathering of the primary orebody from the upper erosion surface of the general region.

8. Formation of residual ore and the admixture of a small amount of transported material.

9. Uplift of the region followed by removal of much of the residual ore and the probable formation of placer deposits in the region. Deep weathering is continuing.

SUMMARY OF THE OCCURRENCE OF TITANIUM MINERALS

The titanium-bearing minerals in the Christy deposit are brookite, rutile, leucoxene, and taeniolite of which the brookite probably is the only recoverable mineral. In the residual ore brookite occurs both as free crystals disseminated in the "clay" and attached to quartzite fragments. Probably most of the brookite grains do not exceed .5 mm in diameter, but crystals up to 6 and 7 mm in maximum diameter are known. In the primary ore practically all of the brookite crystals occur either within or perched on quartzite. As in the residual ore, most of the brookite is less than .5 mm in diameter. Rutile is common throughout the deposit as minute needles in the various quartzite types and much of it has been altered to leucoxene. Although the rutile and leucoxene probably account for 10 to 15 per cent of the TiO_2 content of the ore, this titania cannot be considered recoverable. The TiO_2 present in the taeniolite is unrecoverable, but only a negligible percentage of the total titania present in the ore occurs in this mineral.

THE U. S. BUREAU OF MINES DRILLING PROJECT

The recent drilling project of the U. S. Bureau of Mines at the Christy deposit was begun in January, 1948, and completed in June, 1948. A total of 21 holes with an aggregate footage of 1,488.9 feet was drilled and sampled. The deepest hole drilled was 141 feet (BD-4). The character of the ore; hard, porous quartzite masses separated by lenses of clay of varying thicknesses, made it extremely difficult to obtain cores suitable for metallurgical testing. Three different types of drills were used in an effort to recover acceptable core; a diamond drill, bucket drill, and a churn drill with Baker coring tools. Since detailed descriptions of the drilling equipment and techniques used have been presented by Dupuy (1949) and Reed (1949), only the condition of the recovered cores has been noted briefly here. The core recovered by the Baker coring device (Hole BC-1) was most satisfactory as a high percentage of core was recovered and core fragmentation was not excessive. Although the percentage of the core recovered in the diamond drill holes (Holes C-1 through C-8) was low, the core was clean and the core intervals were small, so that a fairly complete interpretation of the lithology could be made. Core recovery in the bucket drilling was excellent but the core was difficult to log because of fragmentation, particularly where the accessory churn bit was used to break through ledges of hard quartzite and altered novaculite.

Splits of the cores obtained from the Bureau of Mines drilling at the Christy deposit are on permanent file in the Core Library of the Bureau of Mines at Rōlla, Missouri. The library is open to the public for study of the cores at any time that qualified persons wish to make such a study.

All of the core recovered was logged by Holbrook while the drilling was in progress. The residual ore in the cores was designated as such in parentheses in the logs, and the primary ore was described in the logs as porous brookite-quartz rock. A general statement regarding the abundance and grain size of the brookite in the core samples was also included in the logs. These descriptive logs, together with the U. S. Bureau of Mines analyses (Reed, 1949, Figs. 10 through 20) of the core and sludge, appear on pages 131 through 146 of this report.

Since the 1948 drilling project at the Christy deposit was the first extensive core-drilling exploration of any of the brookite deposits at Magnet Cove, it has provided much new subsurface geologic information on these deposits. Some of the more important geologic features of the Christy deposit that were established as a result of this drilling are listed below.

1. The deposit is not simply a surface accumulation but is underlain by a significant body of primary ore.

2. A footwall of steeply dipping altered interbedded novaculite and shale was established on the north side of the orebody.

3. A hanging wall of Missouri Mountain shale at the south limit of the orebody was tentatively established.

4. Oxidized primary ore was encountered to the bottom of the deepest hole (BD-4, 141 feet) as well as all other holes drilled in ore except BC-1.

5. Unoxidized primary ore containing pyrite was encountered in only one hole (BC-1, at a depth of 65 feet.

6. The presence of vanadium in the ore was first recognized by the U. S. Bureau of Mines chemists while analyzing core samples.

RECOMMENDATIONS FOR FURTHER EXPLORATION

It is believed that further drilling could extend both the depth and the southwest limits of the deposit. The northern boundary or footwall of the deposit is well established, and it is not likely that much additional ore could be developed by drilling along either the eastern or western boundaries as shown on Plate VI. Possible extensions of the ore to the southwest should be checked by holes located immediately south of Holes BD-5 and C-8. Since the orebody apparently follows the Arkansas novaculite formation and dips to the south, any holes begun in the Missouri Mountain shale formation (see Hole BD-10, Plate VII) should be drilled deep enough to penetrate the shale and check the possibility of ore in the underlying Arkansas novaculite. If the recovery of samples suitable for metallurgical testing is not a prime consideration in a future drilling project, it is suggested that churn drilling would be both a satisfactory and economical method of exploration. The cuttings should be logged, however, to permit an accurate evaluation of the sample assays.

MO-TI CORPORATION
MOLYBDENUM-TITANIUM PROSPECT

The Mo-Ti Corporation prospect pit located in Section 17, T. 3 S., R 17 W., on the south bank of Cove Creek (See Plate I) has been described by Holbrook (1948). In 1929-1930 the Southern Acid and Sulphur Company churn drilled the deposit as a possible source of pyrite. The recent exploration (1946) has been for molybdenum, but the vein material also contains brookite and some rutile.

The country rock is jacupirangite (mainly magnetite and pyroxene with some nepheline) both fresh and altered along zones which do not entirely coincide with the vein mineralization. The prospect pit lies on the north edge of a triangular shaped flat now covered to a depth of about 8 feet by coarse gravels. The topographic expression and the results of the earlier drilling (Scheid, 1932) indicate widespread mineralization and hydrothermal alteration in this area.

The exposed veins strike roughly N. 50° W. and dip 45°-80° E. The veins are anastomosing and frequently enclose areas of chloritic rock, the alteration product of the jacupirangite.

In the field the vein material is yellow to light gray in color, coarse-grained, soft and friable due to weathering, and in most places contains abundant pyrite.

Thin sections show that 80 per cent of the vein is composed of perthitic microcline ranging up to 3 mm in diameter, and a small amount of chess-board albite. Apatite, brookite, rutile, pyrite, and sphene in varying amounts are also primary constituents. The feldspar is extensively altered to allophane and a small amount of halloysite. Some of the brookite crystals reach 10 mm in diameter. Leucoxene is present in variable amounts.

The introduction of feldspar veins was followed by a molybdenite mineralization. Two to three feet on either side of the rich molybdenite veins there is disseminated molybdenite. Both brookite and pyrite are replaced by molybdenite.

In addition to the large feldspar veins the country rock is cut by small, up to 4 mm wide, veinlets containing dolomite, oligoclase, and pyrite. The thin sections examined were lacking in any important TiO_2 mineralization.

The feldspar veins differ from the microcline-calcite veins of the Magnet Cove Rutile Company property by a total absence of a carbonate and the very much coarser grain size. The veins in grain size and in the presence of perthitic microcline and albite most closely resemble the coarse-grained albite-perthite-carbonate veins of the Magnet Cove Rutile Company property.

The occurrence of abundant brookite in a feldspar vein is suggestive, but little can be said about temperature and pressure conditions which formed brookite in this vein group and rutile in the feldspar-carbonate veins of the Magnet Cove Rutile Company pit.

The molybdenite mineralization at both properties as well as the similarity in vein types suggests contemporaneity of formation of the ore of the two properties.

OTHER KNOWN OCCURRENCES OF BROOKITE AND RUTILE AT MAGNET COVE

All of the rutile and brookite deposits and prospects discussed in the preceding sections have been explored to some extent at least, by test pitting, trenching or drilling. There are, however, several other untested occurrences of rutile and brookite in and adjacent to the Cove that should be mentioned. Because rutile and brookite are rather widely scattered in small quantities in the soils of the Cove, the localities discussed in this section have been restricted to significant concentrations of rutile and brookite float, and to exposures of rutile and brookite in place. All of the localities described in this section are shown on Plate I (in pocket) by either a rutile or brookite symbol, depending on which mineral predominates.

BROOKITE MINERALIZATION ALONG HIGHWAY 270 AT MAGNET

A series of outcrops along U. S. Highway 270 at Magnet show both the metamorphism and the brookite mineralization in the Arkansas novaculite formation near its contact with the Cove intrusives. Immediately east of Magnet the highway cuts through a low ridge of metamorphosed Arkansas novaculite. The novaculite exposed in this cut looks like a very fine-grained sandstone and contains small amounts of taeniolite, magnetite (?) rutile and brookite. West of this novaculite ridge, at the "Y" in the highway at Magnet and somewhat nearer the novaculite-syenite contact, the novaculite has been recrystallized to a friable quartzite composed of quartz grains ranging from .5 mm to .02 mm in diameter (Plate XXIV-A, p. 171). At this point the introduced material is limited to a few large quartz veins lying in a matrix of unidentified clay minerals and iron oxide. Unfortunately the syenite-novaculite contact is not exposed in the highway cut, the westernmost exposure of metamorphosed novaculite being 100 feet or more from igneous rock. This exposure is on the south side of the highway near the center of Magnet and is characterized by quartz veins up to one inch in thickness which cut friable quartzite along tortuous paths. Many of these veins contain vugs lined with imperfect quartz crystals 2 cm long. Accompanying these quartz veins are brookite crystals which reach 5 mm in diameter. The majority of the described brookite specimens from Magnet Cove came from this area. Abundant brookite-quartz float indicates an extension of this mineralization up the hill south of the highway a distance of about 200 feet (see Plate I in pocket).

A thin section shows that rutile needles are common in these quartz veins but not to the extent of darkening the quartz by their numbers. Accompanying the TiO_2 mineralization is an iron oxide, taeniolite, and a clay mineral. The rutile and iron oxide occur in diffuse bands 2-3 mm wide which cut across grain boundaries of the quartz. Typically such a band has an outer zone of abundant rutile, a zone of less intense rutile mineralization, a thin concentrated zone of iron oxide, and a broad zone containing brookite and fresh and altered taeniolite (Plate XXIV-B, p. 171). Acicular rutile is almost entirely altered to leucoxene. The iron oxide occurs as both square and rectangular masses and as a lining of cavities where it has a colloform texture.

RUTHERFORD BROOKITE PROSPECT

This prospect is located on a hill about 400 feet southeast of Magnet community and consists of brookite-quartz float scattered over a roughly elliptical area, 500 feet in maximum diameter. The house on the top of the hill is approximately in the center of this area and the heaviest concentration of brookite-quartz float is around the house. Some of the smoky quartz rock exposed near the southwest corner of the house appears to be in place. The brookite-quartz float gradually gives way to boulders of coarse-grained, gray nepheline syenite to the west and south, and to shale and altered novaculite fragments to the north and east, indicating that the mineralization is probably related to a nepheline syenite-Arkansas novaculite contact. The brookite-quartz float is made up largely of boulders and cobbles of porous masses of quartz crystals with the brookite crystals perched on the quartz. The brookite crystals themselves are euhedral and vary in size from 1/16 inch to ½ inch. There is a marked similarity between the float and contact relationships of this prospect and those of the Christy brookite deposit. The float at the Christy deposit, however, covers a much wider area.

RICHARDSON RUTILE PROSPECT

This prospect is located on the Richardson property in the northwest quarter of Section 17, T. 3 S., R. 17 W., about half a mile east of the Magnet Cove Rutile Company's deposit (see Plate I in pocket). The mineralization here consists of several small, rather widely separated occurrences of rutile rather than a single large mineralized area. Most of the rock exposed at the property is a weathered coarse-grained igneous rock, probably nepheline syenite, and exposures are limited almost entirely to the east-west road that crosses the property and enters the east end of the Magnet Cove Rutile Company property.

On the south side of this road about 400 feet west of the Richardson farm buildings there are several veins exposed in a coarse-grained weathered igneous rock. The veins are stained with iron oxides and consist mainly of fine-grained feldspar with a little fine-grained rutile. The plowed field immediately south of this exposure is said to have been the source of many of the fine rutile specimens from the Cove, but only scattered fragments of rutile-bearing vein material were observed during the recent field work.

About 300 feet southwest of the Richardson farm buildings, adjacent to the mouth of a flowing spring is the abandoned shaft of a pyrite mine that was operated during the Civil War. The rocks on the dump are mainly altered igneous rock, with some feldspar-pyrite vein material containing a small amount of rutile

On the north side of the road about 300 feet east of the Richardson farm buildings, several veins are exposed in weathered, igneous rock. The veins are comprised of both fine and coarse-grained feldspar and contain thin scattered seams of rutile. Doubtlessly other rutile-bearing veins may exist under the soil cover on this property, but the lack of much residual rutile indicates that the mineralization near the surface at least is not extensive.

YORK RUTILE PROSPECT

The York rutile prospect is located near the center of Section 20, T. 3 S., R. 17 W., immediately south of U. S. Highway 270. Residual rutile occurs here in a narrow belt extending from the north side of the highway through the farmyard and into the plowed field directly southeast of the farm buildings. Rutile aggregates up to one inch in maximum dimension and individual crystals ½ inch in maximum diameter are common in the soil throughout the belt. Since no rutile was found in place, the nature of its original occurrence is uncertain. However, this locality is mapped (Williams, 1891, Map IV), as nepheline garnet syenite, and this syenite is exposed in the ridge just east of the rutile occurrence. Detrital garnet and magnetite from the syenite is abundant in the soil and can easily be mistaken for rutile by the casual observer. Striations on the rutile crystals, however, distinguish them from the other black minerals in the soil.

BROOKITE PROSPECTS IN SECTION 7

Two brookite occurrences are located on the Cove rim in the extreme southern portion of Section 7, T. 3 S., R. 17 W., about half a mile due north of the Magnet Cove Rutile Company's pit (see Plate I in pocket).

One of these occurrences is just south of the gravel road that approximately parallels the south line of Section 7. At this locality four trenches have been dug along the north slope of a low hill. These trenches are now caved, but examination of the dump material revealed brookite-bearing feldspar veins in metamorphosed Stanley shale. The brookite in the veins is fine to coarse-grained and usually in well-formed crystals. The feldspar shows considerable range in grain size and is the predominant vein mineral. Several of the vein fragments examined were porous, suggesting the removal of some constituent, possibly a carbonate.

The second brookite occurrence is about 200 yards north of the gravel road in the southwest quarter of the section. Here, brookite-bearing quartz float is scattered over an elongated area 20 by 200 feet on the west slope of a deep ravine. Exposures are limited at this locality, but the float indicates that the brookite-quartz rock occurs as veins in fine-grained sandstone, possibly the Hot Springs sandstone. The brookite-quartz rock is dark gray and porous and may be readily distinguished from the unmineralized sandstone. The brookite occurs as very small grains perched on quartz crystals. So far as is known, no exploration has been undertaken at this locality.

NICHOLS AND CAMPBELL RUTILE PROSPECT

In the discussion of the history of rutile production from Magnet Cove (p. 13), it was pointed out that Messrs. Nichols and Campbell produced a small amount of rutile from properties located in the SW¼ SW¼ Section 18, T. 3 S., R. 17 W. The trenches resulting from that operation still exist, and rutile is exposed in the dump material adjacent to these trenches. The most prominent trench at this locality is about 700 feet long and is shown on Plate I as a series of surface rutile symbols that trend in a northwest-southeast direction. At its northwest end on the hillside above the unimproved road shown on the map the trench exposes metamorphosed shale which apparently contained scattered rutile-feldspar veins with a small amount of rutile. Immediately southeast of the unimproved road the vein material on the trench dump is a hard cream-colored porous feldspar rock with some fine-grained rutile. The trench is deepest at its southeast end where it exposes a soft, altered, gray-green igneous bedrock. The dump material at this end of the trench contains abundant rutile in masses that reach 1½ inches in maximum dimension. Probably much of this rutile is residual, having been derived from the soil overlying altered igneous rock, but some of it, at least, came from feldspar-carbonate veins, several of which are exposed in the altered igneous rock in the trench walls. About 100 yards west of the lower end of this main trench is a series of gulleys which have cut into altered igneous rock. Rutile is common at this locality but is almost entirely restricted to a soil layer 1 to 2 feet thick above the altered igneous rock.

RUTILE VEINS IN SECTION 24

Several rutile-bearing veins are exposed along the road from U. S. Highway 270 to the Jones Mill aluminum plant in the NE¼ of Section 24, T. 3 S., R. 18 W. (see Plate I). The best exposures are in a cut on the west side of the road about 120 yards southwest of Highway 270. Several hard, feldspar-carbonate veins in a soft altered gray-green igneous rock are exposed in this road cut. The veins are cream-colored, sugary-textured, and they contain a little fine-grained rutile. The quantity of rutile available at this locality is negligible, but the outcrop is interesting since it shows the widespread occurrence of rutile mineralization in Magnet Cove.

McKNIGHT PLACER RUTILE DEPOSIT

Although this deposit is located about three miles due south of the Cove, the Cove deposits are believed to be the source of its rutile. The deposit is in the S½ SW¼ of Section 5, T. 4 S., R. 17 W., Hot Spring County, Arkansas. It can be reached by following U. S. Highway 270 north a short distance out of Malvern to its junction with State Highway 84, thence following Highway 84 west a distance of nine-tenths of a mile to the State Highway 171 junction. Highway 171 is then followed 1.7 miles to a side road that intersects the highway on the right. Mr. H. R. McKnight's abandoned open pit is eight-tenths of a mile from the highway along this side road at the south end of a relatively flat-topped ridge. This ridge, which is about 200 feet wide and 1,000 feet long, consists of folded Paleozoic sediments with a mantle of clayey gravel varying from 10 to 20 feet in thickness. The gravel consists of pebbles and cobbles of sandstone, novaculite, and quartz embedded in a gray non-plastic clay, and is well exposed in the walls of the abandoned pit. Although the rutile at this property occurs in the gravel, it was undistinguishable in the pit walls probably because of clay coatings on the rutile pebbles. Most of the visible rutile at the deposit is on the surface, particularly in the vicinity of the numerous shallow test pits north of the open pit. The rutile pebbles are fairly well rounded and several pebbles up to 1 inch in diameter were found. The pebbles are easily identified by their dull, blue-black luster, high specific gravity and pitted surfaces. On freshly broken surfaces the pebbles have a blue-black metallic luster and are made up of an aggregate of individual crystals which are commonly striated and are practically identical to rutile masses of similar size that are found at Magnet Cove.

The quantity of rutile available at this deposit is undoubtedly small, but the fact that the rutile might be concentrated justifies the mention of the deposit.

TRANSPORTATION OF TITANIUM AND QUARTZ

While it has been stated (Lindgren, 1923, p. 424) that titanium is not transported by vein-forming solutions, the evidence given by Ross (1941) showing transportation of titanium in solution is amply confirmed in this study. Ross' conclusion, however, that titanium is probably transported in a vapor phase of titanium fluoride is not entirely acceptable with respect to Magnet Cove. Ross' greatest attention is paid to the Roseland, Virginia, area where apatite is abundant. According to Ross (**Idem**, p. 36):

> "The F in apatite certainly does not represent any such amounts, but the minute percentages in sericitic micas and clinozoisite must be large in aggregate, and the quantity of F that undoubtedly escaped into contiguous rocks was doubtless larger still. The amount of F, therefore, was evidently far in excess of that required to transport all the titanium which after all, is local in its occurrence."

Ross, referring to the Hardy-Walsh properties, says further:

> "The titanium deposits at Magnet Cove, Ark., present mineral relations that seem not inconsistent with such an origin. Here titanium has been carried far into pure quartz sedimentary rock, and taeniolite, a mineral carrying 13 per cent F, has formed abundantly.—A vapor phase rich in fluorine seems a not improbable explanation of these relations."

Ross was apparently not aware of the rutile-bearing feldspar-carbonate veins at the Magnet Cove Rutile Company property and it is not surprising that the possibility of hydrothermal transport of titanium was not considered.

The occurrence of rutile in veins with soda and potash feldspars might well be the result of transportation of titanium as $K_2TiF_6.H_2O$ which is water soluble as the temperature approaches 100°C (Thornton, 1927, p. 48), or in the form of $Na_2TiF_6.H_2O$. This would readily explain the occurrence of fluorine compounds in the immediate vicinity of the Magnet Cove Rutile Company property, a fact which should be emphasized. Apatite occurs in some of the carbonate veins and is rather abundant in the more altered phases of the aegirine phonolite porphyry. Fluorite is common as an introduced mineral in the nepheline syenite (fine-grained type) but only a single fluorite vein was noticed in the aegirine phonolite porphyry. Possibly the titanium was transported from some deep seated source as the fluoride in the vapor phase and hydrolyzed at the time of vein formation, but if so, it would appear that the constituents of calcite, dolomite, albite, microcline and pyrite were also transported in the vapor phase.

The situation with respect to the brookite deposits in quartzite is considerably different and the postulation of transport by a vapor phase is at least not hindered by consideration of the origin of the containing rock. Certain features of the sequence of mineralization, however, must be accounted for. Here a rutile mineralization is accompanied or followed by the formation of taeniolite, which according to Miser and Stevens (1938, p. 109), contains 8.56 per cent fluorine. The brookite mineralization followed the formation of taeniolite, and the close spatial relationship between the minerals has nothing to do with their positions in time. The hypothetical fluorine may well have been dissipated after serving as the transporting agent for the TiO_2, but the presence of earlier taeniolite does not account for the missing fluorine. The occurrence of abundant acicular rutile in brookite-dominant areas makes unattractive a hypothesis involving hydrothermal solutions in the formation of rutile ore deposits, and vapor phases in the formation of brookite ore deposits.

Probably there has been little or no addition of quartz from magmatic sources during the mineralization of the Magnet Cove area. The Magnet Cove intrusives are all deficient in silica. There is not even enough silica to convert large volumes of feldspathoids to feldspar, and many of the dikes have been described as olivine-bearing, further emphasizing the lack of silica. Quartz veins are not known in the Cove interior and the small body of quartz in the Mo-Ti Corporation pit is probably a metamorphosed sandstone or novaculite inclusion.

Quartz veins are limited to the periphery of the Cove and as far as the writer knows, those quartz veins are located in areas in which silica of sedimentary origins is known to occur. There is no doubt but what large volumes of silica have been reconstituted or even transported some distance; but there is little evidence for the "removal of great amounts of silica" as stated by Ross (*Idem*, p. 26). Again the possibility of gaseous transfer in the reorganization of the quartz is not out of the question (Gillingham, 1948), but until there are criteria for recognizing situations involving transport in a vapor phase, a conservative approach would assume that water not at or above its critical temperature is the transporting agent.

BENEFICIATION STUDIES OF THE HOT SPRING COUNTY TITANIUM ORES

Although this report is primarily geological in scope, it is desirable to note briefly the beneficiation studies that have been made on the titanium ores from the Magnet Cove area, particularly since it has been stated that the complex character of the ores has hindered the development of these deposits.

So far as is known to the authors, nothing has been published on the beneficiation of the brookite ore of the Hardy-Walsh deposit. It is believed, however, that the U. S. Bureau of Mines has done some preliminary work on the samples of ore from the test pits at this deposit.

Beneficiation tests on the brookite ore from the Christy deposit have been made by the Allis-Chalmers Company, the Deister Concentrator Company, and the American Cyanamid Company. The only published data on these tests, however, is a brief paper by Falconer and Crawford (1944) on the work done at the American Cyanamid Company laboratory at Stamford, Connecticut. The following excerpt from this paper summarizes the methods employed and results obtained.

> After a considerable amount of experimentation, a scheme of treatment and a reagent combination were developed that permitted a reasonably good recovery of titania in a concentrate analyzing 92.4 per cent TiO_2. In some tests, a slightly better grade of concentrates than this was obtained, but at the expense of a sharp decrease in recovery.
>
> The following scheme of treatment was found to be necessary to secure an effective separation of this ore by flotation:
>
> 1. Agitation (i. e., log washing or its equivalent) of the coarse ore, followed by desliming for removal of the slimes released from the ore.
>
> 2. Fine grinding of the washed ore to approximately minus 150-mesh.
>
> 3. Desliming of the washed and ground ore for removal of secondary slimes produced during grinding.
>
> 4. Conditioning of the ground and deslimed ore with reagents at high solids (70 to 80 per cent).
>
> 5. Rougher flotation of the conditioned feed.
>
> 6. Cleaning of the rougher concentrate at least four times.

It should be noted that all the above tests on the Christy ore were performed prior to the U. S. Bureau of Mines 1948 drilling project, and since the ore samples used were taken from the R.F.C. test pits, the samples contained a high percentage of residual ore. The U. S. Bureau of Mines has made beneficiation tests on the test pit ore at the Christy deposit and is now testing the core samples acquired during the recent (1948) drilling project, however no results of this work have yet been published.

The beneficiation of the rutile ores of the Magnet Cove Rutile Company deposit has been investigated more thoroughly than the brookite ores of the district since this deposit at one time yielded commercial rutile concentrates.

Under the direction of Mr. R. G. Knickerbocker, then Chief of the Metallurgical Division of the U. S. Bureau of Mines at Rolla, beneficiation studies of the ore from the Magnet Cove Rutile Company deposit were resumed in 1947 on samples collected from test pits in the floor of the West Pit. A report on these studies has been published in a recent paper by M. M. Fine and others (1949) and the "Summary and Conclusions" sections of this report has been reprinted below:

> One phase of an extensive investigation of the ore-dressing characteristics of titanium-bearing ores of the Magnet Cove area of Arkansas has been completed, and the results are presented in this paper. A sample of the complex ore from the property of Magnet Cove Rutile Co., Inc., Magnet, Ark., containing rutile, leucoxene, pyrite, ankerite, quartz, apatite, feldspar, iron oxides, clay, and other minerals, was the subject of the investigation.
>
> The treatment process included disintegration of the ore by tumbling in a revolving cylinder and subsequent removal of clay by classification. Gangue minerals and some pyrite were removed by gravity concentration. The rest of the pyrite was removed from the coarse sizes by agglomerate tabling and from the fine sizes by flotation. A finished rutile concentrate was then recovered by sizing, classification, tabling, and magnetic separation. This treatment gave a recovery of 46.35 per cent of the titanium in a product containing 92.2 per cent titania, 1.4 per cent iron, 0.63 per cent silica, 0.52 per cent lime, 0.09 per cent sulphur, and 0.29 per cent phosphorus.
>
> The investigation has shown that the production of commercial-grade rutile concentrates from the Magnet Cove property is technically feasible. The best possibility for improving the recovery obtained to date is in extending the application of flotation to the beneficiation of gravity middlings and similar products. Those flotation tests which have been made on such materials (one of which is given in this report) show a fair degree of concentration. The flotation study, while not productive of very high-grade concentrates, has been promising enough to warrant further work. A method of utilizing noncommercial grade rutile concentrate for the production of titanium matte is being investigated and the preliminary results are reported in another paper. (R. G. Knickerbocker, et al., 1944).

The Metallurgical Branch of the U. S. Bureau of Mines at Rolla is now making beneficiation tests on samples composited from the 1948 drilling project.

It is significant that in most of the beneficiation studies of the Hot Spring County titanium ores to date the purpose has been to produce a 92% (+) TiO_2 concentrate or what is now considered a commercial rutile concentrate, the main market for which is welding rod coatings. It is possible that if commercially feasible processes of converting rutile ultimately into titanium metal (R. G. Knickerbocker, et al., 1949) are developed that a lower-grade concentrate might become commercial with a consequent recovery of a higher percentage of the rutile and brookite in the Hot Spring County ores. This possibility is discussed further in the section on economic geology.

ECONOMIC GEOLOGY

TITANIUM MINERALS AND ORES

Titanium is one of the most abundant elements in the earth's crust, and is a constituent of a number of different minerals. The more common titanium-bearing minerals are ilmenite, rutile, brookite, leucoxene, titanite, and perovskite, of which only ilmenite and rutile are produced commercially in large tonnages at the present time.

Ilmenite,* an iron-titanium oxide, is the most common and the most important commercially of all the titanium minerals. It analyses theoretically 52.6 per cent titanium oxide and is produced from both beach sand and igneous rock deposits in the United States and in several foreign countries (see Table 4). Of the domestic deposits of ilmenite in igneous rock the Tahawus, New York, deposit is the most productive, accounting for about half of the ilmenite consumed in the United States at the present time. Recently a huge deposit of ilmenite in igneous rock has been discovered at Allard Lake in eastern Quebec, Canada; and it is anticipated that full scale production of ilmenite from this deposit will be attained in 1951. The beach sand ilmenite deposits were the source of most of the commercial ilmenite prior to World War II. Of these deposits the ilmenite beach sands in the state of Travancore, India, were the most productive. In the United States ilmenite is produced from beach sand deposits at Jacksonville, Vero Beach, and Starke, Florida.

Rutile is a natural oxide of titanium that theoretically contains 100 per cent titanium dioxide. Normally, however, small percentages of impurities, chiefly iron, are present in this mineral. Rutile occurs in several types of rock and in many different localities, but individual rutile deposits are generally less numerous and smaller than deposits of ilmenite. Rutile is produced commercially from both igneous rock and beach sand deposits in the United States and in several foreign countries (see Table 6). Most of the domestic rutile production has come from deposits in igneous rocks in Nelson County, Virginia. The rutile deposit of the Magnet Cove Rutile Company, previously described, is also an igneous rock occurrence. Much of the domestic rutile production comes from beach sand deposits in Florida as a by-product of the ilmenite operations in that state. Beach sand deposits along the east coast of Australia yield the largest foreign tonnage of rutile.

Leucoxene is variable in its composition but is predominantly titanium oxide. It is an alteration product of ilmenite and other titanium minerals,

* Gillson (1949) has stated that much of the so-called ilmenite in the large beach sand deposits is actually the mineral arizonite which resembles ilmenite in appearance but has a higher theoretical titanium oxide content (61.5 per cent). In the trade, however, arizonite is sold as ilmenite.

Table 6.* World Production of Ilmenite and Rutile Concentrates 1943-1948 by Countries in Metric Tons.

ILMENITE

Country	1943	1944	1945	1946	1947	1948
Australia	5,470	7,287	6,671	5,894	6,293	5,290
Brazil (Exports)	------	3,250	5,000	------	------	7,900
Canada	62,992	30,820	12,234	1,275	6,445	------
India	38,396	102,412	174,848	187,993	257,476	**
Malayan Union	------	------	------	------	13,291	12,909
Norway	66,191	63,975	28,312	52,574	69,711	93,322
United States	184,657	252,749	279,880	256,230	305,296	348,126
Other Countries***	1,029	557	3,726	5,217	8,849	4,992
Total	358,735	461,050	511,271	509,183	668,361	**

RUTILE

Country	1943	1944	1945	1946	1947	1948
Australia	3,816	8,843	9,901	8,283	13,406	15,348
Brazil (Exports)	2,639	1,564	160	28	5	------
Cameroun (French)	1,800	3,320	1,440	1,260	800	**
India	1,891	1,672	620	262	159	**
Norway	172	85	76	63	51	------
United States	2,839	6,279	6,513	6,761	7,767	6,695
Total	12,887	21,763	18,710	16,657	22,188	23,000

* Adapted from a table by B. B. Mitchell in Titanium Preprint from U. S. Bureau of Mines Minerals Yearbook 1948, p. 10.
** Data not available.
*** Egypt, Portugal, Senegal, Spain.

and probably is not a distinct mineral species but a submicroscopic aggregate of rutile crystals. This mineral is produced commercially as a by-product in the Florida beach-sand ilmenite operations.

Brookite, a natural titanium oxide has the same chemical composition as rutile, and even though it differs from rutile in crystal form it would probably be considered rutile in the trade. Brookite is found sparingly in the rocks at many different localities but the deposits in Hot Spring County, Arkansas, are the only known deposits of important size and grade.

Perovskite (calcium titanium oxide) and titanite (calcium titanium silicate) are not produced commercially though there are a few known deposits of these minerals that are of significant size.

USES OF TITANIUM MINERALS

Over 90 per cent of the ilmenite consumed in the United States is used in the manufacture of titanium oxide pigment. This oxide, because of its extreme whiteness, high refractive index, chemical stability and relative cheapness, has become the most widely used white pigment in the paint, paper and rubber industries. Some titanium oxide derived from ilmenite is also used in welding rod coatings. Small amounts of ilmenite are used in titanium alloys and carbide and steel flux. Table 7 shows the tonnages of ilmenite consumed by uses in the United States.

Table 7.* Consumption of Ilmenite and Rutile Concentrates in the United States by Uses in 1948 (Short Tons)

Product	Ilmenite	Rutile
Pigments (manufactured titanium dioxide)**	558,448	-------
Welding Rod Coatings**	145	7,885
Alloys and Carbide	6,377	952
Ceramics	-------	175
Miscellaneous	30	851
Total	565,000	9,863

* Adapted from a table in Titanium Preprint from U. S. Bureau of Mines Minerals Yearbook for 1948, p. 4.

** "Pigments" include all manufactured titanium dioxide consumption of which in welding rod coatings was 1,338 tons in 1948.

Most of the rutile consumed in the United States is used in welding rod coatings. These coatings, which consist of finely-ground rutile and several other ingredients, are applied to the welding rods in an extrusion machine. Rutile in the welding rod coatings reduces the amperage required to maintain the welding arc, stabilizes the arc, and aids in the development of an air-tight envelope in the welding area, thus preventing oxidation during the welding process.

Titanium alloy and carbide manufacture accounts for the second largest tonnage of rutile consumed in the United States. The alloys are prepared by reducing rutile with the desired secondary metal (iron, aluminum, copper, etc.) and they are used as scavengers for sulfur, nitrogen, oxygen and carbon in steel making. Titanium carbide is prepared by reducing rutile with carbon and is widely used as the hard ingredient of high speed cutting tools.

Small but important tonnages of rutile are used as a source of titania in ceramics because it is simple to prepare. After beneficiation and grinding it is directly suitable for use in some enamels or as a raw material for the preparation of several other ceramic products.

TITANIUM METAL

During the past few years the production of metallic titanium has been the subject of extensive research by both government and industry. The potential applications of this metal as a structural material are innumerable because of its unique combination of properties: light weight, strength, and corrosion resistance. The major factor preventing extensive use of titanium at the present time is its high cost ($5 per pound), which in turn is due to the lack of economic methods for extracting, refining, and fabricating the metal. Titanium metal today occupies a position not unlike that held by aluminum in 1884 when it sold for $1.41 per pound. During the succeeding 60-year period metallurgical developments reduced the price of aluminum to 15 cents per pound, and some experts believe that because of the unprecedented amount of effort and money being expended on titanium metal research, this new metal will be developed as a large-scale structural material more quickly, possibly within the next decade.

In 1949 two plants were producing commercial titanium metal in the United States; one plant operated throughout the year producing about 100 pounds a day and a second plant with a somewhat larger capacity went into production at the close of the year. In Canada a government-built plant at Haley, Ontario, produced 25 to 200-pound ingots occasionally for government experimental work. Several different methods of producing titanium metal are known, but the Kroll process, which is used with modifications by both the DuPont company and the U. S. Bureau of Mines, seems at present to be the most successful. In this process titanium metal is obtained by reducing titanium tetrachloride with magnesium metal. Figure 12 is a simplified diagram showing the basic steps in the extraction of titanium metal from ilmenite and rutile using the Kroll process.

Because of the potential importance of titanium metal as a structural material, consideration should be given to the relative importance of the different titanium minerals as ores of titanium metal. Although it contains a much lower percentage of titanium than rutile, ilmenite will probably be the principal ore mineral of titanium simply on the basis of the comparative reserves of the two minerals. It is believed, however, that processes will be developed to use rutile in the production of titanium metal because of its higher metal content, and the fact that large tonnages of rutile are produced as a by-product of beach-sand ilmenite operations.

ECONOMIC POSSIBILITIES OF THE HOT SPRING COUNTY TITANIUM DEPOSITS

Of the rutile and brookite deposits and prospects described in the preceding chapters only the rutile deposit of the Magnet Cove Rutile Company and the Christy brookite deposit have been developed to the point of having commercial possibilities. Drilling and sampling of these two deposits by the U. S. Bureau of Mines has provided the basic data necessary for the calculation of ore reserves, and beneficiation studies by both industrial and federal ore dressing laboratories have developed methods of recovering rutile (Fine, et. al., 1949), and brookite (Falconer, et al., 1944), from these ores in concentrates with a 92 per cent or greater TiO_2 content. To determine whether or not these deposits could be operated profitably under current marketing conditions is beyond the scope of this report, but a consideration of the suitability of Arkansas rutile and brookite for the current, and possible future uses of rutile is justified. Since rutile and brookite are essentially the same chemically, brookite would probably be considered rutile in the trade.

Table 7 shows that welding rod coatings accounted for the bulk of the rutile consumed in the United States in 1948. Rutile acceptable for welding rod coatings should contain a minimum of 92 per cent titanium dioxide as well as a minimum amount of lime, silica, and sulfur. The ultimate test of the suitability of any rutile for welding rod coatings, however, is not chemical composition, but rather the completion of satisfactory test welds using rods coated with such rutile. Although a substantial tonnage of rutile concentrates has been produced from the deposit of the Magnet Cove Rutile Company, so far as is known, this rutile has not been used in commercial welding

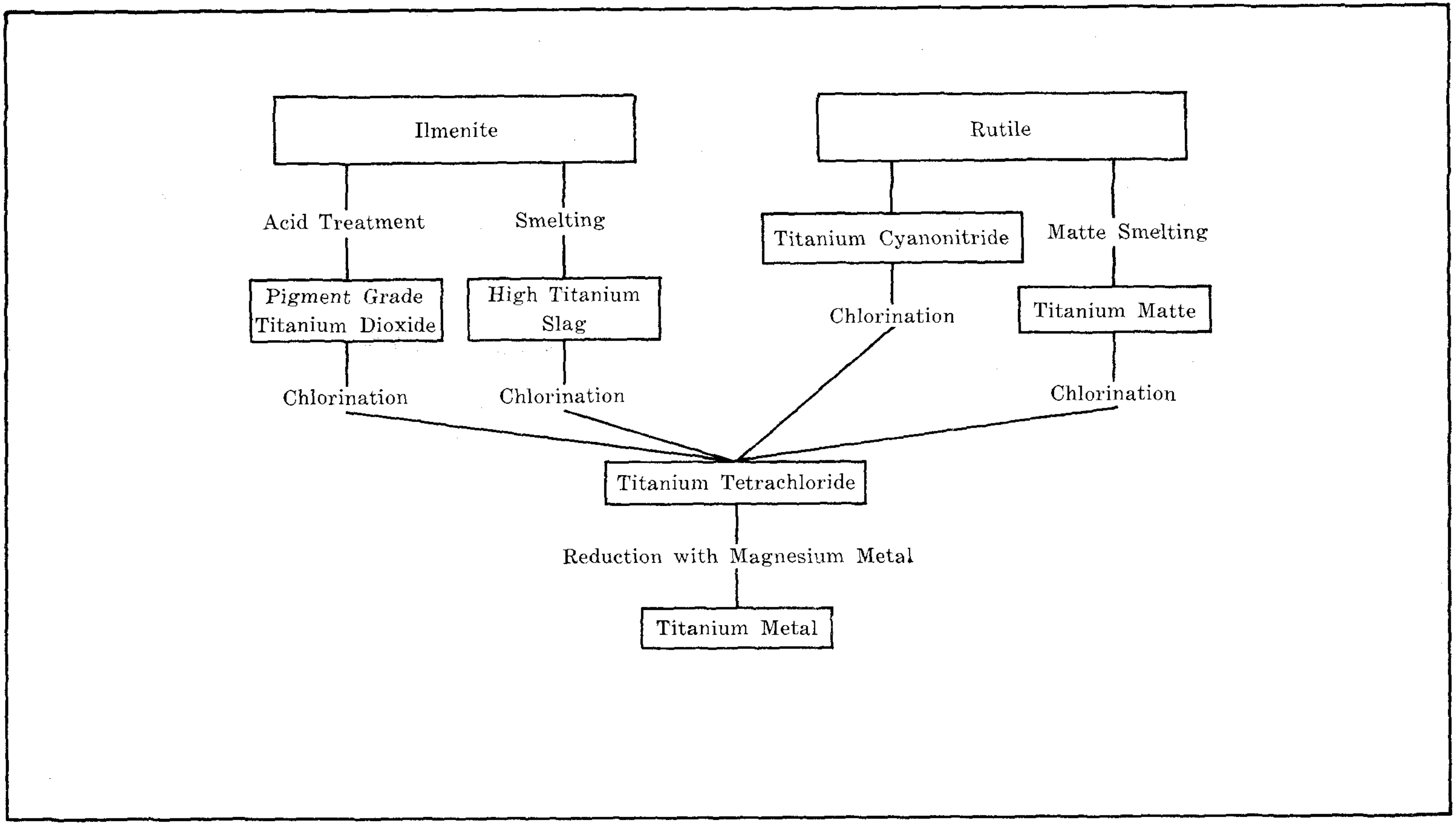


Figure 12. Diagram showing the *basic* steps in the extraction of titanium metal from its ores by the Kroll process.

rod coatings. The Metallurgical Division of the Rolla Branch, U. S. Bureau of Mines, under the direction of R. G. Knickerbocker has recently completed a preliminary investigation (R. D. Van Zante, et al., 1949) of the usability of the rutile from the Magnet Cove Rutile Company deposit in welding rod coatings. Under the conditions of this investigation it was found that "all-weld-metal test specimens made with Arkansas rutile concentrates in the electrode coating are inferior to similarly produced weld metal from arc-welding rods containing commercial rutile in the coating, and to commercial electrodes." This inferiority is due to low ductility of the weld metal from rods coated with Arkansas rutile. It is believed that the low ductility was a result of the high sulfur content of the Arkansas rutile when the rutile samples contained greater than 0.20 per cent of sulfur. With 0.20 per cent sulfur and less in the rutile samples, the low ductility was probably partly induced by other factors not definitely identified. The writers state that additional study of the many factors involved in the arc-welding process, slag characteristics, reducibility of the various forms of rutile, etc., might "permit the development of a coating mixture which would compensate the inhibiting characteristics of Arkansas rutile and make this mineral deposit acceptable for commercial use in welding electrodes."

Tests of brookite concentrates from the Christy deposit as a welding rod coating material may have been made, but no results of such tests have been published. The lessee, Mr. W. O. Christy, stated that a manufacturer of welding rods placed an order for brookite concentrates on the basis of samples of concentrates furnished by Christy. Since brookite has not yet been produced commercially from the deposit, it is still not definitely known whether this material will make satisfactory welding rod coatings.

Probably most of the rutile produced from the Magnet Cove Rutile Company deposit has been consumed in the manufacture of titanium alloys. Therefore, the rutile from this deposit is apparently an acceptable raw material for the manufacture of this titanium product. The suitability of brookite from the Christy deposit for the manufacture of titanium alloys and carbide would have to be established by tests on concentrates of this ore.

The acceptability of the Hot Spring County titanium ores for the ceramic trade does not merit consideration, since at the present time the tonnage of rutile concentrates consumed in the ceramic trade is so small that the demands of this market alone would probably not stimulate the development of new rutile deposits.

Although the current production of titanium metal is insignificant the potential uses of this new structural material justify its consideration as a market for the Hot Spring County ores. As has been stated in the preceding section on titanium metal, the techniques of producing the metal are constantly changing as a result of intensive research, consequently, it is not known what grades and types of titanium ores will be acceptable for metal production. It appears likely, however, that rutile ores will be used in titanium metal production because of their high titanium content and because they have been used in the past and are now being successfully used in the production of titanium tetrachloride, an essential constituent in the Kroll process for producing the metal. Recently metallurgists of the Rolla Branch of the U. S. Bureau of Mines have completed an investigation (R. G. Knickerbocker, et al., 1949) in which rutile concentrates from the Magnet Cove Rutile Company deposit were successfully used in preparing titanium oxide as well as titanium tetrachloride. In this investigation it was pointed out that rutile concentrates that are lower grade than those acceptable for welding rod coatings could probably be used in metal production. A market for lower grade concentrates should stimulate the development of the Hot Spring County deposits, since it would permit milling these ores at lower cost with increased recoveries. When a method of producing relatively cheap titanium metal becomes established, the demand for titanium ores will be greatly increased. It is believed, therefore, that the most promising potential market for the Hot Spring County rutile and brookite ores is in the production of titanium metal.

LOGS OF U. S. BUREAU OF MINES 1945 DRILL HOLES, MAGNET COVE RUTILE COMPANY DEPOSIT

Two separate drilling projects have been completed by the U. S. Bureau of Mines at the Magnet Cove Rutile Company deposit, one in 1945 and a second project in 1948. During the 1945 project 26 holes were completed, including 16 churn drill holes and 10 core drill holes. The following (pp. 82-96) descriptive logs and assays of these 26 holes have been reprinted from a report published by the U. S. Bureau of Mines (Spencer, 1946, pp. 7-23). All of these drill holes are plotted on Plate II. The logs of the second (1948) U. S. Bureau of Mines drilling project at this deposit appear on pages 97-129 of this report, immediately following the logs of the first project.

HOLE A-1

Elevation collar: 253.5

Depth, feet From	To	Description	Analysis, percent TiO_2
0.0	11.8	Clay, sand, gravel overburden, and oxidized material	2.5
11.8	14.5	Metamorphosed shale with some pyrite and rutile	3.8
14.5	17.4	do.	4.5
17.4	19.9	do.	1.4
19.9	22.4	do.	1.3
22.4	24.5	do.	1.1
24.5	27.7	do.	2.9
27.7	31.7	Harder gray rock with pyrite and rutile	3.3
31.7	35.3	do.	3.0
35.3	38.1	do.	2.3
38.1	40.0	do.	3.0
40.0	42.4	do.	2.5
42.4	46.6	do.	4.7
46.6	48.3	do.	3.2
48.3	50.9	Metamorphosed shale, some pyrite and rutile	1.3

HOLE A-2

Elevation collar: 264.4

Depth, feet From	To	Description	Analysis, percent TiO_2
0.0	11.0	Clay, sand, gravel overburden and oxidized material	4.1
11.0	14.4	Metamorphosed shale with some pyrite and rutile	5.1
14.4	17.9	do.	4.5
17.9	22.0	do.	4.4
22	23.8	do.	4.6
23.8	28.1	do.	4.7
28.1	32.4	do.	4.7
32.4	38.2	do.	4.8
38.2	42.0	do.	4.6
42.0	46.5	do.	5.5
45.5	51.5	do.	4.9

HOLE A-3

Elevation collar: 270.8

Depth, feet From	To	Description	Analysis, percent TiO_2
0	11	Overburden, considerable loose gravel	2.9
11	15	Soft brownish rock. Metamorphosed shale	1.8

HOLE C-1

Elevation collar: 257.0

Depth, feet From	To	Description	Analysis, percent TiO_2
0	2	Surface and oxidized material. Sand, clay, gravel, limonite, some rutile.	2.3
2	4	do.	2.0
4	6	do.	2.2
6	8	do.	2.4
8	10	do.	2.8
10	12	do.	2.6
12	14	do.	3.9
14	16	Clay, medium-soft rock, with calcite, feldspar, pyrite, rutile, other minerals	3.8
16	18	do.	4.5
18	20	do.	3.3
20	22	do.	2.8
22	24	do.	2.8
24	26	do.	2.9
26	28	do.	2.1
28	30	do.	1.8
30	32	do.	2.1
32	34	do.	2.8
34	36	do.	2.8
36	38	do.	2.4
38	40	do.	3.4
40	42	do.	3.3
42	44	do.	2.3
44	46	do.	2.8
46	48	do.	4.0
48	50	do.	4.7
50	52	do.	3.4
52	54	do.	2.8
54	56	do.	2.5
56	58	do.	1.7
58	60	do.	.5

HOLE E-1

Elevation collar: 255.0

Depth, feet From	To	Description	Analysis, percent TiO_2
0	2	Light-colored, medium-hard rock, with calcite, feldspar, pyrite, rutile, and other minerals	3.3
2	4	do.	4.1
4	6	do.	2.4
6	8	do.	2.6
8	10	do.	2.5
10	12	do.	2.4
12	14	do.	2.7
14	16	do.	2.6
16	18	do.	2.6
18	20	do.	4.1
20	22	Harder, darker rock with rutile, pyrite, and other minerals	3.1
22	24	do.	3.4
24	26	do.	2.5
26	28	do.	3.0

HOLE E-2

Elevation collar: 275.0

Depth, feet From	To	Description	Analysis, percent TiO_2
0	2	Overburden and oxidized material, clay, sand, and rock. Some rutile	3.8
2	4	do.	4.3
4	6	do.	3.7
6	8	do.	3.9
8	10	do.	4.5
10	12	do.	3.2
12	14	Partly oxidized material. Some pyrite and rutile	3.2
14	16	Dark-gray rock with pyrite, feldspar, rutile	2.9
16	18	do.	3.6
18	20	do.	3.6
20	22	Considerable pyrite	3.8
22	24	Dark-gray rock with pyrite, feldspar, rutile	3.6
24	26	Gray rock (metamorphosed shale), some pyrite and rutile	4.0
26	28	do.	3.6
28	30	Medium hard to hard gray rock with pyrite, rutile, feldspar	3.8
30	32	do.	3.6
32	34	do.	3.6
34	36	do.	2.7
36	38	do.	1.6
38	40	Hard dark rock pyrite and rutile	2.5
40	42	do.	3.2

HOLE E-6

Elevation collar: 252.0

Depth, feet From	To	Description	Analysis, percent TiO_2
0	2	Clay, sand and gravel overburden. Oxidized material. Some rutile	4.3
2	4	do.	4.0
4	6	do.	3.6
6	8	do.	4.1
8	10	do.	4.1
10	12	Calcite, feldspar, and other rock with pyrite and rutile	3.7
12	14	do.	3.6
14	16	do.	2.8
16	18	do.	3.2
18	20	do.	3.7
20	22	do.	3.8
22	24	do.	3.8
24	26	do.	4.1
26	28	do.	3.4
28	30	do.	3.3
30	32	do.	2.3
32	34	do.	2.2
34	36	do.	2.4
36	38	do.	3.2
38	40	Mostly calcite	3.0
40	42	do.	2.7
42	44	do.	2.2
44	46	Calcite, feldspar and other rock with pyrite and rutile	2.7
46	48	do.	3.5
48	50	do.	3.3

HOLE E-7

Elevation collar: 249.0

Depth, feet From	To	Description	Analysis, percent TiO_2
0.0	11.3	Clay, sand, gravel overburden and oxidized material	4.0
11.3	14.3	Clay and soft rock. Oxidized material	4.2
14.3	15.7	Clay, soft rock, pyrite. Unoxidized material	3.2
15.7	22.4	Soft rock with pyrite. Metamorphosed shale	2.7
22.4	24.2	do.	4.1
24.2	26.9	Hard brown rock with calcite, feldspar, rutile	1.9
26.9	27.4	do.	1.7
27.4	29.4	Soft rock with some feldspar, pyrite, rutile	4.9
29.4	32.4	do.	4.3
32.4	35.4	do.	2.7
35.4	38.4	do.	1.9
38.4	40.4	do.	3.9
40.4	42.4	do.	4.3
42.4	44.3	do.	2.3
44.3	49.9	do.	3.1
49.9	52.4	Harder rock with calcite, feldspar, pyrite, rutile	3.1
52.4	54.6	do.	2.5

HOLE G-1

Elevation collar: 280.0

Depth, feet From	To	Description	Analysis, percent TiO_2
0	2	Clay, sand gravel overburden. Some rutile	3.8
2	4	do.	4.6
4	6	Oxidized material. Brown-gray clay, soft rock. Quartz, calcite, rutile, unidentified minerals	4.1
6	8	do.	4.5
8	10	do.	3.6
10	12	do.	3.7
12	14	do.	4.2
14	16	do.	4.2
16	18	Oxidized material. Some pyrite	4.6
18	20	do.	3.9
20	22	Medium-hard rock, with calcite, quartz pyrite, rutile, other minerals	3.0
22	24	do.	4.2
24	26	do.	4.2
26	28	Mostly calcite	4.2
28	30	do.	3.7
30	32	do.	4.9
32	34	Medium-hard rock, with calcite, quartz pyrite, rutile, other minerals	4.0
34	36	do.	3.6
36	38	do.	3.5
38	40	do.	3.4
40	42	do.	4.3
42	44	do.	3.3
44	46	do.	4.1
46	48	do.	4.0
48	50	Harder, darker rock with some pyrite and rutile	3.8
50	52	do.	4.2
52	54	do.	4.0
54	56	do.	3.6

HOLE H-1

Elevation collar: 254.0

Depth, feet From	To	Description	Analysis, percent TiO_2
0	2	Pyrite, rutile and unidentified minerals in clay matrix	4.0
2	4	do.	4.6
4	8	do.	3.2
8	10	do.	2.8
10	12	do.	2.8
12	14	do.	2.8
14	16	do.	1.8
16	18	do.	1.8
18	20	do.	.8
20	22	do.	.6
22	24	do.	.6
24	26	do.	.8
26	28	do.	.6
28	30	do.	1.4
30	32	do.	.8
32	34	do.	.6
34	36	do.	.8
36	38	do.	2.4
38	40	do.	2.4
40	42	do.	3.0
42	44	do.	3.2
44	46	do.	3.2
46	48	do.	3.2
48	50	do.	2.8
50	52	do.	3.6
52	54	do.	3.2
54	56	do.	3.2
56	58	do.	3.2
58	60	do.	3.0

HOLE H-2

Elevation collar: 343.7

Depth, feet From	To	Description	Analysis, percent TiO_2
0	2	Syenite boulders in clay	1.2
2	4	do.	1.0
4	6	do.	.8
6	8	do.	.6
8	10	do.	.6
10	12	do.	.8
12	14	do.	.6
14	16	do.	.6
16	18	Decomposed igneous rock and clay	.4
18	20	do.	2.8
20	22	do.	1.8
22	24	do.	1.0
24	26	do.	.8
26	28	do.	1.4
28	30	do.	1.6
30	32	Harder igneous rock	.8
32	34	Hard dense igneous rock	1.2

HOLE H-3

Elevation collar: 321.0

Depth, feet From	To	Description	Analysis, percent TiO_2
0	2	Overburden, clay, sand, gravel, some rutile	2.4
2	4	do.	2.8
4	6	do.	2.0
6	10	do.	2.4
10	12	Oxidized material. Clay and soft rock. Quartz, calcite, rutile, other minerals	4.4
12	14	do.	3.8
14	16	do.	2.6
16	18	do.	2.8
18	20	do.	2.0
20	22	do.	2.6
22	24	Oxidized to unoxidized material	2.8
24	26	do.	3.0
26	28	Unoxidized material. Medium-hard rock. Quartz, calcite, rutile, pyrite and other minerals	3.0
28	30	do.	4.0
30	32	do.	2.8
32	34	do.	2.1
34	36	do.	1.2
36	38	do.	1.5
38	40	do.	2.3
40	42	do.	2.0
42	44	Harder, darker rock	3.1
44	46	do.	2.3
46	48	do.	3.3
48	50	do.	3.1
50	52	do.	2.4
52	54	do.	2.9
54	56	Hard, dense rock	3.2
56	58	do.	3.1

HOLE H-4

Elevation collar: 271.0

Depth, feet From	To	Description	Analysis, percent TiO_2
0	2	Surface material with pyrite, rutile, clay, rock felsite, with pyrite, rutile and other minerals	2.8
2	4	do.	2.6
4	6	do.	3.3
6	8	Darker rock with pyrite, rutile, mica, other minerals	4.6
8	10	do.	4.7
10	12	do.	5.3
12	14	Light-colored rock, felsite, with pyrite, rutile, other minerals	4.2
14	16	do.	4.1
16	18	do.	3.8
18	20	do.	4.1
20	22	do.	4.0

HOLE H-5

Elevation collar: 271.0

Depth, feet From	To	Description	Analysis, percent TiO_2
0	2	Unoxidized material. Medium soft gray rock with pyrite, rutile, calcite, other minerals	4.5
2	4	do.	4.5
4	6	do.	4.3
6	8	do.	4.5
8	10	do.	4.7
10	12	do.	4.5
12	14	do.	4.2
14	16	do.	3.4
16	18	do.	3.2
18	20	do.	3.2
20	22	do.	3.6
22	24	do.	4.0
24	26	Dark hard rock with rutile and pyrite	4.3
26	28	do.	4.1
28	30	do.	4.1
30	32	do.	4.2
32	34	do.	5.2
34	36	do.	4.8
36	38	Light-colored rock with pyrite and rutile	4.4
38	40	Abundant pyrite	4.0
40	42	Hard, dark, fine-grained rock with pyrite and rutile	4.3
42	44	do.	4.2
44	45	do.	4.2

HOLE H-6

Elevation collar: 274.7

Depth, feet From	To	Description	Analysis, percent TiO_2
0	2	Medium-hard dark rock with pyrite	4.9
2	4	do.	4.9
4	6	do.	5.7
6	8	do.	4.9
8	10	do.	4.9
10	12	do.	4.7
12	14	do.	4.8
14	16	do.	4.1
16	18	Same as above but getting harder with depth	4.1
18	20	do.	4.3
20	22	do.	4.1
22	24	do.	4.1
24	26	do.	5.0
26	28	do.	4.9

HOLE H-7

Elevation collar: 258.4

Depth, feet From	To	Description	Analysis, percent TiO_2
0	2	Calcite, pyrite, quartz, rutile, and other minerals in clay matrix	4.5
2	4	do.	3.9
4	6	do.	4.8
6	8	do.	4.1
8	10	do.	5.2
10	12	do.	4.9
12	14	do.	5.0
14	16	do.	4.0
16	18	do.	4.2
18	20	do.	3.5
20	22	do.	3.6
22	24	do.	4.6
24	26	do.	6.2
26	28	do.	5.1
28	30	do.	4.9
30	32	do.	4.1
32	34	do.	4.5
34	36	Mostly calcite	3.1
36	38	do.	3.3
38	40	do.	3.5
40	42	do.	2.3
42	44	do.	2.6
44	46	Calcite, pyrite, quartz, rutile, and other minerals in clay matrix	3.8
46	48	do.	3.7
48	50	do.	3.6
50	52	do.	3.4
52	54	do.	2.9
54	56	do.	3.9
56	58	do.	4.1
58	60	do.	2.3
60	62	do.	1.4
62	64	do.	2.7
64	66	do.	2.1
66	68	do.	2.3
68	70	do.	2.7
70	72	do.	2.3
72	74	do.	0.8
74	76	do.	2.5
76	78	Hard dark rock	2.3
78	80	Calcite, pyrite, quartz, rutile, and other minerals in clay matrix	1.8
80	82	do.	2.3
82	84	do.	3.0
84	86	do.	3.0
86	88	do.	3.1
88	90	do.	2.3
90	92	do.	2.2
92	94	do.	2.7
94	96	do.	3.0
96	98	do.	3.7
98	100	do.	3.0
100	102	do.	2.5
102	104	do.	3.4
104	106	do.	2.0
106	108	do.	2.2
108	110	do.	1.7
110	112	do.	1.5

HOLE H-7 (Continued)

Depth, feet From	To	Description	Analysis, percent TiO_2
112	114	Calcite, pyrite, quartz, rutile and other minerals in clay matrix	1.5
114	116	do.	1.8
116	118	do.	2.7
118	120	do.	2.7
120	122	do.	2.6
122	124	do.	2.4
124	126	do.	3.0
126	128	do.	2.1
128	130	do.	2.6
130	132	do.	2.7
132	134	do.	2.1
134	136	do.	2.4
136	138	do.	2.0
138	140	do.	1.9
140	142	do.	1.8
142	144	do.	1.5
144	146	do.	1.8
146	148	do.	1.0
148	150	do.	1.2

HOLE K-1

Elevation collar: 277.0

Depth, feet From	To	Description	Analysis, percent TiO_2
0	2	Overburden of clay, sand, gravel and some rutile	2.3
2	4	do.	2.3
4	6	do.	2.4
6	8	Oxidized material. Brown and gray clay and rock. Some rutile	2.6
8	10	do.	2.3
10	12	do.	4.4
12	14	Oxidized material. Brown and gray clay and rock. Some rutile	4.9
14	16	do.	4.9
16	18	do.	4.9
18	20	do.	5.1
20	22	Dark rock with considerable pyrite. Some rutile	4.1
22	24	do.	5.1
24	26	do.	5.1
26	28	do.	4.7
28	30	do.	4.0
30	32	do.	5.1
32	34	do.	3.7
34	36	do.	3.7
36	38	do.	4.2
38	40	do.	3.8
40	42	do.	4.1
42	44	do.	4.4
44	46	Lighter rock with calcite, pyrite, and rutile	4.2
46	48	do.	3.8
48	50	do.	5.0
50	52	do.	4.1
52	54	do.	4.1
54	56	do.	3.8
56	58	do.	3.4
58	60	do.	3.6
60	62	do.	3.7

HOLE K-2

Elevation collar: 268.0

Depth, feet From	To	Description	Analysis, percent TiO_2
0	2	Gray-brown medium soft rock (felsite) with calcite, pyrite, clay, rutile and other minerals	3.6
2	4	do.	5.0
4	6	do.	4.3
6	8	do.	4.6
8	10	do.	4.6
10	12	do.	6.3
12	14	do.	6.9
14	16	do.	7.1
16	18	do.	5.6
18	20	do.	6.2
20	22	do.	5.3
22	24	do.	4.5
24	26	do.	4.4
26	28	do.	3.9
28	30	do.	4.2
30	32	do.	4.5
32	34	do.	4.4
34	36	do.	4.1
36	38	do.	4.7
38	40	do.	4.9
40	42	do.	4.9
42	44	do.	5.1
44	46	do.	5.1
46	48	do.	4.8
48	50	do.	4.0
50	52	do.	3.7
52	54	do.	4.2
54	56	do.	5.5
56	58	do.	3.7
58	60	do.	3.3
60	62	do.	2.5
62	64	do.	2.8
64	66	do.	4.7
66	68	do.	4.2
68	70	do.	3.9
70	72	do.	3.9
72	74	do.	4.2

HOLE K-3

Elevation collar: 293.0

Depth, feet From	To	Description	Analysis, percent TiO_2
0	2	Overburden of clay, sand, gravel, some rutile	2.1
2	4	do.	2.1
4	6	do.	1.8
6	8	do.	1.9
8	10	do.	1.6
10	12	Oxidized material. Gray-white clay, soft rock limonite, some rutile	1.5
12	14	do.	1.2
14	16	do.	1.6
16	18	do.	3.0
18	20	do.	3.1
20	22	do.	4.5
22	24	do.	4.6
24	26	do.	3.5
26	28	Light clay, soft rock, abundant pyrite, some calcite, rutile, and other minerals	2.1
28	30	do.	2.3
30	32	do.	3.6
32	34	do.	2.5
34	36	do.	1.9
36	38	do.	1.6
38	40	Mostly pyrite	1.6
40	42	do.	1.8
42	44	do.	1.4
44	46	do.	1.3
46	48	do.	1.8
48	50	do.	1.1
50	52	Light clay, soft rock, abundant pyrite, some calcite, rutile and other minerals	1.5
52	56	do.	No sample
56	58	do.	1.2
58	60	do.	1.1
60	62	do.	.7
62	64	do.	1.0
64	66	do.	.9
66	68	do.	.7
68	70	do.	.7
70	72	do.	.9
72	74	do.	1.0
74	76	Mostly pyrite	2.1
76	78	do.	1.8
78	80	Light clay, soft rock, abundant pyrite, some calcite, rutile, and other minerals	1.6
80	82	do.	2.3
82	84	do.	1.8
84	86	do.	3.2
86	88	do.	1.3
88	90	do.	2.3
90	92	do.	2.0
92	94	do.	1.9
94	96	do.	1.7
96	98	do.	1.5
98	100	do.	1.4

HOLE K-4B

Elevation collar: 263.0

Depth, feet From	To	Description	Analysis, percent TiO_2
0.0	11.0	Overburden and oxidized material	----
11.0	15.8	Oxidized material. Clay and soft rock	2.5
15.8	17.6	do.	2.5
17.6	21.1	Gray clay with calcite, pyrite, and rutile	3.6
21.1	23.4	Gray clay and rock. Some pyrite and rutile	3.2
23.4	27.2	do.	1.6
27.2	31.4	do.	2.4
31.4	35.8	do.	2.3
35.8	41.8	do.	3.3
41.8	48.1	Clay and soft rock with calcite, pyrite, and rutile	3.2
48.1	52.0	Calcite	.6
52.0	54.0	Calcite to soft rock. Some pyrite and rutile	2.3

HOLE L-1

Elevation collar: 296.5

Depth, feet From	To	Description	Analysis, percent TiO_2
0	2	Overburden. Syenite boulders in clay	1.9
2	4	do.	1.8
4	6	do.	1.9
6	8	do.	1.3
8	10	Oxidized material. Brown clay, medium-soft rock	2.2
10	12	do.	2.2
12	14	do.	1.7
14	16	do.	.9
16	18	do.	1.2
18	20	do.	2.0
20	22	Unoxidized material. Calcite, pyrite, quartz, other minerals	1.1
22	24	do.	1.5
24	26	do.	.8
26	28	do.	1.0
28	30	do.	.9
30	32	do.	.9
32	34	do.	1.0
34	36	do.	1.3
36	38	do.	1.0
38	40	Hard igneous rock	1.1
40	42	do.	.6

HOLE M-1

Elevation collar: 234.9

Depth, feet From	To	Description	Analysis, percent TiO_2
0	10	Overburden and oxidized material to 9 feet. Hard rock below 9 feet	2.8

HOLE M-2

Elevation collar: 239.7

Depth, feet From	To	Description	Analysis, percent TiO_2
0.0	11.3	Clay, sand, gravel overburden, and oxidized material	3.1
11.3	14.8	Dark rock and clay. Some pyrite and rutile	5.2
14.8	16.8	Light rock and clay. Some pyrite and rutile	2.2
16.8	19.3	Clay and seamy rock. Some pyrite and rutile	4.1
19.3	22.0	Clay, soft rock with calcite, feldspar, pyrite and rutile	2.7
22.0	24.6	do.	1.9
24.6	27.1	do.	2.3
27.1	29.5	Clay with rutile, calcite, feldspar, abundant pyrite	2.9
29.5	32.5	do.	2.7
32.5	33.5	do.	3.5
33.5	36.7	do.	6.8
36.7	40.0	do.	4.5
40.0	42.5	Calcite, feldspar, rutile, pyrite and some dark blue rock	2.5
42.5	45.0	Clay and rock with calcite, feldspar, pyrite, rutile	2.6
45.0	47.9	Seamy rock with some pyrite, calcite, rutile	2.4
47.9	50.0	do.	2.4

HOLE M-3

Elevation collar: 245.6

Depth, feet From	To	Description	Analysis, percent TiO_2
0	12	Overburden and oxidized material to 10 feet. Hard rock below 10 feet	2.8

HOLE M-4

Elevation collar: 248.4

Depth, feet From	To	Description	Analysis, percent TiO_2
0.0	11.9	Overburden oxidized material to 8 feet. 8 to 10 feet unoxidized material. 10 to 11.9 feet harder rock	3.3
11.9	17.0	Rock and clay with some pyrite and rutile	2.3
17.0	20.0	Medium-hard rock, with some pyrite and rutile	4.7
20.0	22.0	Hard rock with pyrite and rutile	2.2
22.0	23.7	do.	1.1
23.7	29.6	Same as above, with void spaces	2.0
29.6	31.0	Hard, dark rock, with some pyrite and rutile. Dike rock	3.9

HOLE O-1

Elevation collar: 244.9

Depth, feet From	To	Description	Analysis, percent TiO_2
0	11	Light clay and pyrite to 7 feet. Dike rock below 7 feet	3.9
11	12	Hard dark rock. Dike rock	3.9

LOGS OF U. S. BUREAU OF MINES 1948 DRILL HOLES, MAGNET COVE RUTILE COMPANY DEPOSIT

In 1948 the U. S. Bureau of Mines completed its second drilling project at the Magnet Cove Rutile Company deposit. A total of 27 holes were core-drilled during this project, and of these, 9 were diamond drill holes and 18 were Baker core drill holes. The following (pp. 98-129) descriptive logs and assays of these 27 holes are the result of a cooperative effort of the U. S. Bureau of Mines and the Arkansas Division of Geology. The assays have been reprinted from a report published by the U. S. Bureau of Mines (Reed, 1949, Figs. 4 through 30) and the core descriptions are by Holbrook. The drill hole numbering system and the grid system established during the 1945 project were retained during the 1948 project. The coordinates of the individual holes refer to their location on Plate II.

HOLE NO. A-4

COORD.-N 200, W 600 — COLLAR ELEV.-395'
DRILL-BAKER CORE — TOTAL DEPTH-125'

CORE ANALYSIS

INTERVAL IN FEET	% TiO_2	% V_2O_5
0-7	2.80	
7-14	4.50	
14-21	3.75	
21-28	3.45	
28-35	1.80	
35-42	2.35	
42-45	2.25	
45-47	2.20	
47-52	3.05	
52-59	3.95	0.09
59-65	3.90	
65-70	3.40	
70-77	3.75	
77-84	3.95	
84-91	4.50	
91-98	4.80	
98-104	3.55	
104-110	3.20	

LITHOLOGY

INTERVAL IN FEET	Description
0-2	Brown clay with metamorphosed sedimentary fragments
2-14	Drab, gray-green, altered phonolite
14-17	Same, with minor rutile seams and much fine-grained pyrite
17-28	Altered phonolite harder than above - no visible rutile - quartzite inclusion at 27'
28-68	Softer altered phonolite - color varies from dark greenish-black to light gray-green - contains scattered feldspar carbonate with little rutile. One foot of feldspar-carbonate at 65' contains some medium-grained rutile
68-70	Feldspar-carbonate rock containing some fine-grained and some medium-grained rutile
70-77	Dark green to black altered phonolite
77-91	Altered phonolite - contains one foot of feldspar-carbonate with some fine-grained rutile at 79'-80'
91-98	Porphyritic dike rock
98-106	Altered phonolite
106-107	Unaltered phonolite

Continued

HOLE NO. A-4 (Cont'd)

CORE ANALYSIS			LITHOLOGY	
INTERVAL IN FEET	$\%TiO_2$	$\%V_2O_5$	INTERVAL IN FEET	Description
110-116	3.70		107-125	Altered phonolite
116-123	2.65	0.10		
123-125	2.05			

HOLE NO. B-1

COORD.-N 500, W 400 — COLLAR ELEV.-401'

DRILL-BAKER CORE — TOTAL DEPTH-20'

CORE ANALYSIS			LITHOLOGY	
INTERVAL IN FEET	$\%TiO_2$	$\%V_2O_5$	INTERVAL IN FEET	Description
NO SAMPLES			0-6	Drab, gray altered phonolite with scattered limonite stains
			6-10	Drab clay as above with large fragments of metamorphosed sediments and few coarse-grained nepheline syenite fragments
			10-13	Gray-green, iron-stained, soft, altered phonolite
			13-17	No core recovered
			17-20	Very fine-grained, calcareous, blue-black, igneous rock (unaltered phonolite)

HOLE NO. B-2

COORD.-N 200, W 400 — COLLAR ELEV.-392'

DRILL-BAKER CORE — TOTAL DEPTH-120'

CORE ANALYSIS			LITHOLOGY	
INTERVAL IN FEET	$\%TiO_2$	$\%V_2O_5$	INTERVAL IN FEET	Description
0-5	2.79	0.09	0-4.5	Brown clay containing fragments of slate, sandstone, quartzite and altered igneous rock - minor rutile grains
5-10	6.15	0.15	4.5-12	Slightly iron-stained, gray-green clay (altered porphyritic igneous rock)
10-15	3.40	0.11	12-17	Dark green, fine-grained altered phonolite containing hard sedimentary rock fragments, probably shale - also contains one foot of feldspar-carbonate with no rutile at 13'
15-20	3.96	0.13	17-20	Altered feldspar-carbonate rock with some rutile
20-26	1.39	0.09	20-27	Gray-green clay (altered phonolite) with sedimentary rock fragments including some buff, fine-grained sandstone

Continued

HOLE NO. B-2 (Cont'd)

CORE ANALYSIS			LITHOLOGY	
INTERVAL IN FEET	%TiO_2	%V_2O_5	INTERVAL IN FEET	Description
26-31	3.42	0.13	27-35.5	Altered phonolite - contains above fragments at 31'-33'
31-36	3.87	0.14		
36-41	2.12	0.08	35.5-39	Feldspar-carbonate rock with much very fine-grained rutile, the hard fragments are very fine-grained dolomite - some medium-grained rutile
			39-43	Dark green altered phonolite
41-46	2.68	0.12	43-46.5	Very fine-grained, buff, massive, altered porphyritic igneous rock
46-50	5.45	0.09	46.5-52.5	Altered and unaltered phonolite
50-55	4.65	0.12	52.5-55	Feldspar-carbonate rock with abundant fine-grained rutile
55-60	4.46	0.15	55-62	Altered phonolite
60-65	4.55	0.17		
65-70	2.36	0.06	62-70	Feldspar-carbonate rock with abundant fine-grained rutile
70-73	2.22	0.05	70-110	Mostly feldspar-carbonate rock with some gray-green clay - contains some fine-grained, much medium-grained, and some coarse-grained rutile
73-78	2.22	0.05-		
78-82	3.06	0.05-		
82-87	4.10	0.05-		
87-91	2.45	0.05-		
91-95	4.95	0.11		
95-100	3.30	0.11		
100-106	2.75	0.09		
106-110	2.75	0.09		
110-115	1.70	0.19	110-120	Very coarse-grained white dolomite with minor rutile
115-120	0.60	0.11		

HOLE NO. B-3

COORD.–N 00, W 400
DRILL–BAKER CORE

COLLAR ELEV.–385'
TOTAL DEPTH–161'

CORE ANALYSIS

INTERVAL IN FEET	$\%TiO_2$	$\%V_2O_5$
0-7	2.80	
7-14	2.55	
14-21	1.70	
21-27	0.90	
27-34	2.65	
34-41	1.85	
41-48	0.30	
48-55	1.05	
55-62	1.00	
62-69	0.70	0.07
69-73	0.65	
73-79	1.05	
79-84	0.40	
84-89	0.40	
89-96	Less than 0.05	
96-103	0.35	
103-110	0.95	

LITHOLOGY

INTERVAL IN FEET	Description
0-6	Dark brown surface clay
6-20	Brown to gray clay
20-23	Soft, friable, white feldspar-carbonate and pyrite
23-28	Coarse-grained barren calcite and pyrite
28-37	Blue-gray, soft, altered feldspar-carbonate with some fine-grained rutile (Sugary-textured albite-dolomite vein type)
37-55	Soft, gray feldspar-carbonate and clay with some fine-grained rutile - one foot of hard feldspar-carbonate with much coarse-grained rutile at 37'
55-57	Mainly fine-grained, granular pyrite with some carbonate
57-65	Mainly coarse-grained calcite fragments with pyrite and some fine-grained rutile
65-81	Same as above (rutile rare) some biotite
81-89	Soft, granular, feldspar-carbonate with some fine-grained rutile
89-96	Coarse-grained barren calcite with some altered biotite and pyrite
96-112	Calcite fragments with some pyrite, no rutile

Continued

HOLE NO. B-3 (Cont'd)

CORE ANALYSIS			LITHOLOGY	
INTERVAL IN FEET	% TiO_2	% V_2O_5	INTERVAL IN FEET	Description
110-117	Less than 0.05		112-117	Coarse-grained massive calcite
117-124	Less than 0.05		117-121	Same as 96-112
			121-124	Coarse-grained massive calcite
124-130	0.30	0.06	124-127	Calcite fragments
			127-130	Coarse-grained calcite with scattered silicates
130-137	0.20		130-141	Coarse-grained barren calcite
137-143	1.70			
			141-143	Altered phonolite
143-150	0.30		143-154	Coarse-grained barren calcite
150-154	Less than 0.05			
154-161	0.80	0.06	154-161	Coarse-grained calcite and silicates

HOLE NO. B-4

COORD.-N 400, W 400 — COLLAR ELEV.-397'

DRILL-BAKER CORE — TOTAL DEPTH-65'

CORE ANALYSIS				LITHOLOGY	
INTERVAL IN FEET	% TiO_2	% V_2O_5	%S	INTERVAL IN FEET	Description
0-6	2.06	0.09	0.01	0-23	Metamorphosed shale fragments and fine-grained nepheline syenite pebbles in clay
6-10	1.65	0.09	0.02		
10-17	1.60	0.10	0.11		
17-23	2.28	0.10	0.34		
23-29	3.13	0.10	1.60	23-38.5	Altered gray-green phonolite - contains large biotite flakes in places
29-35	3.54	0.09	1.08		
35-38.5	3.64	0.09	0.86		

Continued

HOLE NO. B-4 (Cont'd)

CORE ANALYSIS				LITHOLOGY	
INTERVAL IN FEET	% TiO_2	% V_2O_5	%S	INTERVAL IN FEET	Description
38.5-39.5	1.59	0.08	2.79	38.5-41.5	Granular feldspar-carbonate with some fine-grained rutile
39.5-47	4.30	0.09	2.09		
47-54	3.90	0.08	3.54	41.5-61	Light, gray-green altered phonolite
54-61	3.04	0.06	1.26		
61-65	2.80	0.06	3.71	61-65	Black, hard, fine-grained calcareous rock (unaltered phonolite)

HOLE NO. C-1

COORD.-N 200, W 200 COLLAR ELEV.-387'

DRILL-BAKER CORE TOTAL DEPTH-102'

CORE ANALYSIS			LITHOLOGY	
INTERVAL IN FEET	% TiO_2	% V_2O_5	INTERVAL IN FEET	Description
0-6	1.85	0.05	0-2	Surface clay containing sedimentary and altered igneous rock fragments
			2-6	Dark gray clay with large altered igneous rock fragments
6-12	2.40	0.05	6-12	Mostly metamorphosed sedimentary rock fragments (sandy shales) blue-gray to gray in color, some fine-grained, hard, dark gray clay
12-18	7.95	0.09	12-18	Feldspar-carbonate - abundant coarse-grained rutile (12'-14') some fine-grained rutile (14'-18')
18-22	3.40	0.06	18-27	Soft, gray-green to flesh-colored altered feldspar-carbonate containing some fine-grained rutile (18'-22') - Hard feldspar-carbonate fragments with some medium-grained rutile at 26'
22-28	2.35	0.05		
28-34	1.65	0.11	27-34	Soft, granular, feldspar-carbonate with some fine-grained rutile
34-40	1.95	0.13	34-37.5	Altered phonolite - feldspar-carbonate contact - some fine-grained rutile in feldspar-carbonate
			37.5-39	Altered phonolite
40-45	2.25	0.09	39-45	Granular feldspar-carbonate - no visible rutile
45-51	3.00	0.15	45-49	Altered phonolite with a small vein of hard brown, fine-grained feldspar-carbonate
51-57	3.15	0.09	49-60	Mainly altered phonolite with seams of micaceous feldspar-carbonate. The mica is on outside of seams, feldspar-carbonate in center - only a trace of rutile in the seams.
57-60	3.35	0.16		
60-64	3.80	0.15		

Continued

HOLE NO. C-1 (Cont'd)

CORE ANALYSIS			LITHOLOGY	
INTERVAL IN FEET	% TiO_2	% V_2O_5	INTERVAL IN FEET	Description
64-69	3.75	0.13	60-73	Altered phonolite with scattered, granular carbonate seams
69-73	3.50	0.10		
73-78	4.15	0.11	73-78	Probably altered phonolite
78-84	3.60	0.13	78-84	Dark green altered phonolite with one foot granular feldspar-carbonate at 81' - no rutile
84-88	3.55	0.18	84-91	Altered phonolite - contains one foot of feldspar-carbonate at 84' with some fine-grained rutile
88-91	4.25	0.10		
91-94	1.75	0.08	91-97	Feldspar-carbonate fragments - granular feldspar-carbonate - green clay - some fine-grained rutile
94-97	1.10	0.05		
97-100	3.20	0.10	97-100	Altered phonolite
100-102	1.05	0.13	100-102	Soft, granular feldspar-carbonate with some rutile

HOLE NO. C-2

COORD.-N 500, W 200
DRILL-BAKER CORE

COLLAR ELEV.-399'
TOTAL DEPTH-123'

CORE ANALYSIS			LITHOLOGY	
INTERVAL IN FEET	% TiO_2	% V_2O_5	INTERVAL IN FEET	Description
0-6	2.20	0.09	0-6	Brown oxidized surface clay
6-12	3.00	0.13	6-12	Brown and black mottled clay containing abundant altered novaculite fragments
12-18	3.85	0.15	12-18	Altered, fairly-hard phonolite
18-23	3.50	0.08	18-24	Hard, blue-black, fine-grained calcareous igneous rock with pyrite cubes (unaltered phonolite)
23-30	3.80	0.17	24-26.5	Light gray altered phonolite
			26.5-28	Altered igneous rock
30-36	3.65	0.07	28-41	Hard, blue-black calcareous rock (unaltered phonolite)
36-42	3.70	0.09		
42-48	4.40	0.10	41-48	Gray clay containing hard feldspar-carbonate fragments

Continued

HOLE NO. C-2 (Cont'd)

CORE ANALYSIS

INTERVAL IN FEET	% TiO_2	% V_2O_5
48-54	3.25	0.07
54-60	1.20	0.05
60-67	3.85	0.09
67-73	4.35	0.07
73-80	11.60	0.09
80-86	1.80	<0.05
86-91	2.70	<0.05
91-98	3.55	<0.05
98-104	5.75	0.07
104-111	4.45	0.09
111-118	6.95	0.05
118-123	2.65	0.06

LITHOLOGY

INTERVAL IN FEET	Description
48-54	Gray-green clay with hard feldspar-carbonate fragments - some fine-grained rutile
54-60	Hard, cream-colored, fine-grained feldspar-carbonate fragments containing some fine-grained rutile (microcline-calcite vein type)
60-65	Blue-green clay - soft, granular feldspar-carbonate with much fine-grained rutile
65-67	Fairly hard, gray-green altered phonolite
67-91	Hard, fine-grained feldspar-carbonate with much fine-grained rutile - carbonate is dolomite - large pyrite cubes common
91-98	Hard feldspar-carbonate with some fine-grained rutile
98-109	Hard feldspar-carbonate fragments containing much fine-grained rutile - much coarse-grained pyrite
109-111	Altered phonolite
111-117	Feldspar-carbonate with much fine-grained rutile
117-123	Altered phonolite (117'-118') - remainder is hard, black, very fine-grained igneous rock with disseminated fine-grained pyrite (unaltered phonolite)

HOLE NO. D-1

COORD.-N 500, E 00
DRILL-BAKER CORE

COLLAR ELEV.-394'
TOTAL DEPTH-157'

CORE ANALYSIS			LITHOLOGY	
INTERVAL IN FEET	%TiO_2	%V_2O_5	INTERVAL IN FEET	Description
0-7	5.85	0.13	0-7	Brown surface clay containing novaculite (?) fragments and coarse-grained rutile
7-11	3.65	0.08	7-11	Soft feldspar-carbonate rock containing fine-grained rutile and a little coarse-grained rutile
11-15	3.10	0.09	11-17	Clay and hard, dark, fine-grained feldspar-carbonate fragments low in rutile
15-21	3.80	0.10	17-21	Altered phonolite (?)
21-24	2.50	0.11	21-30	Hard, white, feldspar-carbonate fragments with some medium-grained rutile and much fine-grained pyrite
24-29	3.65	0.13		
29-35	3.65	0.13	30-36	Hard, very fine-grained feldspar-carbonate with very fine-grained rutile - some dark blue-green clay
35-42	3.60	0.11	36-49	Hard, dark fine-grained igneous rock fragments (unaltered phonolite) and dark clay
42-49	3.70	0.15		
49-56	5.35	0.18	49-51	Feldspar-carbonate rock - much medium-grained rutile
			51-57.5	Hard, dark, green-black very fine-grained igneous rock fragments (unaltered phonolite)
56-63	4.20	0.18	57.5-62	Brown, fine-grained, hard feldspar-carbonate fragments with some medium-grained rutile from 57.5' to 59' - remainder soft altered phonolite
63-69	3.35	0.15	62-66	Hard, gray, fine-grained feldspar-carbonate fragments with some fine-grained rutile
69-76	1.85	0.09	66-73	Soft, altered phonolite with two one-foot feldspar-carbonate veins - some fine-and medium-grained rutile at 71' to 72'
76-83	2.90	0.10	73-90	Hard feldspar-carbonate fragments in green clay - some fine-grained rutile 73' to 76' - much fine- and medium-grained rutile 76' to 83' - some fine-grained rutile 83' to 90'
83-90	2.60	0.09		
90-97	1.85	0.09	90-94	Hard feldspar-carbonate fragments containing some fine-grained rutile
			94-97	Alternating dark green clay and hard feldspar-carbonate fragments - little rutile
97-104	2.00	0.06	97-102	Hard feldspar-carbonate fragments containing some medium-grained rutile - a little coarse-grained rutile
104-111	2.25	0.07	102-107	Green clay (altered phonolite?) - contains one foot of hard feldspar-carbonate fragments with some medium-grained rutile at 104'
			107-112	Hard feldspar-carbonate fragments with some fine- and medium-grained rutile

Continued

HOLE NO. D-1 (Cont'd)

CORE ANALYSIS			LITHOLOGY	
INTERVAL IN FEET	% TiO_2	% V_2O_5	INTERVAL IN FEET	Description
111-117	2.40	0.09	112-116	Dark green altered phonolite - contains some feldspar-carbonate veins with medium-grained rutile
117-123	1.35	<0.05	116-125	Soft feldspar-carbonate with some coarse-grained and some medium-grained rutile
123-128	1.85	<0.05	125-128	Hard, fine-grained feldspar-carbonate fragments with some fine-grained rutile
128-133	1.75	<0.05	128-157	Soft, granular feldspar-carbonate with green clay streaks and some fine-and medium-grained rutile - one foot of dark green altered phonolite at 147'
133-140	2.25	0.05		
140-147	1.05	0.07		
147-152	4.25	0.16		
152-157	3.50	0.10		

HOLE NO. D-3

COORD.-N 00, E 00
DRILL-BAKER CORE

COLLAR ELEV.-380'
TOTAL DEPTH-115'

CORE ANALYSIS			LITHOLOGY	
INTERVAL IN FEET	% TiO_2	% V_2O_5	INTERVAL IN FEET	Description
0-7	2.95		0-2	Brown surface clay and soil
			2-7	Drab, brown-gray clay containing abundant fragments of hard metamorphosed sediments and soft light gray shale
7-14	1.15		7-10	Dark brown plastic clay with scattered manganese stains
			10-15	Drab gray gritty clay (altered phonolite) with vein of coarse-grained calcite (13'-15')
14-21	0.70		15-18	Altered phonolite with streaks of green feldspar-carbonate - no rutile
21-28	0.60		18-28	Coarse-grained barren calcite
28-34	NO SAMPLES		28-34	No core recovered
34-40	0.30		34-35	Soft, friable white feldspar-carbonate - some fine-grained rutile
40-47	Less than 0.05		35-48	Barren, coarse-grained calcite

Continued

HOLE NO. D-3 (Cont'd)

CORE ANALYSIS			LITHOLOGY	
INTERVAL IN FEET	% TiO_2	% V_2O_5	INTERVAL IN FEET	Description
47-54	0.10			
54-61	Less than 0.05		48-65	Small fragments of coarse-grained calcite with some pyrite - no rutile
61-68	0.95	0.13		
			65-68	Gray-green clay and coarse-grained calcite
68-74	1.00		68-75.5	Medium-grained, barren calcite and silicates - two feet of altered phonolite at 72'-74'
74-80	2.50			
			75.5-85	Altered phonolite with granular, white feldspar-carbonate seams
80-87	2.05			
			85-87	Soft, dark green, fine-grained igneous rock (altered phonolite)
87-94	0.40		87-91	Mixed altered phonolite and coarse-grained calcite fragments
94-101	4.50			
101-108	3.55		91-115	Altered phonolite - varies in color from buff to dark green - contains 3" lens of barren brown carbonate at 113'
108-115	3.75	0.16		

HOLE NO. E-7

COORD.-N 200, E 200
DRILL-DIAMOND DRILL

COLLAR ELEV.-387'
TOTAL DEPTH-188.5'

CORE ANALYSIS			SLUDGE		LITHOLOGY	
INTERVAL IN FEET	% TiO_2	% V_2O_5	% TiO_2	% V_2O_5	INTERVAL IN FEET	Description
0-7	3.80	0.13			0-7	Soil and limonite-stained clay
7-10	2.20	0.13			7-12	Limonite-stained clay
10-12.5	2.85	0.14				
12.5-15	4.40	0.13			12-15	Very fine-grained, sugary-textured feldspar-carbonate rock
15-20	3.10	0.16			15-19	Green altered phonolite
20-23.3	3.15	0.15	3.45	0.18	19-22	Feldspar-carbonate rock cut by coarse-grained albite-dolomite vein, rutile and pyrite

HOLE NO. E-7 (Cont'd)

CORE ANALYSIS			SLUDGE	
INTERVAL IN FEET	% TiO_2	% V_2O_5	% TiO_2	% V_2O_5
23.3-27	3.90	0.23		
27-30.5	3.60	0.18	3.15	0.20
30.5-32.5	4.30	0.23	3.50	0.16
32.5-34	4.20	0.11	2.75	0.20
34-36	4.25	0.19		
36-38	4.20	0.18	3.90	0.23
38-40	3.50	0.17		
40-43	3.90	0.16		
43-48	1.80	0.10	1.15	0.05-
48-49.8	3.20	0.05-	2.60	0.14
49.8-52	2.70	0.10		
52-53.5	1.65	0.11	3.05	0.13
53.5-57.5	3.10	0.18		
57.5-62	2.40	0.09	1.25	0.13
62-63.5	2.55	0.13	2.80	0.11
63.5-67	3.25	0.15		
67-69	2.35	0.14	2.55	0.14
69-73	4.45	0.16	4.75	0.17
73-76.5	1.35	0.18	2.15	0.10
76.5-81.5	2.00	0.10	3.20	0.08
81.5-84.2	2.00	0.13		
84.2-85.2	1.25	0.11		
85.2-87.2	3.75	0.13		
87.2-89.2	3.05	0.18		
89.2-93	2.40	0.10	2.55	0.05-
93-98	3.85	0.15		
98-100	3.55	0.11		
100-102.2	3.85	0.10		
102.2-104	3.00	0.14		
104-106.2	3.50	0.06		
106.2-108.2	3.50	0.10		
108.2-111.4	2.30	0.08	2.25	0.05-
111.4-113.4	2.25	0.10		
113.4-117	2.90	0.10		
117-119.2	4.25	0.22		
119.2-122.2	2.90	0.17		
122.2-125	2.15	0.13		
125-130	2.95	0.13	2.25	0.09
130-133	4.35	0.16	3.00	0.08
133-134	2.40	0.09		
134-138	1.05	0.13	1.40	0.14
138-141	2.90	0.18		
141-144	2.00	0.13		

LITHOLOGY	
INTERVAL IN FEET	Description
22-27	Green altered phonolite - 1' dike or inclusion
27-30	Feldspar-carbonate rock
30-32	Green altered phonolite
32-36	Hard, gray, fine-grained feldspar-carbonate cut by coarse-grained, altered, rutile-bearing dolomite veins
36-38	Same, with some interspersed altered phonolite
38-42	Altered phonolite
42-47	Mostly soft altered feldspar-carbonate rock
47-53	Hard feldspar-carbonate fragments containing both fine and coarse-grained rutile
53-67	Altered phonolite with 1.5 feet of hard feldspar-carbonate rock at 62 feet with medium-grained rutile - and flesh-colored dolomite veinlets - fragments are vuggy
67-69	Hard feldspar-carbonate with some fine-grained rutile
69-73	Altered dark green phonolite
73-82	Hard feldspar-carbonate fragments with some fine-grained rutile - much green clay, possibly altered feldspar-carbonate. One foot of green altered phonolite at 81'-82'
82-86	Soft feldspar-carbonate fragments - some very fine-grained rutile - streaks of molybdenite
86-90	Dark green porphyritic rock with 1 foot of hard feldspar-carbonate fragments at 87'
90-93	Hard, light brown feldspar-carbonate fragments with minor fine-grained rutile
93-102	Light green altered phonolite - some vein material with very fine-grained rutile scattered through 96'-100' interval
102-108	Altered feldspar-carbonate with fine- and medium-grained rutile - few masses of coarse white dolomite (104' to 105' is phonolite)
108-112	Brown, hard feldspar-carbonate fragments with some fine- and medium-grained rutile
112-119	Altered phonolite with scattered thin veins of hard feldspar-carbonate - minor rutile in the vein material
119-125	Dark green, soapy altered phonolite - hard feldspar-carbonate fragments containing fine-grained rutile from 122' to 124'
125-138	Feldspar-carbonate fragments containing some fine-grained rutile throughout - medium-grained rutile from 131' to 134' - thin (2"-3") seams of altered igneous rock are scattered through the vein material
138-143	Altered feldspar-carbonate veins and altered phonolite - feldspar-carbonate contains medium-grained rutile

HOLE NO. E-7 (Cont'd)

CORE ANALYSIS			SLUDGE		LITHOLOGY	
INTERVAL IN FEET	% TiO_2	% V_2O_5	% TiO_2	% V_2O_5	INTERVAL IN FEET	Description
144-145.5	1.40	0.09	2.35	0.10	143-146	Hard feldspar-carbonate fragments with some fine-grained rutile
145.5-152	1.20	0.07			146-148	Massive feldspar-carbonate with very fine- and coarse-grained rutile
					148-153	White, coarse-grained barren calcite - the feldspar-carbonate-calcite contact dips about 60° to axis of the core
152-154.8	0.55	0.05			153-155	Hard feldspar-carbonate fragments - rutile
154.8-159.6	1.35	0.10			155-158	Feldspar-carbonate - fine-grained rutile
					158-160	Altered igneous rock (phonolite?)
159.6-162.6	3.20	0.10			160-165	Altered, grey-green feldspar-carbonate rock with abundant fine-grained rutile
162.6-167	3.95	0.22			165-169	Altered, green-black, soft, fine-grained igneous rock (phonolite?)
167-168	5.30	0.22				
168-170.5	3.40	0.13			169-171	Green, altered feldspar-carbonate with much fine-and medium-grained rutile
170.5-177.5	1.40	0.06			171-176	Coarse-grained, barren calcite with scattered biotite and pyrite - some rutile
					176-179	Altered phonolite
177.5-178.9	4.00	0.17				
178.9-182	2.50	0.17			179-182	Altered feldspar-carbonate with rutile
					182-184	Coarse-grained calcite
182-188.5	1.50	0.09			184-188.5	Feldspar-carbonate with rutile - hard, fine-grained unaltered igneous (?) rock from 188' to 188.5'

HOLE NO. E-8

COORD.-N 00, E 200 COLLAR ELEV.-379'
DRILL-BAKER CORE TOTAL DEPTH-98'

CORE ANALYSIS			LITHOLOGY	
INTERVAL IN FEET	% TiO_2	% V_2O_5	INTERVAL IN FEET	Description
0-7	2.00	0.11	0-3	Brown clayey surface soil
7-14	0.95	0.11	3-13	Yellow-brown gritty clay
14-21	2.10	0.09	13-20	Green to blue-gray, granular feldspar-carbonate rock with some fine-grained rutile - patches of white, friable, sugary carbonate
			20-21	Altered phonolite
21-27	0.60	0.07	21-29	Soft, granular, feldspar-carbonate rock - patches of very fine-grained blue-gray mineral (molybdenite) (21'-22') and (27'-28') - a little very fine-grained rutile
27-34	0.75	0.08	29-30	Coarse-grained barren calcite
			30-34	Feldspar-carbonate containing some fine-grained rutile
34-39	1.35	0.11	34-37	Altered phonolite
			37-39	Feldspar-carbonate with some fine-grained rutile
39-46	0.80	0.07	39-48	Mainly barren calcite with scattered biotite grains, a clear acicular silicate, and pyrite

Continued

HOLE NO. E-8 (Cont'd)

CORE ANALYSIS			LITHOLOGY	
INTERVAL IN FEET	$\%TiO_2$	$\%V_2O_5$	INTERVAL IN FEET	Description
46-53	1.25	0.10	48-51	Feldspar-carbonate rock
53-60	2.60	0.20	51-60	Mainly altered phonolite with some thin feldspar veins, rutile rare
60-66	0.45	0.06	60-77	Barren, coarse-grained calcite with scattered silicates and pyrite
66-72	0.50	0.05		
72-78	1.55	0.07		
78-85	4.80	0.21	77-86	Greenish, soft altered phonolite varies from dark green to gray-green in color
85-92	3.50	0.18	86-92	Phonolite (as above) alternating with some feldspar-carbonate lenses at 90' the clay has a waxy surface
92-98	3.10	0.09	92-98	Interbedded, light gray-green clay and feldspar-carbonate lenses

HOLE NO. F-1

COORD.-N 600, E 400
DRILL-DIAMOND DRILL

COLLAR ELEV.-383'
TOTAL DEPTH-182.3'

CORE ANALYSIS			SLUDGE		LITHOLOGY	
INTERVAL IN FEET	$\%TiO_2$	$\%V_2O_5$	$\%TiO_2$	$\%V_2O_5$	INTERVAL IN FEET	Description
0-10.7	1.50				0-2	Soft feldspar-carbonate rock - some fine-grained rutile
			1.30	0.06		
					2-11	Hard, white, fine-grained feldspar-carbonate rock with coarse-grained pyrite - some medium and fine-grained rutile
			1.25			
			0.70			
10.7-19.4	1.10				11-20	Soft, friable, feldspar-carbonate with some fine-grained rutile - locally hard feldspar-carbonate fragments
					20-21	Mainly very coarse-grained, gray dolomite-rutile rare
19.4-27.9	2.10				21-39	Fine-grained, soft, friable feldspar-carbonate containing coarse dolomitic veins - also coarse-grained pyrite with some feldspar and medium-grained rutile
27.9-31	3.80					
			1.85			
31-44.6	1.25					

Continued

HOLE NO. F-1 (Cont'd)

CORE ANALYSIS

Interval in Feet	% TiO_2	% V_2O_5
44.6-56.9	2.35	
56.9-70.5	2.90	
70.5-80.6	3.50	
80.6-89.3	2.90	
89.3-95.6	16.20	0.15
95.6-103	12.60	
103-110.4	2.40	
110.4-120.1	1.55	
120.1-128.9	3.55	
128.9-139.2	3.35	
139.2-154.1	4.10	
154.1-167.2	2.00	

SLUDGE

% TiO_2	% V_2O_5
1.40	
1.05	
1.15	
0.85	
1.45	
1.45	0.07
3.10	
8.35	
0.40	
1.25	
1.65	
1.60	
0.90	
1.65	
1.00	

LITHOLOGY

Interval in Feet	Description
39-42	Dark brown, fine-grained carbonate rock fragments
42-61	Feldspar-carbonate same as 21'-39' with abundant coarse-grained dolomite and coarse-grained pyrite - much fine and medium-grained rutile - some coarse-grained rutile at 57'-61'
61-63	Very fine-grained, soft feldspar-carbonate with coarse pyrite cubes - much medium-grained rutile
63-72	Fine-grained, soft, feldspar-carbonate with coarse-grained dolomitic veins - some medium- and coarse-grained rutile - coarse-grained pyrite
72-92	Soft, gray-green feldspar-carbonate with some fine-grained rutile - some medium-grained and some very coarse-grained rutile and large well-formed pyrite cubes
92-96	Abundant rutile in hard feldspar-carbonate rock
96-98	Friable feldspar-carbonate - much fine-grained, some medium-grained rutile
98-100	Feldspar-carbonate - very abundant rutile
100-106	Soft, white to light green, friable, fine-grained feldspar-carbonate with much fine-grained rutile
106-122	Hard, fine-grained, flesh-colored feldspar-carbonate containing large pyrite cubes - some medium-grained rutile (typical microcline-calcite vein)
122-130	Hard feldspar-carbonate fragments including fine-grained brown carbonate rock, flesh-colored feldspar-carbonate and light gray feldspar-carbonate - all containing much medium-grained rutile
130-134	Hard, flesh-colored, porous feldspar-carbonate fragments containing much medium-grained rutile
134-137	Feldspar-carbonate - some fine-grained rutile
137-140	Hard feldspar-carbonate - some medium-grained rutile
140-142	Hard feldspar-carbonate - veinlets of medium-grained rutile
142-148	Flesh-colored, hard feldspar-carbonate fragments containing much medium-grained rutile in veinlets (microcline-calcite vein type)
148-151	No core recovered
151-156	Friable, fine-grained feldspar-carbonate rock containing some medium- and fine-grained rutile and coarse pyrite cubes
156-160	Hard, very fine-grained, flesh-colored feldspar-carbonate rock with some medium-grained rutile

Continued

HOLE NO. F-1 (Cont'd)

CORE ANALYSIS			SLUDGE		LITHOLOGY	
INTERVAL IN FEET	%TiO_2	%V_2O_5	%TiO_2	%V_2O_5	INTERVAL IN FEET	Description
			2.70	0.10	160-176	Alternating flesh-colored feldspar-carbonate rock with some medium-grained rutile and brown to gray barren carbonate rock - some of the barren rock may be igneous
167.2-176	1.40					
176-182.3	1.55				176-179	Hard, medium-grained, flesh-colored feldspar-carbonate rock with much medium-grained rutile
					179-182	Soft, clayey feldspar-carbonate with much fine- and medium-grained rutile

HOLE NO. G-2

COORD-N 200, E 600
DRILL-BAKER CORE

COLLAR ELEV.-387'
TOTAL DEPTH-118'

CORE ANALYSIS			LITHOLOGY	
INTERVAL IN FEET	%TiO_2	%V_2O_5	INTERVAL IN FEET	Description
0-5	4.27	0.09	0-15	Surface and oxidized material - mostly transported
5-11	5.00	0.12		
11-16	4.04	0.13		
			15-16	Green clay containing pebbles and some rutile
16-21	4.38	0.17	16-20	Green altered igneous rock, probably phonolite
			20-21	Fragments feldspar-carbonate, rutile and pyrite
21-25	4.82	0.11	21-22	Feldspar rock
			22-25	Green clay (altered phonolite)
25-31	3.86	0.08	25-27	Feldspar-carbonate rock with pyrite and rutile
			27-31	Green clay, probably altered phonolite
31-37	3.24	0.08	31-35	Green clay (altered phonolite)
			35-39	Feldspar-carbonate
37-41	2.48	0.09	39-40	Green clay
			40-41	Coarse-grained calcite with biotite, other silicates
41-47	2.95	0.10	41-43	Altered feldspar-carbonate matrix
			43-49	Green clay (altered phonolite)
47-53	3.59	0.07	49-51	Altered feldspar-carbonate
			51-53	Green clay matrix - some carbonate veinlets
53-56	1.73	0.05	53-61	Altered feldspar-carbonate
56-58	2.90	0.07		
58-64	3.68	0.08	61-64	Altered green igneous rock, probably phonolite with veins of light green clay (altered feldspar?)
64-70	2.30	0.05-	64-69	Light gray-green clay
			69-70	Dark green altered phonolite

Continued

HOLE NO. G-2 (Cont'd)

CORE ANALYSIS			LITHOLOGY	
INTERVAL IN FEET	$\%TiO_2$	$\%V_2O_5$	INTERVAL IN FEET	Description
70-76	2.55	0.05	70-75	Feldspar-carbonate with abundant rutile in light clay matrix
76-79	2.45	0.05-	75-79	Gray-green clay (altered feldspar-carbonate), no visible rutile - with calcite streaks, rutile and pyrite
79-85	3.54	0.08	79-94	Light clay matrix, rutile and pyrite, abundant carbonate fragments (feldspar carbonate rock)
85-87	1.46	0.05-		
87-93.5	1.43	0.05		
93.5-100	2.70	0.11	94-96	No core available
			96-100	Altered feldspar-carbonate rock, abundant rutile and pyrite
100-106	3.13	0.08	100-106	Light gray-green clay with one foot of abundant rutile and some pyrite at 105'
106-107	1.78	0.08	106-118	Mostly fairly hard feldspar-carbonate rock - some clay, abundant rutile and pyrite - some very fine-grained black streaks are probably molybdenite
107-108	2.33	0.08		
108-109	1.08	0.07		
109-110	1.15	0.05-		
110-115	2.23	0.05-		
115-118	2.30	0.05-		

HOLE NO. G-4

COORD.-N 600, E 600
DRILL-DIAMOND DRILL

COLLAR ELEV.-379'
TOTAL DEPTH-151'

CORE ANALYSIS				SLUDGE		LITHOLOGY	
INTERVAL IN FEET	$\%TiO_2$	$\%V_2O_5$	%S	$\%TiO_2$	$\%V_2O_5$	INTERVAL IN FEET	Description
0-11.8	2.44	0.08	4.56			0-3	Altered phonolite (gray)
				1.91	0.07	3-31	Hard, fine-grained feldspar-carbonate rock - much medium-grained rutile
				1.82	0.09		
11.8-25.7	3.36	0.06	5.63	1.91	0.09		
				2.40	0.09		
25.7-30.4	2.45	0.07	4.59				
30.4-34.5	3.45	0.09	1.50			31-41	Dark brown, unaltered phonolite with one 6" feldspar-carbonate-rutile vein
34.5-45.7	2.97	0.10	2.60				
				1.45	0.07		
				2.64	0.09		

Continued

HOLE NO. G-4 (Cont'd)

CORE ANALYSIS				SLUDGE		LITHOLOGY	
INTERVAL IN FEET	%TiO_2	%V_2O_5	%S	%TiO_2	%V_2O_5	INTERVAL IN FEET	Description
45.7-58.9	2.16	0.10	3.83	2.09	0.09		
				2.02	0.09		
				1.78	0.08	41-79	Fine-grained feldspar-carbonate rock with some fine and medium-grained rutile
58.9-68.1	2.74	0.10	3.95				
68.1-75.7	1.56	0.06	3.34				
75.7-81.1	2.12	0.07	4.21				
81.1-90.3	2.36	0.07	2.69			79-92	Mainly altered phonolite with some feldspar-carbonate veins containing some fine-and medium-grained rutile
90.3-101.7	1.82	0.07	2.54			92-100	Hard green to black altered and unaltered phonolite
101.7-110.5	2.80	0.07	2.20			100-105	Hard green to brown fine-grained unaltered phonolite mostly calcareous with a few feldspar-carbonate-rutile veins
110.5-117.9	2.44	0.07	2.71			105-116	Hard, feldspar-carbonate fragments with some fine and medium-grained rutile
117.9-123.5	2.93	0.06	2.33			116-119	Hard feldspar-carbonate rock with some medium-and fine-grained rutile
123.5-127.9	2.93	0.06	3.44			119-128	Hard fine-grained unaltered phonolite, dark brown to black in color, containing a few scattered rutile veins
127.9-135.8	2.37	0.07	2.41				
135.8-145	3.78	0.08	3.21			128-151	Hard feldspar-carbonate rock containing much fine- and medium-grained rutile
145-146.6	3.60	0.09	6.63				
146.6-151	1.85	0.08	1.48	2.06	0.09		

HOLE NO. H-9

COORD.-N 00, E 800 | COLLAR ELEV.-378'
DRILL-DIAMOND DRILL | TOTAL DEPTH-149.8

Core Analysis: Interval in Feet	Core Analysis: $\%TiO_2$	Core Analysis: $\%V_2O_5$	Sludge: $\%TiO_2$	Sludge: $\%V_2O_5$
0-4	3.05	0.05-		
4-10	6.05	0.09		
10-13	4.55	0.08		
13-15.5	4.35	0.13		
15.5-17.5	1.95	0.05-		
17.5-19.5	2.70	0.05		
19.5-21.5	4.33	0.08		
21.5-23.5	4.20	0.11		
23.5-25.5	4.90	0.14		
25.5-27.5	4.10	0.09	4.54	0.12
27.5-29.5	0.83	0.05-		
29.5-31.5	0.75	0.05-	1.91	0.05-
31.5-33.5	0.30	0.05-	0.52	0.05-
33.5-35.5	0.54	0.05-	0.60	0.05-
35.5-37.5	0.17	0.07		
37.5-39.5	0.25	0.05-	0.93	0.05-
39.5-41.5	0.23	0.05-		
41.5-43.5	0.30	0.05-		
43.5-45.5	1.13	0.05-		
45.5-47.5	1.75	0.06		
47.5-49.5	1.97	0.13		
49.5-51.5	1.16	0.05-		
51.5-53.5	2.00	0.07		
53.5-55.5	1.58	0.05	2.28	0.05-
55.5-61	2.04	0.07		
61-65	1.71	0.05		
65-70	1.93	0.05-		
70-75	1.00	0.09		
75-80	2.77	0.11		
80-85	3.43	0.05		
85-90	2.05	0.09		
90-94	0.65	0.05-		
94-99	1.20	0.05-		
99-103.8	0.34	0.05-		
103.8-108.5	0.53	0.05-		
108.5-113.3	0.53	0.05-		

Lithology: Interval in Feet	Description
0-8	Soil
8-15	Brown oxidized clay (surface weathering)
15-18	Weathered feldspar-carbonate rock
18-22	Feldspar-carbonate rock cut by albite-dolomite veins - fairly abundant rutile
22-26	Altered igneous rock (green clay with abundant fine-grained pyrite - probably altered phonolite)
26-29	Fine-grained feldspar-carbonate - fine-grained pyrite abundant - much rutile
29-36	Coarse-grained calcite cut by small veins of albite-dolomite and feldspar which carry abundant rutile
36-44	Coarse-grained calcite contains black biotite plates 1/2" wide - some white silicate (wollastonite?)
44-46	Altered phonolite cut by coarse-grained calcite and by altered veinlets containing rutile and pyrite
46-50	Green altered igneous rock containing abundant biotite (amphibole fourchite dike?)
50-54	Green coarse-grained igneous rock
54-57	Coarse-grained calcite containing pyrite veins and biotite
57-61	Green, fine-grained altered igneous rock containing abundant fine-grained biotite
61-70	Medium-grained, green altered igneous rock has large (1/8"-1/4") phenocrysts and abundant feldspar-carbonate veinlets - much rutile - coarse-grained calcite at 61'-62'
70-73	Coarse-grained calcite containing pyrite and biotite
73-80	Fine-grained green igneous rock, probably phonolite cut by coarse-grained calcite and small feldspar-carbonate veinlets containing rutile
80-88	Fine-grained altered green igneous rock, probably phonolite - few small veinlets containing pyrite and minor rutile
88-94	Coarse-grained calcite containing pyrite - no visible rutile
94-96	Fine-grained, altered green igneous rock probably phonolite
96-112	Coarse-grained calcite with pyrite, biotite and a little rutile - coarse-grained altered, green, igneous rock with large biotite phenocrysts (104'-105')

Continued

HOLE NO. H-9 (Cont'd)

CORE ANALYSIS			SLUDGE		LITHOLOGY	
INTERVAL IN FEET	%TiO_2	%V_2O_5	%TiO_2	%V_2O_5	INTERVAL IN FEET	Description
113.3-118.1	3.08	0.08			112-124	Altered green igneous rock (probably phonolite) cut by abundant veinlets carrying rutile and pyrite
118.1-123	4.01	0.09				
123-128	2.33	0.05			124-127	Same as above cut by calcite veins
128-132.8	2.93	0.05			127-130	Coarse-grained calcite containing biotite and pyrite - some fine-grained crystals possibly brookite
132.8-136.8	3.38	0.07			130-140	Fine-grained feldspar-carbonate with rutile and pyrite - altered green igneous rock at 131'-132' and 139'-140'
136.8-139.8	5.23	0.05				
139.8-143.8	3.44	0.07	3.52	0.05-	140-144	Fine-grained feldspar-carbonate - some pyrite, rutile, and brookite veinlets
143.8-147	2.71	0.08			144-149	Coarse-grained igneous rock, large feldspathoid phenocrysts
147-149.8	2.14	0.05			149-150	Feldspar-carbonate - pyrite and rutile

HOLE NO. I-1

COORD.- N 200, E 1000 — COLLAR ELEV.-390'

DRILL-BAKER CORE — TOTAL DEPTH - 101'

CORE ANALYSIS			LITHOLOGY	
INTERVAL IN FEET	%TiO_2	%V_2O_5	INTERVAL IN FEET	Description
0-6	1.10	0.05-	0-12	Limonite-stained clay - some stained pyrite and white clay nodules - no noticeable rutile
6-12	0.98	0.05-		
12-20	0.80	0.05-	12-20	Limonite-stained and clayey feldspar-carbonate rock, pyrite and rutile
20-26	0.88	0.07-	20-26	Feldspar-carbonate rock, clay in spots - pyrite veinlets, some rutile
26-32	0.95	0.05-	26-32	Feldspar-carbonate rock - some green clay along contact with igneous rock
32-36	3.50	0.08	32-34	Green altered igneous rock probably phonolite
			34-36	Feldspar-carbonate rock
36-40	2.35	0.05-	36-40	Feldspar-carbonate rock with some coarse-grained calcite, pyrite and rutile
40-44	2.90	0.05-	40-44	Feldspar-carbonate rock - streaks of this rock are now clay but there are fresher sections
44-50	3.73	0.05-	44-50	Feldspar-carbonate rock with one foot of green clay in middle

Continued

HOLE NO. I-1 (Cont'd)

CORE ANALYSIS

INTERVAL IN FEET	%TiO_2	%V_2O_5
50-55	3.48	0.05-
55-57	2.90	0.05-
57-60	0.85	0.05-
60-65	0.95	0.05-
65-67	0.65	0.05-
67-72	1.15	0.05-
72-76	2.74	0.10
76-78	2.33	0.05
78-81.1	4.37	0.12
81.1-86	2.64	0.07
86-91	1.13	0.07
91-96	3.23	0.08
96-101	3.84	0.09

LITHOLOGY

INTERVAL IN FEET	Description
50-54	Green clay - probably altered phonolite
54-74	Feldspar-carbonate rock - contains some green clay (57'-60')
74-76	Green clay probably altered phonolite
76-80	Feldspar-carbonate rock - some clay alteration
80-82	Green clay
82-92	Feldspar-carbonate rock cut by coarse-grained calcite - abundant rutile
92-101	Mixed green clay and feldspar-carbonate rock - apparently along a contact

HOLE NO. J-1

COORD.-N 1085, E 1200
DRILL-DIAMOND DRILL

COLLAR ELEV.-399'
TOTAL DEPTH-134.9'

CORE ANALYSIS				SLUDGE		
INTERVAL IN FEET	%TiO_2	%V_2O_5	%S	%TiO_2	%V_2O_5	%S
0-4.7	3.80	0.08	2.47	4.06	0.08	0.71
4.7-6.9	3.14	0.08	1.34	5.56	0.09	2.43
6.9-11.9	2.58	0.09	1.62	3.40	0.07	0.85
11.9-16.3				2.92	0.07	1.79
16.3-19.3	3.82	0.09	3.21			
19.3-22.7	2.83	0.08	2.55	3.30	0.09	2.02
22.7-27.2	3.11	0.08	0.76	2.15	0.09	4.70
27.2-30.7	2.43	0.09	3.39	4.14	0.09	4.94
30.7-32.5				4.38	0.09	3.47
32.5-35.9	3.14	0.09	1.72			
35.9-37.9	2.02	0.08	2.34			
37.9-40.5	2.90	0.09	4.59	3.25	0.09	2.48
40.5-45.7	3.45	0.08	3.62			
45.7-49.6	3.28	0.08	2.85	4.35	0.09	2.66

LITHOLOGY

INTERVAL IN FEET	Description
4-5	White, hard, very fine-grained feldspar-carbonate with some medium-grained rutile
5-7	Biotitic, light gray-green igneous rock
7-19	Soft green altered phonolite containing a few thin veinlets of feldspar-carbonate and rutile
19-26	Mixed altered phonolite and hard feldspar-carbonate fragments - some coarse-grained rutile 19'-20'
26-33	Dark brown, hard, vuggy feldspar-carbonate rock containing seams and nests of medium-grained rutile and large, well-formed pyrite cubes
33-36	Altered phonolite (?)
36-48	Same as 26'-33' contains some medium-grained rutile

Continued

HOLE NO. J-1 (Cont'd)

CORE ANALYSIS				SLUDGE			LITHOLOGY	
INTERVAL IN FEET	$\%TiO_2$	$\%V_2O_5$	%S	$\%TiO_2$	$\%V_2O_5$	%S	INTERVAL IN FEET	Description
49.6-53	3.50	0.08	1.80				48-64	Very fine-grained altered igneous rock - black with green-blue streaks (phonolite?)
53-57	3.50	0.09	2.49					
57-63.4	3.76	0.09	1.91					
63.4-66.4	2.82	0.09	2.88				64-73	Alternating brown, unaltered phonolite and vuggy feldspar-carbonate rock - rutile prominent 63.9'-64.5'
66.4-67.5	2.55	0.09	2.73					
67.5-69.5	2.12	0.08	3.92	3.89	0.09	3.67		
69.5-73.9	3.30	0.09	2.08	3.30	0.07	1.95		
73.9-75	3.02	0.10	3.54				73-79	Feldspar-carbonate rock fragments - some fine, medium- and coarse-grained rutile
75-80.3	3.72	0.10	3.08					
80.3-83.8	4.60	0.09	1.93				79-110	Dark green to black very fine-grained compact phonolite with scattered feldspar-carbonate rutile veins - also contains lenses of brown fine-grained, hard rock
83.8-91.5	4.50	0.09	2.97					
91.5-94.5	4.30	0.07	5.23					
94.5-100.4	4.10	0.10	3.38					
100.4-104.6	4.26	0.10	2.09					
104.6-108.6	4.61	0.12	2.91					
108.6-112.2	4.19	0.13	4.39					
112.2-114.2	3.28	0.12	7.86				110-119	Brown, vuggy feldspar-carbonate with some fine- and medium-grained rutile
114.2-115.6	2.04	0.12	9.39					
115.6-117.2	3.33	0.11	7.87	2.50	0.08	3.05		
117.2-121	2.97	0.12	5.55				119-121	Mixed, dark green phonolite and brown vesicular feldspar-carbonate with some medium-grained rutile
121-122.5	4.00	0.10	5.91				121-124	Brown, porous, rutile-bearing rock (feldspar-carbonate)
122.5-123.8	2.44	0.10	5.29					
123.8-126	4.08	0.15	3.42					
126-129.4	3.92	0.11	3.33				124-135	Mainly very fine-grained dark green altered phonolite with some scattered brown feldspar-carbonate
129.4-131.7	2.67	0.09	7.73					
131.7-134.9	4.18	0.09	2.70					

HOLE NO. J-2

COORD.-N 700, E 1200
DRILL-BAKER CORE

COLLAR ELEV.-385'
TOTAL DEPTH-139.7'

CORE ANALYSIS

INTERVAL IN FEET	%TiO_2	%V_2O_5	%S
0-3			
3-11.5	3.68	0.08	2.90
11.5-18.1	3.33	0.10	4.11
18.1-24.9	3.60	0.10	2.06
24.9-31.8	3.90	0.09	3.09
31.8-39.4	2.38	0.07	0.94
39.4-44.3	2.02	0.07	0.71
44.3-49.4	1.60	0.07	0.74
49.4-57.6	1.22	0.08	0.78
57.6-64.4	3.16	0.08	1.83
64.4-68.5	3.06	0.09	3.82
68.5-75.4	2.65	0.08	3.18
75.4-82.4	2.30	0.07	3.39
82.4-91.1	2.30	0.08	3.16
91.1-103.4	2.34	0.08	1.82
103.4-112.8	1.15	0.09	3.87

LITHOLOGY

INTERVAL IN FEET	Description
0-14	Gray, hard, fine-grained calcareous rock (unaltered phonolite) containing thin seams of dolomite and medium-grained rutile
14-16	Dark brown, fine-grained calcareous rock (unaltered phonolite) with feldspar-carbonate-pyrite veinlets
16-18	Brecciated phonolite somewhat altered
18-22	Dark brown, fine-grained, calcareous rock (unaltered phonolite)
22-48	Friable, white, feldspar-carbonate rock containing streaks of dark green soapy clay - large pyrite cubes common - much medium- and fine-grained rutile
48-55	Coarse-grained, massive, brownish calcite with patches of dark green soapy clay - a few grains of rutile
55-58	Green clay and feldspar-carbonate rock with much fine- and medium-grained rutile
58-63	Dark brown, hard, fine-grained unaltered phonolite - cut by veins of coarse-grained calcite.
63-66	Brecciated, brown rock cemented with feldspar-carbonate - some medium-grained rutile
66-69	Friable feldspar-carbonate with much medium-grained rutile
69-77	Hard, fine-grained feldspar-carbonate with some fine-grained rutile
77-88	Fine-grained feldspar-carbonate rock with some medium-grained rutile in veinlets - color of feldspar-carbonate varies from light green to white
88-94	Gray, fine-grained igneous rock (unaltered phonolite) containing some fine-grained and some medium-grained rutile
94-98	Feldspar-carbonate with some medium-grained rutile
98-104	Gray, fine-grained, hard igneous rock, non-calcareous with a few thin scattered seams of rutile
104-109	Mainly soft, green, altered igneous rock (phonolite) with a few scattered rutile grains
109-112	Feldspar-carbonate with much medium-grained rutile

Continued

HOLE NO. J-2 (Cont'd)

CORE ANALYSIS				LITHOLOGY	
INTERVAL IN FEET	$\%TiO_2$	$\%V_2O_5$	%S	INTERVAL IN FEET	Description
112.8-123.9	2.72	0.09	2.26	112-121	Fine-grained feldspar-carbonate rock with some fine-grained rutile
				121-127	Mainly soft, gray, friable, altered igneous rock (phonolite?)
123.9-132.3	2.04	0.09	1.63	127-133	Feldspar-carbonate with some medium- and fine-grained rutile
132.3-139.7	3.14	0.09	2.48	133-136	Buff plastic clay
				136-139.7	Gray, hard feldspar-carbonate with some medium- and fine-grained rutile

HOLE NO. J-3

COORD.-N 400, E 1200
DRILL-BAKER CORE

COLLAR ELEV.-390'
TOTAL DEPTH-109'

CORE ANALYSIS				LITHOLOGY	
INTERVAL IN FEET	$\%TiO_2$	$\%V_2O_5$	%S	INTERVAL IN FEET	Description
0-7	3.74	0.11	0.96	0-9	Dark brown surface clay containing some medium-grained rutile
7-14	2.78	0.11	1.13	9-14	Heavily iron-stained, soft gray, altered igneous rock
14-21	0.64	0.07	2.54	14-42	Soft, gray-green, granular feldspar-carbonate rock with a little fine-grained rutile (some iron staining 14' to 19')
21-27	0.69	0.07	2.13		
27-33	0.62	0.09	3.29		
33-39	1.00	0.08	2.82		
39-46	2.30	0.08	2.52	42-57	Dark, fine-grained, hard calcareous rock (unaltered phonolite) containing small (6") patches of soft and hard feldspar-carbonate rock - some feldspar-carbonate and medium-grained rutile (46'-48')
46-50	2.30	0.09	4.43		
50-57	2.34	0.08	1.93		
57-63	0.20	0.08	0.75	57-68	Coarse-grained barren calcite - some medium-grained rutile (66'-68')

Continued

HOLE NO. J-3 (Cont'd)

CORE ANALYSIS				LITHOLOGY	
INTERVAL IN FEET	%TiO_2	%V_2O_5	%S	INTERVAL IN FEET	Description
63-68	0.95	0.04	1.16		
68-75	3.02	0.03	1.36	68-73	Hard feldspar-carbonate rock with much medium-grained rutile
75-82	2.62	0.08	1.96	73-84	Hard, brown, fine-grained calcareous rock (unaltered phonolite)
82-89	2.59	0.07	1.99	84-90	Dark, brown-gray, friable feldspar-carbonate rock with no visible rutile
				90-92	Soft, granular, dark green altered phonolite
89-96	3.72	0.10	1.67		
96-103	1.82	0.09	7.04	92-103	Dark gray, granular, soft feldspar-carbonate-some fine-grained rutile
103-109	3.04	0.09	1.32	103-109	Dark brown, fine-grained hard calcareous rock (unaltered phonolite)

HOLE NO. K-5

COORD.-N 200, E 1400 COLLAR ELEV.-393'
DRILL-DIAMOND DRILL TOTAL DEPTH-132.5'

CORE ANALYSIS			LITHOLOGY	
INTERVAL IN FEET	%TiO_2	%V_2O_5	INTERVAL IN FEET	Description
0-5	2.45	0.11	0-2	Brown residual surface clay
			2-5	Heavily iron-stained gray-green clay (altered phonolite)
5-8	1.20	<0.05	5-7	Slightly iron-stained gray clay (altered phonolite)
8-11	1.45	0.09		
11-14	3.90	0.22	7-19	Heavily iron-stained gray-green clay (altered phonolite)
14-17	4.75	0.26		
17-20	3.40	0.25		
20-24	2.65	0.25	19-24	Dark green, altered igneous rock probably phonolite
24-29	2.40	0.15		
29-34	1.75	0.10	24-39	Very fine-grained, greenish-black, hard unaltered igneous rock (unaltered phonolite) containing scattered thin calcite veinlets
34-38.5	2.00	0.13		
38.5-48.5	3.00	0.09	39-50	Very fine-grained, black, unaltered igneous rock-contains 6" feldspar-carbonate-rutile vein (45'-45'6")

HOLE NO. K-5 (Cont'd)

<table>
<tr><th colspan="3">CORE ANALYSIS</th><th colspan="2">LITHOLOGY</th></tr>
<tr><th>INTERVAL IN FEET</th><th>%TiO_2</th><th>%V_2O_5</th><th>INTERVAL IN FEET</th><th>Description</th></tr>
<tr><td>48.5-57.5</td><td>0.90</td><td>0.06</td><td rowspan="3">50-74</td><td rowspan="3">Coarse-grained, calcite with traces of very fine-grained rutile - some biotite and pyrite patches</td></tr>
<tr><td>57.5-67</td><td>0.25</td><td>0.07</td></tr>
<tr><td>67-76</td><td>0.25</td><td>0.07</td></tr>
<tr><td>76-79.7</td><td>3.35</td><td>0.11</td><td rowspan="2">74-82</td><td rowspan="2">Altered feldspar-carbonate rock containing some very fine-grained rutile - cut by very fine-grained black dike at 76 feet</td></tr>
<tr><td>79.7-82.2</td><td>1.80</td><td>0.05</td></tr>
<tr><td rowspan="2">82.2-92.5</td><td rowspan="2">2.75</td><td rowspan="2">0.06</td><td>82-88</td><td>Dark, hard unaltered phonolite</td></tr>
<tr><td>88-92</td><td>Gray, fine-grained, hard feldspar-carbonate containing some very fine-grained rutile</td></tr>
<tr><td>92.5-102.5</td><td>2.55</td><td>0.10</td><td rowspan="4">92-132.5</td><td rowspan="4">Mainly black, fine-grained unaltered phonolite cut by scattered feldspar-carbonate-rutile veinlets</td></tr>
<tr><td>102.5-112.5</td><td>3.25</td><td>0.05</td></tr>
<tr><td>112.5-122.5</td><td>2.55</td><td>0.08</td></tr>
<tr><td>122.5-132.5</td><td>3.50</td><td>0.09</td></tr>
</table>

HOLE NO. L-2

COORD.-N 530, E 1600 COLLAR ELEV.-378'
DRILL-BAKER CORE TOTAL DEPTH-60'

<table>
<tr><th colspan="4">CORE ANALYSIS</th><th colspan="2">LITHOLOGY</th></tr>
<tr><th>INTERVAL IN FEET</th><th>%TiO_2</th><th>%V_2O_5</th><th>%S</th><th>INTERVAL IN FEET</th><th>Description</th></tr>
<tr><td>0-7</td><td>2.84</td><td>0.09</td><td>0.40</td><td>0-7</td><td>Dark brown surface clay containing a few pebbles of metamorphosed sediments</td></tr>
</table>

Continued

HOLE NO. L-2 (Cont'd)

CORE ANALYSIS

INTERVAL IN FEET	%TiO_2	%V_2O_5	%S
7-14	3.30	0.09	1.10
14-21	3.08	0.08	3.18
21-28	3.56	0.07	2.97
28-35	2.96	0.08	3.12
35-42	3.89	0.08	2.06
42-49	4.08	0.09	1.59
49-56	3.89	0.09	1.38
56-60	3.86	0.09	1.80

LITHOLOGY

INTERVAL IN FEET	Description
7-10	Iron-stained, gray-green feldspar-carbonate
10-28	Gray-green, granular feldspar-carbonate containing some fine-grained and medium-grained rutile
28-40	Dark gray, fine-grained hard unaltered phonolite with a few 6" feldspar-carbonate lenses
40-47	Soft, green feldspar-carbonate with some fine-grained rutile
47-54	Hard, gray, fine-grained, non-calcareous igneous rock (unaltered phonolite)
54-60	Dark brown, fine-grained, hard, calcareous igneous rock (unaltered phonolite)

HOLE NO. M-5

COORD.-N 1000, E 1800 COLLAR ELEV.-391'

DRILL-BAKER CORE TOTAL DEPTH-121'

CORE ANALYSIS

INTERVAL IN FEET	%TiO_2	%V_2O_5	%S
0-7	0.73	0.08	0.55
7-14	0.34	0.07	4.33
14-21	1.12	0.08	7.46
21-28	1.46	0.08	10.43
28-34	1.78	0.08	6.44
34-41	1.37	0.08	6.18

LITHOLOGY

INTERVAL IN FEET	Description
0-3	Brown surface clay containing pebbles of novaculite and nepheline syenite (fine-grained type)
3-8	Iron-stained, soft feldspar-carbonate
8-11	Soft, granular, white feldspar-carbonate with some fine-grained rutile
11-13	Feldspar-carbonate - some fine-grained rutile
13-14	Altered phonolite
14-54	Soft, granular, gray-green to white feldspar-carbonate, some fine-grained and medium-grained rutile - locally contains hard, white feldspar-carbonate-rutile fragments

Continued

HOLE NO. M-5 (Cont'd)

CORE ANALYSIS				LITHOLOGY	
INTERVAL IN FEET	$\%TiO_2$	$\%V_2O_5$	%S	INTERVAL IN FEET	Description
41-48	1.38	0.08	12.53		
48-54	0.87	0.09	10.77		
54-61	0.49	0.08	11.59	54-61	Gray-green, granular feldspar-carbonate - little rutile
61-68	0.66	0.08	5.96	61-66	Gray-green, soft feldspar-carbonate with some fine-grained rutile
68-75	1.80	0.07	6.13	66-74	Hard, gray-to-brown, fine-grained feldspar-carbonate with some fine-grained rutile
75-82	0.56	0.07	6.68	74-82	Gray-green, granular, soft feldspar-carbonate with a little fine-grained rutile
82-86	1.65	0.07	9.20	82-85	Hard, very fine-grained, cream-colored feldspar-carbonate fragments with a little fine-grained rutile
				85-86	Dark brown unaltered phonolite
86-93	1.97	0.09	6.07	86-100	Brownish-gray to cream, hard, vuggy feldspar-carbonate rock containing much medium-grained rutile
93-98	1.68	0.08	8.51		
98-104	1.39	0.08	4.09	100-101	Dark brown, hard, fine-grained calcareous rock (unaltered phonolite)
				101-103	Same as 86-100
104-111	0.86	0.09	2.04	103-108	Hard, fine-grained green to dark brown igneous rock (unaltered phonolite)
111-118	0.58	0.08	3.02	108-115	Soft, granular feldspar-carbonate rock containing some fine-grained rutile
				115-117	Hard, fine-grained, buff feldspar-carbonate with some fine-grained rutile
118-121	1.05	0.09	0.53	117-121	Black, calcareous igneous rock - coarser-grained than the phonolite - may be nepheline syenite

HOLE NO. N-1

COORD.-N 1400, E 2100
DRILL-DIAMOND DRILL

COLLAR ELEV.-418'
TOTAL DEPTH-96.5'

CORE ANALYSIS			SLU.	LITHOLOGY	
INTERVAL IN FEET	$\%TiO_2$	$\%V_2O_5$	$\%TiO_2$	INTERVAL IN FEET	Description
0-2.2	0.70			0-3	Brick red, residual surface clay
2.2-10.5	0.60			3-10	Mixed red and buff clay

Continued

HOLE NO. N-1 (Cont'd)

CORE ANALYSIS			SLU.	LITHOLOGY	
INTERVAL IN FEET	$\%TiO_2$	$\%V_2O_5$	$\%TiO_2$	INTERVAL IN FEET	Description
10.5-15.5	3.35			10-25	Soft, granular light green clay with abundant limonite stains (17.5'-20.5') - probably albite-perthite-carbonate vein type that has been altered
15.5-20.5	4.80				
20.5-25	4.10				
25-28.6	4.25			25-28	Coarse-grained granular rock, altered - similar to above but gray in color - heavy limonite staining from 26.6' to 28'
28.6-33.6	1.70			28-44	Black, hard, fine-grained unaltered dike rock probably monchiquite - in places porphyritic
33.6-38.6	1.00				
38.6-43.6	1.85				
43.6-47.2	0.75	CORE 0.07	1.65	44-48	Friable, altered feldspar rock - feldspar coarse-grained (albite-perthite-carbonate vein type)
47.2-50.2	0.70		2.10	48-50	Altered coarse-grained igneous rock (nepheline syenite - fine-grained type of Williams)
50.2-53.3	1.50		1.45	50-53	Albite-perthite-carbonate vein
53.3-57.4	2.05	SLUDGE 0.08	0.95	53-57	Altered nepheline syenite (fine-grained type)
57.4-60.2	0.90		0.90	57-60	Friable mixture of feldspar particles, pyrite fragments and gray clay - pyrite predominates
60.2-65.2	1.45		1.00	60-70	No core recovered
65.2-69.7			1.90		
69.7-74.7			0.90	70-96	Light to dark green, soft, altered nepheline syenite containing scattered, hard feldspar-carbonate veins 2 to 3 inches wide containing some fine-grained rutile
74.7-78			1.20		
78-79.7			0.80		
79.7-82.9			1.05		
82.9-85.1					
85.1-88.1			1.20		
88.1-96.5	1.65				

HOLE NO. N-2

COORD.-N 600, E 2040
DRILL-BAKER CORE

COLLAR ELEV.-378'
TOTAL DEPTH-47.5'

CORE ANALYSIS

INTERVAL IN FEET	$\%TiO_2$	$\%V_2O_5$	%S
0-7	3.08	0.09	0.24
7-13	4.66	0.08	1.21
13-18	2.86	0.08	1.33
18-25	2.72	0.08	7.64
25-32	2.06	0.09	22.97
32-39	3.06	0.09	4.08
39-45	2.93	0.08	2.44
45-47.5	3.04	0.09	1.35

LITHOLOGY

INTERVAL IN FEET	Description
0-8	Dark gray clay, heavily iron-stained
8-12	Soft, light gray, altered phonolite
12-18	Black, dense, hard, fine-grained calcareous rock with scattered pyrite crystals (unaltered phonolite)
18-25	Soft, granular feldspar-carbonate rock with much pyrite - rutile if present is very fine-grained
25-28	Mainly coarse-grained pyrite with some coarse-grained dolomite
28-31	Soft feldspar-carbonate rock with numerous thin seams of fine-grained pyrite - some medium-grained rutile
31-47	Dark, massive, hard unaltered phonolite containing a few scattered, hard feldspar-carbonate veins with medium and coarse-grained rutile

HOLE NO. O-2

COORD.-N 800, E 2300
DRILL-DIAMOND DRILL

COLLAR ELEV.-377'
TOTAL DEPTH-91'

CORE ANALYSIS			SLUDGE	
INTERVAL IN FEET	$\%TiO_2$	$\%V_2O_5$	$\%TiO_2$	$\%V_2O_5$
0-4.5	2.68	0.05-		
4.5-9.5	2.37	0.05	4.60	0.12
9.5-11.7	3.26	0.19	4.55	0.13
11.7-12.7	2.94	0.10	5.57	0.12
12.7-17.3	2.87	0.11		
17.3-22.1	2.90	0.05		
22.1-27.1	2.90	0.11		
27.1-29.1	5.35	0.07		
29.1-34.1	2.67	0.05-		

LITHOLOGY

INTERVAL IN FEET	Description
0-12	Hard feldspar-carbonate-pyrite rock with rutile (microcline-calcite vein type)
12-24	Hard, brown, fine-grained rock with much pyrite, probably unaltered phonolite with abundant sugary-grained feldspar-carbonate veinlets (rutile bearing)
24-33	White, hard calcite-feldspar rock with much rutile both fine-grained and coarse-grained and much pyrite

Continued

HOLE NO. O-2 (Cont'd)

CORE ANALYSIS			SLUDGE	
INTERVAL IN FEET	$\%TiO_2$	$\%V_2O_5$	$\%TiO_2$	$\%V_2O_5$
34.1-39.1	2.34	0.05		
39.1-44.1	4.25	0.05		
44.1-49.1	3.55	0.05		
49.1-52.3	3.25	0.15		
52.3-57.7	2.63	0.16		
57.7-63	4.20	0.12		
63-65	3.55	0.10		
65-70	3.04	0.09		
70-75	3.27	0.21		
75-80	3.02	0.20		
80-81	3.60	0.13		
81-86	3.47	0.09		
86-91	3.87	0.13		

LITHOLOGY	
INTERVAL IN FEET	Description
33-37	Brown-gray, fine-grained feldspar-carbonate rock with coarse calcite veins- much rutile
37-57	Medium-grained, white, hard calcite-pyrite rutile-microcline rock - rutile abundant and fine-grained
57-62	Brown-gray, fine-grained feldspar-carbonate rock - rutile bearing
62-64	Dark brown, unaltered igneous rock with calcite veinlets (probably phonolite)
64-70	Hard, fine-grained, gray feldspar-carbonate rock with much rutile associated with the coarse calcite
70-74	Hard, unaltered phonolite with a few barren coarse calcite veins
74-77	Brown feldspar-dolomite, containing coarse-grained rutile patches
77-81	Very fine-grained unaltered phonolite containing rutile-calcite veinlets - rutile is medium-grained
81-86	Feldspar-calcite rock - abundant fine-grained rutile - much pyrite
86-88	Dolomite-feldspar rock - much very fine-grained rutile
88-91	Same as 81'-86' interval

HOLE NO. O-3

COORD.-N 1200, E 2300 COLLAR ELEV.-395'
DRILL-DIAMOND DRILL TOTAL DEPTH-100.6

CORE ANALYSIS			SLUDGE	
INTERVAL IN FEET	$\%TiO_2$	$\%V_2O_5$	$\%TiO_2$	$\%V_2O_5$
0-2	1.90	0.10		
2-6.5	1.40	0.15		
6.5-8.7	0.65	0.09		
8.7-9.7	0.70	0.05		
9.7-14	0.55	0.12	0.35	0.05
14-18.6	0.55	0.09	0.60	0.06
18.6-20.2	0.50	0.11		
20.2-23	0.70	0.11		
23-26.5	0.70	0.11	0.55	0.08
26.5-28.5	0.85	0.10		
28.5-31.8	0.75	0.10		

LITHOLOGY	
INTERVAL IN FEET	Description
0-4	Red-brown, gritty clay
4-10	Mostly white novaculite fragments - some clay and altered igneous fragments
10-20	Coarse-grained rock composed mainly of feldspar - minor amounts of pyrite trace of rutile (typical albite-perthite-carbonate vein)
20-32	Dark green, mottled, medium-hard altered coarse-grained igneous rock (probably nepheline syenite - Diamond Jo type) - layer of albite-perthite-carbonate rock at 30'-31'

Continued

HOLE NO. O-3 (Cont'd)

Core Analysis: Interval in Feet	Core Analysis: $\%TiO_2$	Core Analysis: $\%V_2O_5$	Sludge: $\%TiO_2$	Sludge: $\%V_2O_5$
31.8-33.3	0.70	0.09		
33.3-34.3	0.70	0.09		
34.3-35.2	0.95	0.09	0.55	0.08
35.2-36.6	0.80	0.09		
36.6-37.7	1.90	0.09		
37.7-39.8	1.90	0.09	1.25	0.07
39.8-41.8	1.00	0.09		
41.8-43.3	0.80	0.09		
43.3-43.7	0.90	0.09		
43.7-46.9	0.85	0.09	0.50	0.07
46.9-48.7	1.25	0.05-		
48.7-49.9	1.10	0.05-		
49.9-51.9	0.65	0.05-		
51.9-54.8	0.65	0.05-		
54.8-59.5	0.70	0.05-		
59.5-64.5	1.15	0.05-		
64.5-69.5	1.55	0.05-		
69.5-74.5	2.85	0.05-		
74.5-79.5	0.85	0.05-		
79.5-84.5	1.40	0.05-		
84.5-88.3	0.65	0.05-	0.80	0.05
88.3-90.6	0.55	0.05-		
90.6-95.6	0.65	0.05		
95.6-100.6	0.75	0.06		

Lithology: Interval in Feet	Description
32-37	Albite-perthite-carbonate rock
37-40	Gray, fine-grained, hard feldspar-carbonate rock with abundant fine-grained rutile
40-44	Altered nepheline syenite (Diamond Jo type)
44-49	Feldspar rock (same as 30'-31' above)
49-68	Coarse-grained, dark-green nepheline syenite
68-71	Coarse-grained feldspar - pyrite vein with abundant coarse-grained rutile
71-82	Altered, coarse-grained nepheline syenite
82-83	Coarse-grained feldspar-rutile vein, abundant coarse-grained rutile
83-100	Altered, coarse-grained nepheline syenite - rutile rare in widely scattered feldspar veins

HOLE NO. O-4

COORD.-N 600, E 2300
DRILL-BAKER CORE

COLLAR ELEV.-392'
TOTAL DEPTH-37'

Core Analysis: Interval in Feet	$\%TiO_2$	$\%V_2O_5$	%S
0-7	4.64	0.07	0.27
7-14	4.42	0.08	0.30
14-21	4.38	0.09	0.25

Lithology: Interval in Feet	Description
0-11	Dark, gray-green, soft altered phonolite with spotty iron oxide staining
11-14	Dark brown clay containing some fine and medium-grained rutile - probably weathered feldspar-carbonate vein
14-21	Brown altered and unaltered phonolite

Continued

HOLE NO. O-4 (Cont'd)

CORE ANALYSIS				LITHOLOGY	
INTERVAL IN FEET	% TiO_2	% V_2O_5	%S	INTERVAL IN FEET	Description
21-28	3.37	0.08	1.94	21-37	Dark brown to black, dense, hard calcareous rock (unaltered phonolite) containing calcite veins and a few coarse scattered pyrite crystals
28-32	3.01	0.08	2.24		
32-37	3.11	0.09	1.57		

LOGS OF U. S. BUREAU OF MINES 1948 DRILL HOLES, CHRISTY BROOKITE DEPOSIT

In 1948 the U. S. Bureau of Mines completed a core-drilling project at the Christy brookite deposit. A total of 21 holes were drilled during this project, including 7 diamond drill holes, 13 bucket drill holes, and 1 Baker core drill hole. The following (pp. 131-151) logs and assays of these drill holes are a result of the cooperative effort of the U. S. Bureau of Mines and the Arkansas Division of Geology. The assays have been reprinted from a report published by the U. S. Bureau of Mines (Reed, 1949, Figs. 10 through 20) and the core descriptions are by Holbrook. The coordinates of the individual drill holes refer to their location on Plate VI.

HOLE NO. C-1

COORD.-N-10117, E-10479 COLLAR ELEV.-595.8'
DRILL-DIAMOND DRILL TOTAL DEPTH-112'

	CORE		LITHOLOGY
INTERVAL IN FEET	%TiO_2	%V_2O_5	Description
0-10	4.78	0.65	Quartz fragments most abundant - a few magnetite grains - some limonite fragments - limonite and clay coat most of the mineral grains - some rounded grains - some brookite crystals (residual ore)
10-15	5.45	0.65	Mineral grains cleaner than surface material - quartz most abundant - brookite common - a few red clay fragments (residual ore)
15-20	4.45	0.56	
20-25	6.65	0.38	Mostly cloudy, gray quartz fragments - some brookite crystals - very little clay
25-30	6.35	0.56	
30-35	8.80	0.60	Same as above with more clay fragments, less brookite
35-40	5.15	0.73	Mostly smoky quartz - some brookite in both smoky and clear quartz - a few yellow and white clay fragments
40-45	7.50	1.33	Mostly buff and brown clay fragments - some cream-colored clay - abundant brookite - much clear and smoky quartz
45-50	8.05	1.35	
50-55	6.15	0.77	Abundant white and buff clay fragments - abundant smoky and clear quartz - brookite common
55-60	6.65	0.96	Mostly yellow, green, and brown clay fragments - much clear and smoky quartz and brookite
60-65	5.77	0.84	Abundant brookite and quartz - some buff, white and gray clay fragments - a few limonite fragments
65-70	5.60	1.29	
70-75	6.73	1.16	Much gray, green and buff clay and quartz - some brookite (the lower limit of the oxidized zone probably falls in this interval)
75-80	3.87	0.85	Mostly gray-green soft clay - may be altered shale or very fine-grained altered igneous rock - some pyrite
80-85	3.50	0 93	Mostly gray-green clay as above - some brown and buf clay, pyrite, quartz and brookite
85-90	2.35	0.79	(First core recovered) Mostly fine-grained gray-green altered igneous rock or altered shale

Continued

HOLE NO. C-1 (Cont'd)

	CORE		LITHOLOGY
INTERVAL IN FEET	%TiO_2	%V_2O_5	Description
90-95	1.90	0.42	Dark green, fairly soft altered shale
95-100	3.51	0.86	Hard, compact, very fine-grained black shale - contains narrow pyrite seams at 100'-102'
100-102			
102-112	3.50	0.86	No core recovered - cuttings showed oxidized ore similar to that above the shale - may have been contamination from upper part of hole as it was uncased below 54'

HOLE NO. C-3A

COORD.-N-10157, E-10689 COLLAR ELEV.-602.5'

DRILL-DIAMOND DRILL TOTAL DEPTH-67'

	%TiO_2		%V_2O_5		LITHOLOGY
INTERVAL IN FEET	CORE	SL.	CORE	SL.	Description
0-5	11.70		0.29		Porous brookite quartz masses in gray clay
5-8.5	6.27		0.37		Porous brookite quartz fragments with some cream clay
8.5-10.5	3.72	5.40	0.31	0.30	Mainly cream, white and tan clay containing quartz fragments and crystals
10.5-12.5	1.70	4.18	0.06	0.16	Mainly very fine-grained sugary altered novaculite 8" of buff and white clay
12.5-13.5	0.27	3.15	0.02	0.09	
13.5-15.5	0.20	3.00	0.01	0.06	Very fine-grained altered novaculite
15.5-16.5	5.15	2.18	0.23	0.11	Cream clay - no quartz or brookite visible
16.5-19	1.43	1.46	0.14	0.05	Mainly dark gray altered novaculite - top 6" is cream clay with some brookite-quartz
19-21	0.18	1.10	0.00	0.02	Dark, hard altered novaculite and soft, white sugary altered novaculite - at 22'-24' thin seams of brookite in novaculite and some gray clay
21-24	0.70	4.65	0.00	0.10	
24-25.5	3.45	4.70	0.03	0.11	Limonite, hard yellow clay and hard, altered novaculite
25.5-27	0.50	3.70	0.03	0.12	Very fine-grained, dark gray, altered novaculite with thin, barren seam of buff clay
27-30	0.17	2.90	0.05	0.04	
30-33	0.16	1.50	0.00	0.00	
33-35	0.16	1.15	0.03	0.00	
35-37	0.27	1.35	0.04	0.05	Very fine-grained gray to white altered novaculite locally contains limonite-stained fractures
37-39	0.17	1.05	0.03	0.04	
39-41.5	0.23	2.21	0.03	0.04	
41.5-44.5	0.27	4.10	0.02	0.06	
44.5-46.5	1.20	1.60	0.06	0.03	Cream clay, limonite fragments, and gray altered novaculite fragments
46.5-48.5		1.58		0.00	No core recovered
48.5-50.5	1.66	1.95	0.00	0.00	
50.5-52.5	1.60	1.75	0.00	0.00	Cream-colored barren clay
52.5-53.5	1.42	1.51	0.00	0.03	

Continued

HOLE NO. C-3A (Cont'd)

	%TiO_2		%V_2O_5		LITHOLOGY
INTERVAL IN FEET	CORE	SL.	CORE	SL.	Description
53.5-55.5	0.25	1.23	0.03	0.02	
55.5-57.5	0.41	1.70	0.00	0.03	Dark gray and black novaculite with a thin seam of cream clay
57.5-59	1.04	1.50	0.01	0.05	Cream-colored clay
59-61	0.50	1.63	0.03	0.03	Alternating cream clay and altered novaculite layers
61-61.9	0.43	1.30	0.00	0.02	
61.9-65	0.11	1.30	0.00	0.07	Dark gray altered novaculite
65-67	0.31	1.51	0.00	0.06	

HOLE NO. C-4

COORD.-N-10056, E-10697 COLLAR ELEV.-593.2'
DRILL-DIAMOND DRILL TOTAL DEPTH-122'

	%TiO_2		%V_2O_5		LITHOLOGY
INTERVAL IN FEET	CORE	SL.	CORE	SL.	Description
0-2					No core recovered
2-4					
4-6	5.87	2.10	0.60	0.24	Porous, medium-grained quartz with fine-grained brookite - in part cemented with limonite (residual ore)
6-8	1.91	1.40	0.29	0.33	Red clay, qtz., brookite frags.(residual ore)
8-10	1.34	1.10	0.42	0.36	Porous qtz., white clay, red clay - little brookite (residual ore)
10-12	1.36	0.90	0.55	0.43	Porous qtz. frags., limonite cement, some brookite
12-14	1.20	0.85	0.37	0.52	F. and c.gr. porous qtz. - some brookite and white clay
14-16	1.53	1.35	0.98	0.39	Dark brown, friable, sandy porous quartz - thin seam of red clay - little brookite
16-18	0.66	1.49	0.39	0.62	
18-20	0.89	1.00	0.60	0.36	
20-22		1.39		0.69	No core recovered
22-24		1.70		0.54	
24-26	6.39	3.32	0.30	0.38	Porous, coarsely cryst. qtz. - no brookite visible
26-29	1.34	2.78	0.35	0.59	Mainly porous c. gr. qtz. - a few clay seams
29-31.5	4.38	6.09	0.38	1.07	Mainly banded gray clay - a little brookite-qtz. at top
31.5-34	6.28	8.39	1.79	1.25	Brown clay with some sandy qtz. - limonite frags.
34-36	8.37	5.30	1.45	1.02	C.gr. brookite-qtz. and brown to black clay
36-38		9.93		1.25	No core recovered
38-41.7	4.42	7.50	0.98	0.62	Buff and cream clay with many sandy quartz fragments and much brookite
41.7-44	3.97	9.60	0.76	0.66	Some buff clay - mostly brown porous quartz with abundant fine-grained brookite
44-46.5	11.25	13.50	0.84	1.28	
46.5-49	4.75	6.55	0.94	0.62	
49-51.5		4.20		0.83	No core recovered
51.5-53.3	4.25	3.25	0.36	0.40	Brown, porous brookite-quartz - no clay
53.3-55	8.05	5.80	0.26	0.25	Dark gray, porous quartz frags. - abundant brookite
55-57.5	12.15	10.00	0.56	0.56	V. f.gr. porous qtz. - much f.gr. brookite
57.5-60.5	5.49	6.22	0.62	0.95	Same, but coarser-grained quartz

Continued

HOLE NO. C-4 (Cont'd)

	%TiO_2		%V_2O_5		LITHOLOGY
INTERVAL IN FEET	CORE	SL.	CORE	SL.	Description
60.5-63.5	2.26	4.55	0.57	0.88	Gray to brown porous quartz - some brookite
63.5-66.5	7.80	5.75	0.81	0.87	
66.5-68.5	12.60	8.88	0.87	1.02	Limonite frags. - some brown and gray porous qtz. frags. - some brookite
68.5-71.5	10.70	8.55	0.85	1.17	Porous, ferruginous, fine-grained quartz - much very fine-grained brookite
71.5-74.5	10.13	10.00	0.66	1.72	
74.5-77.5	6.50	10.15	0.46	1.17	
77.5-80.5	10.70	9.60	0.81	1.13	
80.5-83.5	9.25	9.60	2.05	1.15	White and yellow clay with a few coarse-grained quartz fragments
83.5-86.7	3.92	7.78	1.14	2.30	Red and brown clay with coarse-grained quartz fragments
86.7-90	6.45	6.34	2.92	2.16	Mixture of c.gr. qtz. masses, brookite-qtz. frags. and brown por. qtz. frags. - some limonite frags.
90-93	1.15	7.57	0.24	1.81	Mostly brown clay
93-97	6.30	6.72	0.90	1.33	Brown to black sandy, porous brookite-quartz fragments - some banded clay
97-100	8.97	5.60	1.34	0.99	Gray clay - some gray, porous, hard quartz
100-103	1.43	4.40	0.18	0.74	Hard, gray, granular, porous quartz fragments
103-106	6.72	6.14	0.31	0.47	Fragments of blue-gray, hard, porous brookite-quartz
106-109	5.50	6.53	0.76	0.28	Same as above with some buff and cream clay
109-112	2.00	4.00	0.19	0.32	
112-115	2.40	4.81	0.13	0.38	Brown and cream clay with hard porous quartz fragments
115-118	1.63	3.20	0.19	0.29	Brown plastic clay
118-122	1.35	3.89	0.27	0.38	Brown, green, and yellow clay

HOLE NO. C-5

COORD.-N-9991, E-10701 COLLAR ELEV.-583

DRILL-DIAMOND DRILL TOTAL DEPTH-132'

	%TiO_2		%V_2O_5		LITHOLOGY
INTERVAL IN FEET	CORE	SL.	CORE	SL.	Description
0-3	5.32		0.67		Hard, gossanized brookite-quartz (residual ore)
3-5	5.68		0.43		Mostly gossanized, brookite-quartz with some buff clay (residual ore)
5-8	2.87	5.04	0.22	0.17	Mainly friable porous quartz - some clay (residual ore)
8-11	4.27	3.56	0.20	0.18	Same, with some fine-grained brookite (residual ore)
11-15.5	3.74	3.18	0.25	0.24	Hard and friable porous brookite-quartz - 1.5' of buff clay at bottom

Continued

HOLE NO. C-5 (Cont'd)

	%TiO_2		%V_2O_5		LITHOLOGY
INTERVAL IN FEET	CORE	SL.	CORE	SL.	Description
15.5-20	5.07	8.52	0.28	0.75	Mainly buff and pink clay - few fragments of porous brookite-quartz
20-22.5	6.43	6.51	0.16	0.47	Porous brookite-quartz fragments
22.5-26	4.64	5.32	0.06	0.28	Same as above, with some cream clay
26-29	4.64	4.67	0.06	0.25	Very friable, brown porous quartz - much fine-grained brookite
29-32	6.88	6.12	0.18	0.29	Brown, porous brookite-quartz with some coarse-grained quartz veins and clay seams
32-35	3.58	3.90	0.15	0.28	Mainly white clay - with some brookite-quartz fragments
35-38	1.60	1.91	0.23	0.34	
38-41	2.77	3.63	0.06	0.49	Brown, friable brookite-quartz
41-44	3.54	5.27	0.19	0.47	Mainly brookite-quartz - much gray clay
44-47	3.87	2.00	0.37	0.60	Same, without clay
47-50	1.27	2.60	1.72	0.64	Very fine-grained brookite-quartz
50-53	0.98	1.91	0.14	0.66	Porous, brown quartz - some coarse-grained quartz - little brookite
53-56	1.17	2.06	0.36	0.64	Hard, gray, partly porous quartz - little brookite
56-59	5.00	5.00	0.24	0.67	One foot of above material - rest is black, porous brookite-quartz with coarse quartz veins
59-60.5	6.23	6.50	0.11	0.44	Hard brown porous quartz
60.5-62.5	6.45	3.67	0.34	0.62	Hard, black, gray, and brown porous quartz-brookite rare
62.5-65.5	1.83	2.20	0.67	0.66	
65.5-68	0.93	2.60	1.15	0.85	
68-70.5	1.28	1.36	0.23	0.37	Black, hard, porous quartz with brookite
70.5-73.5	14.80	4.68	0.56	0.69	Brown to black porous quartz - brookite abundant
73.5-76	5.54	2.83	0.22	0.34	Mainly white clay - some brown brookite-quartz fragments
76-79	4.95	3.20	0.44	0.37	
79-82	3.82	3.99	0.42	0.55	Top half white clay - bottom, brown porous quartz with some brookite
82-85	2.13	1.47	0.23	0.43	Hard gray quartzite with much brookite
85-88	3.07	2.05	0.17	0.44	Hard gray to black quartzitic material - some brookite
88-91	3.50	3.14	0.48	0.35	Mainly white and pink clay - some porous quartz fragments with brookite
91-94	2.87	2.80	0.09	0.18	Gray porous quartz with much brookite
94-97		3.06		0.37	No core recovered
97-100	3.55	2.88	0.37	0.39	All gray and brown porous quartz with much brookite
100-103	8.44	4.64	0.63	0.87	
103-106		6.88		1.52	No core recovered
106-109	10.35	11.70	1.53	1.79	Brown clay with brown porous quartz fragments
109-112	15.11	11.40	0.89	1.98	Both hard and friable porous quartz - brookite abundant

Continued

HOLE NO. C-5 (Cont'd)

	%TiO_2		%V_2O_5		LITHOLOGY
INTERVAL IN FEET	CORE	SL.	CORE	SL.	Description
112-117	5.65	8.80	1.50	2.08	Varicolored clay with porous quartz fragments, all containing brookite
117-122	9.69	9.58	0.87	1.90	Gray porous quartz - some buff clay seams - all brookite-bearing
122-127		9.70		1.98	No core recovered
127-130	15.47	9.95	0.44	1.59	Gray to black, hard to friable porous quartz - abundant brookite
130-132	3.07	7.20	0.38	1.02	Gray porous quartz with much brookite

HOLE NO. C-6

COORD.-N-10068, E-10113 COLLAR ELEV.-

DRILL-DIAMOND DRILL TOTAL DEPTH-104.5'

	%TiO_2		%V_2O_5		LITHOLOGY
INTERVAL IN FEET	CORE	SL.	CORE	SL.	Description
0-2.5	3.42		0.39		Quartz and brookite disseminated in red clay (residual ore)
2.5-5	3.22		0.46		Same with some gossanized brookite-quartz fragments (residual ore)
5-6	1.85		0.51		
6-9.25	6.55		0.35		Porous fine-grained brookite-quartz fragments - scattered veins of coarse-grained quartz (residual ore)
9.25-12.5	3.95	4.35	0.44	0.62	Mostly brown, limonite-stained, porous soft brookite-quartz - some clay (residual ore)
12.5-15.5	4.00	8.55	0.70	0.59	Hard,massive limonite - some gossanized, porous brookite-quartz - few buff clay seams
15.5-17.5	4.67	4.00	0.36	0.48	Mottled clay and brown, porous brookite-quartz
17.5-20	3.45	4.55	0.32	0.41	Half cream clay and half brookite-quartz locally gossanized
20-22.5	1.98	4.10	0.21	0.28	Buff clay and pink clay with white patches
22.5-25.5	2.35	6.30	0.26	0.40	All pink clay as above
25.5-28.5	6.31	6.50	0.88	0.35	Mainly gossanized porous quartz with one foot of buff clay
28.5-30.5		13.25		0.28	No core recovered
30.5-32.5	8.12	5.80	0.49	0.24	Mixed porous quartz fragments and buff clay
32.5-33.5	4.60		0.36		Buff clay
33.5-34.5	4.15		0.13		Pink clay with porous quartz fragments
34.5-35.5	12.20	7.85	0.25	0.16	Porous fine-grained brookite-quartz fragments
35.5-37	2.60		0.25		White and gray clay
37-38.5	11.25	10.70	0.18	0.21	Gray brookite-quartz - brookite very fine-grained
38.5-40	7.60		0.20		
40-41	9.10		0.24		Friable brookite-quartz and cream clay
41-42	7.00	8.75	0.27	0.29	
42-43					No core recovered
43-44	5.40		0.46		Hard brookite quartz
44-45	5.40	6.70	0.26	0.30	
45-46	11.70		0.09		Alternating layers of porous brookite-quartz and cream clay
46-47	5.20		0.21		
47-48	5.65	10.55	0.12	0.20	
48-49					
49-50					No core recovered
50-51	8.93	8.15	0.19	0.26	Cream clay and porous brookite-quartz
51-52					No core recovered
52-53	12.50		0.26		
53-54	14.20	11.25	0.37	0.18	Porous, clay-coated brookite-quartz fragments
54-55					No core recovered

Continued

HOLE NO. C-6 (Cont'd)

	%TiO_2		%V_2O_5		LITHOLOGY
INTERVAL IN FEET	CORE	SL.	CORE	SL.	Description
55-56	13.15	9.60	0.51	0.31	Friable porous clay-coated brookite-quartz fragments
56-57.5	8.20		0.56		
57.5-60	4.50	8.35	0.58	0.38	Dark brown clay, brookite crystals, and brookite-quartz fragments
60-62	4.25		0.40		Coarse-grained quartz in brown clay - some brookite
62-63	7.55	9.45	0.35	0.25	
63-64					No core recovered
64-65	8.85		0.31		Hard, gray porous-quartz
65-67		10.75		0.31	No core recovered
67-69	13.70		0.28		Hard, slightly porous brookite-quartz
69-71	8.75	12.80	0.18	0.24	
71-72.5	15.86		0.29		
72.5-74.5	19.13	18.60	0.37	0.37	Porous brookite-quartz core is vuggy - quartz and brookite coated with limonite
74.5-75.5	11.00		0.23		
75.5-77.5	15.60	20.00	0.27	0.35	
77.5-79.5	12.80	15.25	0.17	0.30	Hard, brown, porous brookite-quartz - some clay
79.5-82	16.80	16.70	0.40	0.38	Hard porous brookite-quartz
82-83	10.60		0.30		Hard porous brookite quartz - some white clay
83-85	15.00	12.45	0.33	0.28	
85-87	16.20	14.40	0.24	0.28	Hard porous brookite-quartz
87-89	19.50	21.00	0.35	0.41	Porous brookite-quartz - some buff clay
89-91	12.80	17.00	0.18	0.42	Friable, porous, brookite - quartz fragments
91-93	8.35	18.10	0.44	0.36	Hard porous brookite-quartz - some clay
93-95	12.25	16.20	0.43	0.30	Fine-grained, hard, porous brookite-quartz
95-97	18.70	21.00	0.26	0.29	
97-98.5	13.60	15.45	0.27	0.26	
98.5-100.5	14.85	11.60	0.18	0.23	Same with some coarse quartz veins
100.5-102.5	8.35	15.25	0.28	0.32	Friable and hard porous brookite-quartz
102.5-104.5	5.85	14.50	0.24	0.38	Top foot is brookite-quartz and clay - bottom foot is altered novaculite

HOLE NO. C-7

COORD.-N-10061, E-9989 — COLLAR ELEV.-558.6'

DRILL-DIAMOND DRILL — TOTAL DEPTH-86.83'

	%TiO		%VO		LITHOLOGY
INTERVAL IN FEET	CORE	SL.	CORE	SL.	Description
0-1					Brown to red clay containing disseminated brookite-quartz fragments and free brookite (residual ore)
1-2	4.12		0.21		
2-3	6.12		0.36		
3-4	4.15		0.31		
4-5	6.72		0.31		
5-6	8.90		0.47		
6-8	2.85		0.36		Sandy porous brookite-quartz (residual ore)
8-10	0.75	4.45	0.37	0.33	
10-11.5	0.41	0.79	0.29	0.44	
11.5-13.5	0.79	0.45	0.18	0.26	Mainly brown and white clay with few porous quartz fragments
13.5-15.5	2.61	2.55	0.22	0.55	Brown and white clay
15.5-17.5	3.55	4.75	0.16	0.21	Gossanized, porous brookite-quartz
17.5-20	10.58	5.23	0.08	0.16	Gray, hard, vuggy brookite-quartz
20-22	12.80	2.17	0.12	0.15	
22-24	1.13	1.73	0.14	0.13	Red, friable porous brookite-quartz fragments
24-26	1.50	0.90	0.21	0.03	Hard, f. gr. porous quartz - little brookite

Continued

HOLE NO. C-7 (Cont'd)

	%TiO		%VO		LITHOLOGY
INTERVAL IN FEET	CORE	SL.	CORE	SL.	Description
26-28	1.51	1.40	0.17	0.00	Ferruginous, porous brookite-quartz - little brookite
28-30	10.35	2.86	0.14	0.01	Same, with 1' of white clay
30-32	12.75	4.73	0.23	0.04	Brown hard porous brookite-quartz - much brookite
32-34	12.70	5.80	0.21	0.06	
34-36	4.00	6.31	0.08	0.07	
36-38	0.28	2.52	0.03	0.00	Sugary, altered novaculite - white to light brown
38-40	0.35	0.80	0.05	0.02	
40-41.33	0.90	1.48	0.19	0.00	Altered novaculite and sandy porous quartz
41.33-42.5	3.40		0.14		Gray, hard, med. gr. quartz, with brookite
42.5-44	0.78	0.40	0.16	0.00	Hard to friable porous brookite-quartz
44-45					Hard, gray porous brookite-quartz
45-46	0.45	0.77	0.19	0.02	
46-47.5	1.05		0.16		Same, with some altered novaculite
47.5-49	0.45	0.65	0.05	0.02	Brookite-quartz and altered novaculite
49-50.5	1.05		0.10		Hard, gray, c. gr. brookite-quartz
50.5-52	0.80	0.57	0.23	0.00	Porous brookite-quartz with some cream clay
52-53.5					No core recovered
53.5-55	0.78	0.75	0.05	0.02	Porous quartz, altered novaculite and brown clay
55-56.5	0.35		0.10		Porous brookite-quartz -little brookite, some clay
56.5-58	1.18	0.58	0.02	0.00	Hard, med. gr., qtz. with much v. f. gr. brookite
58-60	2.77		0.02		Same, with thin layer of alt. novac. at bottom
60-62	1.00	1.25	0.26	0.27	Gossanized, coarse-grained porous quartz
62-63.5	1.51	0.37	0.00	0.01	C. gr. hard gray quartz with some f. gr. brookite some alt. novaculite
63.5-64.5	0.18		0.00		
64.5-66	0.05	0.66	0.00	0.00	White, sugary altered novaculite
66-67	0.00		0.00		
67-69.25	2.05	0.61	0.05	0.02	Mainly altered novaculite - some sandy porous quartz with much v. f. gr. brookite
69.25-70.25		2.10		0.12	No core recovered
70.25-72.5	1.47		0.07		Sandy, porous brookite quartz - brookite abundant
72.5-74	1.25	2.45	0.03	0.04	
74-76	1.65	1.55	0.04	0.02	Hard, gray, porous brookite-quartz - 1' layer of altered novaculite at 78'
76-78.25	0.95	1.31	0.05	0.00	
78.25-80	0.38	1.10	0.04	0.05	Altered brown novaculite and coarse-grained hard brookite-quartz
80-82	1.50	1.38	0.03	0.08	
82-86.83	0.23	0.47	0.01	0.03	White, sugary altered novaculite - cut by 5" gray-green, altered igneous dike at 83'

HOLE NO. C-8

COORD.-N-9972, E-10133 COLLAR ELEV.-

DRILL-DIAMOND DRILL TOTAL DEPTH-115'

	%TiO_2		%V_2O_5		LITHOLOGY
INTERVAL IN FEET	CORE	SL.	CORE	SL.	Description
0-3.5	3.23		0.30		Red surface clay with porous quartz fragments and brookite (residual ore)
3.5-6.5	3.63		0.42		Porous brookite-quartz partly cemented by limonite (residual ore)
6.5-9	0.96		0.22		
9-11	1.43	1.50	0.63	0.37	Mostly brookite-quartz gossan - some cream and buff clay
11-13.5	1.51		0.20		Sandy and gossanized porous quartz fragments - brookite rare
13.5-16	1.76	1.80	0.11	0.19	Sandy, friable porous brookite-quartz

Continued

HOLE NO. C-8 (Cont'd)

	%TiO_2		%V_2O_5		LITHOLOGY
INTERVAL IN FEET	CORE	SL.	CORE	SL.	Description
16-18.5	1.64	2.21	0.13	0.14	Same, with some buff clay seams
18.5-21	0.76	2.30	0.16	0.21	
21-23.5	1.42	1.60	0.23	0.16	
23.5-26		2.45		0.26	No core recovered
26-28.5	0.63	0.83	0.24	0.26	Sandy porous quartz fragments - brookite rare
28.5-31	0.58	0.88	0.13	0.20	Porous and vuggy quartz - brookite rare
31-33.5	0.61	0.91	0.22	0.27	Sandy porous quartz - brookite rare
33.5-35.5	1.46	1.20	0.17	0.21	White and cream clay - some brookite-quartz
35.5-38	1.25	1.35	0.24	0.17	Mainly buff and white clay - some gossanized brookite-quartz
38-40.5	0.63	0.80	0.14	0.16	Mainly barren porous quartz - some white and buff clay
40.5-43	0.52	1.15	0.13	0.37	Sandy quartz with limonite - little brookite
43-46	1.11	0.75	0.24	0.22	
46-48.5	0.53	0.52	0.28	0.32	Hard porous quartz with white clay
48.5-51	1.45	0.87	0.40	0.39	Quartz gossan - little brookite
51-53.5	1.41	1.65	0.74	0.38	
53.5-56	3.20	0.35	0.31	0.32	
56-58.5	3.06	4.55	0.59	0.98	Buff clay with porous quartz
58.5-61	5.04	4.98	1.07	0.79	
61-63.5	6.23	10.13	0.72	0.57	Quartz gossan - brookite rare
63.5-66	3.83	10.91	0.52	0.77	Gossanized porous quartz with some brookite
66-67.5	10.48	7.70	1.46	0.32	Gossanized brookite-quartz with cream-colored clay lenses
67.5-70	7.15	8.04	0.89	0.54	
70-72.5		6.10		0.38	Porous brookite-quartz rock with coarse-grained quartz veins
72.5-75	7.15	8.65	0.44	0.42	Brown clay with some brookite-quartz
75-77.5		9.47		0.46	
77.5-80		11.55		0.62	No core recovered
80-82.5	8.91	10.64	0.40	0.50	Hard brookite-quartz rock - much brookite
82.5-85	9.91	10.36	0.65	0.47	Porous brookite-quartz with some brown clay
85-86.5	26.30	20.96	0.38	0.37	Hard brookite-quartz - brookite very fine-grained and abundant
86.5-88	24.74		0.44		
88-90.5	20.50	8.70	0.21	0.21	Hard, gray porous brookite-quartz - brookite abundant
90.5-92.5	16.80	10.20	0.38	0.20	Cream-colored clay,brookite, brookite-quartz seams
92.5-94.5	7.45	14.06	0.36	0.22	White clay and porous quartz
94.5-97		19.30		0.51	No core recovered
97-98	19.60		0.32		Hard brookite-quartz - much brookite
98-100.5	9.58	17.65	0.14	0.58	
100.5-102.5	12.25	13.40	0.42	0.51	
102.5-105	9.65	6.10	0.26	0.22	
105-107.5		5.95		0.13	No core recovered
107.5-110	2.40	4.78	0.36	0.18	Gray, sandy porous brookite-quartz
110-112.5	1.20	3.70	0.16	0.15	Gray, hard porous quartz - brookite poor
112.5-115	0.30	3.25	0.04	0.09	

HOLE NO. BD-1

COORD.-N-10178.2, E-10526.4 COLLAR ELEV.-601'
DRILL-BUCKET DRILL TOTAL DEPTH-46'

	CORE		LITHOLOGY
INTERVAL IN FEET	$\%TiO_2$	$\%V_2O_5$	Description
0-21			No core - this hole was started in the bottom of a test pit 21 feet deep
21-24	5.91	0.96	Quartz fragments - much fine-and coarse-grained brookite, a few fragments of altered novaculite, buff clay, white clay, and a few magnetite grains
24-29	6.31	1.35	Red, brown and white clay abundant; much fine-grained brookite both in quartz and as free crystals - much quartz
29-34	7.97	1.38	Quartz fragments (clay coated) - some white and brown clay fragments, much fine-grained brookite
34-39	8.21	1.56	Buff and white clay fragments, some quartz and fine-grained brookite
39-44	8.67	1.04	Reddish brown quartz fragments containing some medium- and coarse-grained brookite - a few brown clay fragments
44-46	12.15	1.11	Fine- to coarse-grained quartz masses containing much fine- and coarse-grained brookite.

HOLE NO. BD-2

COORD.-N-10083, E-10292 COLLAR ELEV.-590.5'
DRILL-BUCKET DRILL TOTAL DEPTH-34'

	CORE		LITHOLOGY
INTERVAL IN FEET	$\%TiO_2$	$\%V_2O_5$	Description
0-5	6.10	0.33	Mostly porous quartz fragments in red clay - some brookite (residual ore)
5-10	3.10	0.17	Mostly white clay - a few porous quartz fragments - brookite rare
10-15	3.05	0.26	Mostly porous quartz fragments - some with brookite- much white clay as in 5'-10' above
15-20	5.85	0.30	Mostly white and brown clay fragments - some porous quartz fragments - brookite rare
20-25	3.55	0.35	White and pink clay fragments

Continued

HOLE NO. BD-2 (Cont'd)

	CORE		LITHOLOGY
INTERVAL IN FEET	%TiO_2	%V_2O_5	Description
25-30	1.80	0.05	Mostly white clay fragments - few coarse-grained quartz fragments with some brookite
30-34	1.50	0.06	Mainly white clay fragments - few altered white novaculite fragments

HOLE NO. BD-3

COORD.-N-10119, E-10482 COLLAR ELEV.-596.6

DRILL-BUCKET DRILL TOTAL DEPTH-52'

	CORE		LITHOLOGY
INTERVAL IN FEET	%TiO_2	%V_2O_5	Description
0-5	3.96	0.82	NOTE: This hole was not logged as it is only 5 feet from Hole C-1. C-1 was logged because of its greater depth.
5-10	5.05	1.03	
10-15	7.88	1.74	
15-20	6.95	1.96	
20-25	4.66	0.62	
25-30	8.88	0.92	
30-35	8.26	1.07	
35-40	6.55	0.84	
40-45	6.28	1.55	
45-50	8.88	1.59	
50-52	9.70	1.18	

HOLE NO. BD-4

COORD.-N-10022, E-10499 — COLLAR ELEV.-583.2'

DRILL-BUCKET AND DIAMOND DRILLS — TOTAL DEPTH-141'

INTERVAL IN FEET	CORE %TiO_2	CORE %V_2O_5	LITHOLOGY Description
0-5	6.05	0.86	Mainly fine-and coarse-grained quartz with much fine- and medium-grained brookite - some brown clay fragments - some magnetite grains - some of the quartz and brookite grains show slight rounding (residual ore).
5-10	10.07	2.17	Mostly fine-grained brown quartz fragments - some slightly rounded - a few brown clay fragments - much fine- and medium-grained brookite - a few magnetite grains (residual ore)
10-15	8.55	1.76	Same as above - no rounded grains
15-20	7.87	1.52	Same - brookite fine-grained, magnetite absent
20-25	6.04	0.85	Mostly quartz, both fine-grained porous masses and coarse-grained vein quartz - some fine-grained brookite and brown clay
25-30	7.22	0.41	Mostly fine-grained porous, gray quartz, some fine-grained brookite - some flesh-colored clay fragments
30-35	7.33	0.39	
35-40	7.04	0.32	Same - some brookite fine to very fine-grained
40-45	4.17	0.41	Same as 35-40 - some fine-grained brookite
45-46	3.96	0.55	

DIAMOND DRILL					
INTERVAL IN FEET	%TiO_2 CORE	%TiO_2 SL.	%V_2O_5 CORE	%V_2O_5 SL.	Description
46-49	5.05	3.13	0.97	0.88	Hard gossanized brookite-quartz - sandy porous brookite-quartz with quartz veins - some buff clay
49-51	3.28	3.51	0.28	0.38	Sandy porous brookite-quartz - seam of buff clay
51-53	1.40	2.17	0.33	0.28	Fine-grained, sandy, porous brookite quartz with coarse quartz veins
53-55	4.25	2.17	0.38	0.68	Sandy, porous, limonite-stained brookite-quartz
55-57	3.35	2.53	0.31	0.67	Brown, porous, sandy brookite-quartz with a few fragments of brown altered novaculite
57-59	3.60	4.86	0.33	0.74	Mostly brown porous brookite-quartz - some brown altered novaculite
59-61	2.58	2.83	0.46	0.37	No samples available for logging
61-63	3.25	2.25	0.57	0.75	
63-65	5.18	3.08	0.59	0.56	Gray, porous brookite-quartz - very fine-grained brookite
65-67	9.50	7.86	0.51	0.79	Gray to brown porous brookite-quartz
67-69	6.75	7.50	0.72	0.98	Limonite-stained, brown, porous brookite-quartz fragments
69-71	9.00	8.48	1.16	0.86	Mainly quartz fragments - some brookite
71-72		9.80		0.72	No core recovered
72-76	5.35	9.87	0.98	0.79	No sample available for logging
76-78	7.70	9.58	0.76	0.77	
78-80	10.25	7.67	0.94	0.90	Mainly quartz fragments - brookite abundant
80-81	6.73	6.82	1.65	1.46	Limonite fragments - some quartz and brookite
81-82	6.64		2.26		Limonite, quartz, manganese oxides - some brookite
82-84	4.25	7.67	1.60	1.86	Dark brown quartz - much limonite - some brookite
84-86	6.38		2.21		Same, with some manganese oxides

Continued

HOLE NO. BD-4 (Cont'd)

DIAMOND DRILL					LITHOLOGY
	$\%TiO_2$		$\%V_2O_5$		Description
INTERVAL IN FEET	CORE	SL.	CORE	SL.	
86-88	8.71	6.82	2.03	1.31	Brown novaculite - brown quartz - much brookite
88-90		8.04		1.28	No core recovered
90-92	8.38	8.15	1.97	1.29	No sample available for logging
92-95	5.59	7.50	0.57	1.01	
95-97	2.17	7.28	0.31	0.76	
97-99	5.17	6.40	1.82	1.19	
99-101		7.75		0.84	No core recovered
101-103	0.58	1.90	0.23	0.23	No sample available for logging
103-105	5.53	3.66	0.62	0.52	
105-107	4.73	4.03	0.67	0.57	Mainly quartz fragments, some white clay, some brookite
107-110	6.68	5.48	0.64	0.60	Mostly brown quartz - brookite abundant - much manganese oxide
110-113	9.25	8.30	1.01	1.02	Mostly quartz fragments - brookite abundant - limonite and manganese oxides common
113-116	9.80	7.95	1.60	0.88	No sample available for logging
116-119	5.55	7.32	1.13	1.15	Mostly yellow-brown clay - much quartz - some brookite, limonite and manganese oxides
119-124	13.45	8.60	1.68	1.47	No sample available for logging
124-128	8.15	10.55	1.54	1.40	Mostly white, gray and brown clay - much quartz and abundant brookite
128-132	6.54	9.08	1.53	1.54	No sample available for logging
132-135	11.01	9.40	1.12	1.69	Mostly brown quartz with much brookite
135-138		8.59		1.33	No core recovered
138-141	2.80	5.75	1.28	1.26	No sample available for logging

HOLE NO. BD-5

COORD.-N-10016, E-10304 COLLAR ELEV.-586.7'

DRILL-BUCKET AND DIAMOND DRILLS TOTAL DEPTH-110'

	CORE		LITHOLOGY
INTERVAL IN FEET	$\%TiO_2$	$\%V_2O_5$	Description
0-5	4.10	0.71	Mainly quartz fragments - abundant fine- and coarse-grained brookite - several limonite fragments - several yellow clay fragments - some magnetite grains (residual ore)
5-10	5.45	0.81	Mostly quartz - many buff, white and pink clay fragments, much fine-grained brookite
10-15	5.80	0.81	
15-20	6.95	1.09	

Continued

HOLE NO. BD-5 (Cont'd)

	CORE		LITHOLOGY
INTERVAL IN FEET	% TiO_2	% V_2O_5	Description
20-25	6.51	0.72	Mostly quartz, some brown clay fragments - some fine-grained brookite
25-30	6.28	0.66	
30-35	5.40	0.59	
35-40	4.05	0.49	Mostly buff and white clay, some quartz, some fine-grained brookite
40-45	5.72	0.42	Mostly fine-grained porous quartz masses with some brown clay fragments and much very fine-grained brookite
45-50	6.65	0.52	Mostly gray fine-grained and coarse-grained quartz, some brown clay fragments, much fine-grained to very fine-grained brookite
50-55	6.05	0.93	Same as above but with much less brookite
55-61	8.40	0.55	Mostly fine-grained porous quartz with some fine-grained brookite

DIAMOND DRILL					
	% TiO_2		% V_2O_5		
INTERVAL IN FEET	CORE	SL.	CORE	SL.	
61-64	3.90	4.00	0.37	0.32	Hard to porous brookite-quartz - some gossan at bottom
64-67	3.15	4.66	0.12	0.19	Smoky, coarse quartz crystals with brookite common - some white clay
67-69	0.82	4.28	0.05	0.15	Dark, gray altered novaculite with some coarse-grained smoky brookite-quartz at top
69-72	0.20	1.65	0.02	0.10	Dark gray altered novaculite
72-75	1.62	1.65	0.06	0.06	Dark gray altered novaculite and medium-grained porous quartz with fine-grained brookite
75-77	9.70	2.70	0.26	0.13	Fine-grained porous quartz - fine-grained brookite abundant
77-79	11.03	6.16	0.26	0.17	Mostly brown clay with porous quartz fragments
79-81	12.70	2.26	0.22	0.13	Gossanized porous brookite-quartz and brown clay abundant brookite
81-83	9.42	3.81	0.23	0.11	Mainly gossanized porous quartz and brown clay fragments - some brookite
83-87.5	1.10	2.16	0.00	0.06	Altered dike (?) gray in color, containing much pyrite
87.5-90	2.20	4.12	0.20	0.19	Cream clay with green veinlets - brown and green very fine-grained clay - some coarse-grained quartz gossanized
90-92.5	2.90	3.76	0.06	0.19	Porous brookite-quartz - 6" black novaculite
92.5-95	0.46	1.25	0.01	0.08	
95-96.5	0.39	1.27	0.00	0.06	Light brown altered novaculite
96.5-98.5	0.20		0.00		
98.5-101.5	0.10	1.50	0.00	0.07	
101.5-103	1.15	2.40	0.04	0.19	Brown novaculite - some gray hard brookite-quartz
103-105	2.51	2.91	0.43	0.36	Porous, brown, sandy brookite-quartz - partly gossanized
105-107.5	3.70	4.25	0.55	0.50	Porous brookite-quartz
107.5-110	1.82	3.0[illegible]	0.37	0.27	Porous brookite-quartz - some gray-green clay, coarse quartz crystals, and brookite

HOLE NO. BD-6

COORD.-N-10202, E-10350 COLLAR ELEV.-598.1'
DRILL-BUCKET DRILL TOTAL DEPTH-59'

	CORE		LITHOLOGY
INTERVAL IN FEET	%TiO_2	%V_2O_5	Description
0-5	5.45	0.35	Mostly quartz fragments with much red gritty clay, and abundant medium-grained brookite - some altered novaculite fragments (residual ore)
5-10	5.32	0.47	Same as above with some white clay (residual ore)
10-15	7.35	0.30	Mainly porous quartz fragments with some brookite - much red gritty clay and many white altered novaculite fragments
15-20	9.47	0.24	
20-25	10.60	0.21	Mainly brown clay with many quartz fragments - fine-grained brookite abundant
25-30	3.30	0.18	Mostly brown clay with some blue novaculite fragments and white clay fragments - brookite rare
30-35	1.15	0.04	White clay (?) fragments - drab gray shale - black shale - some brown clay
35-40	1.40	0.00	Drab gray, soft shale - few limonite fragments
40-45	1.85	0.00	Mostly drab gray soft shale - some blue, soft shale, buff clay and altered novaculite
45-50	2.65	0.04	Pink clay fragments with some black novaculite
50-55	1.60	0.01	Mostly hard unaltered light to dark gray novaculite - some green and buff clay
55-59	1.35	0.05	Hard, gray novaculite with some buff shale and cream-colored shale

HOLE NO. BD-7

COORD.-N-10263, E-10575 COLLAR ELEV.-597.7
DRILL-BUCKET DRILL TOTAL DEPTH-39'

	CORE		LITHOLOGY
INTERVAL IN FEET	%TiO_2	%V_2O_5	Description
0-5	11.70	0.97	Porous brookite-quartz in red clay - some free brookite (residual ore)
5-10	9.90	0.84	
10-15	2.75	0.24	Mostly brown clay - many white fragments (altered shale?) several fragments of gray and brown waxy clay

Continued

HOLE NO. BD-7 (Cont'd)

	CORE		LITHOLOGY
INTERVAL IN FEET	%TiO_2	%V_2O_5	Description
15-20	1.50	0.24	Mostly brown clay - some gray and white clay
20-25	1.25	0.19	Brown and black clay - some black novaculite and white clay
25-30	1.30	0.09	Mostly green waxy clay - some black and brown clay
30-35	1.10	0.11	Much black waxy olay - many flesh-colored clay fragments - some hard novaculite and brown clay
35-39	1.43	0.06	Mostly black, brown, and green clay - some hard novaculite

HOLE NO. BD-8

COORD.-N-10252, E-10485 COLLAR ELEV.-601.8'
DRILL-BUCKET DRILL TOTAL DEPTH-48'

	CORE		LITHOLOGY
INTERVAL IN FEET	%TiO_2	%V_2O_5	Description
0-5	8.38	0.31	Porous brookite-quartz fragments in red, gritty clay - brookite fine-grained (residual ore)
5-10	9.65	0.37	
10-15	8.60	0.44	
15-20	1.00	0.10	Buff, altered shale - hard gray novaculite and dark brown clay
20-25	2.66	0.12	Mostly brown clay, some black and green clay - some hard altered novaculite
25-30	1.00	0.09	Mostly gray shale - some altered novaculite and white clay
30-35	3.33	0.12	Mostly buff and white clay - some novaculite and gray shale
35-40	2.45	0.12	Brown clay with some white clay
40-45	1.81	0.19	Buff and white clay - a little novaculite and black clay
45-48	1.09	0.07	Hard, white altered shale (?) - some hard novaculite

HOLE NO. BD-9

COORD.-N-10211, E-10248 COLLAR ELEV.-584.1'
DRILL-BUCKET DRILL TOTAL DEPTH-35'

	CORE		LITHOLOGY
INTERVAL IN FEET	%TiO_2	%V_2O_5	Description
0-5	4.27	0.16	Mainly quartz fragments with some altered novaculite and brookite - all in red gritty clay (residual ore)
5-10	2.66	0.12	Mostly white and red clay - some altered novaculite - some porous quartz fragments - minor brookite (residual ore)
10-15	1.76	0.00	Buff clay with some altered novaculite
15-20	1.07	0.06	Gray shale with some white clay and hard altered novaculite
20-25	1.35	0.05	Light brown clay with some white clay, gray shale and altered novaculite
25-30	1.50	0.06	Buff clay - some altered hard novaculite
30-35	1.94	0.01	Buff-to-white clay

HOLE NO. BD-10

COORD.-N-9791, E-10712 COLLAR ELEV.-548'
DRILL-BUCKET DRILL TOTAL DEPTH-16.5'

	CORE		LITHOLOGY
INTERVAL IN FEET	%TiO_2	%V_2O_5	Description
0-5	2.72	0.19	Mostly red shale - some novaculite fragments - some gossanized porous quartz with brookite (transported ore)
5-10	1.49	0.09	Mostly red clay - some banded pink, yellow and white clay - some very fine-grained altered novaculite - no brookite
10-15	0.88	0.01	Mostly light-colored altered shale (?), one fragment containing rounded quartz grains
15-16.5	0.77	0.01	Mostly white, buff, and pink altered shale(?) fragments - some angular fragments of silty shale

HOLE NO. BD-11

COORD.-N-9892, E-10707 COLLAR ELEV.-565'
DRILL-BUCKET DRILL TOTAL DEPTH-45'

	CORE		LITHOLOGY
INTERVAL IN FEET	% TiO_2	% V_2O_5	Description
0-5	2.22	0.29	Quartz fragments in red-brown clay - no brookite visible (residual ore)
5-10	1.66	0.29	Porous quartz fragments, in part gossanized - brookite rare - red brown clay coating (residual ore)
10-15	2.85	0.41	Gossanized quartz - flesh-colored clay with white patches and embedded quartz crystals
15-20	3.25	0.36	Flesh-colored clay as above - washed sample showed only small brookite concentration
20-25	2.55	0.41	Few large, white altered shale (?) fragments - several fragments of altered gray-to-white novaculite - flesh-colored clay as above, some of the included quartz crystals brookite-bearing
25-30	1.08	0.12	Mostly buff clay with little included quartz - no brookite
30-35	2.77	0.26	One large, porous brookite-quartz fragment - mostly buff clay some white clay
35-40	1.88	0.39	White altered novaculite fragments - solid brookite-quartz fragments - many buff and white clay fragments some of which contain embedded quartz (no brookite)
40-45	1.25	0.21	Brown-to-buff clay with embedded quartz-brookite rare

HOLE NO. BD-12

COORD.-N-10008, E-10889 COLLAR ELEV.-574.2'
DRILL-BUCKET DRILL TOTAL DEPTH-15'

	CORE		LITHOLOGY
INTERVAL IN FEET	% TiO_2	% V_2O_5	Description
0-5	0.91	0.09	Light brown surface clay with altered novaculite fragments-latter have abundant limonite specks in them - only very small amount of brookite in the clay
5-10	0.99	0.11	Mostly light brown clay - few quartz-gossan fragments and a few porous quartz fragments - brookite rare
10-15	2.30	0.32	Mostly altered novaculite fragments with some light brown clay - no brookite

HOLE NO. BD-13

COORD.–N-10026, E-10797
DRILL-BUCKET DRILL

COLLAR ELEV.-578.2'
TOTAL DEPTH-48'

	CORE		LITHOLOGY
INTERVAL IN FEET	%TiO_2	%V_2O_5	Description
0-5	1.70	0.26	Porous quartz masses and red clay - brookite not common (residual ore)
5-10	1.77	0.31	
10-15	5.15	0.34	Same as above with large quartz, gossanized fragments (residual ore)
15-20	11.28	0.45	Same with some cream and buff clay fragments containing brookite-quartz fragments - brookite rare
20-25	14.75	0.41	Only a few porous quartz fragments all carrying abundant brookite - mostly light red-brown clay
25-30	8.76	0.39	Mostly buff and white clay containing quartz crystals and fragments and abundant brookite
30-35	9.74	0.54	Some barren white clay fragments - some buff clay fragments containing quartz and brookite-quartz - most of the sample is clay
35-40	3.15	0.55	Mostly brown to buff clay with included quartz and brookite-quartz fragments - some hard, porous brookite-quartz fragments
40-45	4.13	0.28	Mostly barren buff and white clay - the buff clay carries smaller amount of quartz fragments than above - some hard, porous quartz fragments with little brookite
45-48	3.52	0.37	Gossanized porous quartz fragments - mostly buff clay with included quartz fragments (washed sample shows only minor percent of brookite)

HOLE NO. BC-1

COORD.-N-9918, E-10526 COLLAR ELEV.-565.8'

DRILL-BAKER CORE TOTAL DEPTH-82'

	CORE		LITHOLOGY
INTERVAL IN FEET	%TiO_2	%V_2O_5	Description
0-5	7.38	0.38	Red and brown gritty clay containing quartz fragments and crystals - much brookite (residual ore)
5-10	9.90	0.41	
10-17	11.80	0.38	Brown gritty clay containing fragments of porous quartz - some brookite (residual ore)
17-20	8.20	0.44	Dark brown gritty clay (residual ore)
20-21	5.85	0.36	
21-24	5.55	0.35	Very fine-grained, plastic buff and cream-colored clay - little brookite
24-28	5.60	0.59	Gray, brown and black, sandy porous quartz - some buff gritty clay
28-32	6.95	0.57	Varicolored gritty clay with much embedded brookite and quartz
32-35	4.45	0.62	Black and buff gritty clay containing much embedded brookite and quartz
35-38	4.60	0.40	Mainly porous quartz - with some brookite and buff clay
38-41	5.20	0.23	Cream-colored plastic clay - no brookite
41-44	4.95	0.29	
44-47	5.45	0.22	
47-50	5.05	0.20	
50-53	4.60	0.41	
53-56	4.70	0.28	
56-59	4.05	0.31	
59-62	5.32	0.28	
62-65	4.90	0.35	Brown and cream-colored plastic clay with some porous quartz fragments and brookite
65-68	4.65	0.24	Greenish-gray clay with abundant disseminated pyrite
68-70	3.75	0.34	Black and green clay and gray granular clay - all containing pyrite - the black clay contains some brookite
70-73	3.60	1.21	Black, granular clay - some porous brookite-quartz masses
73-76	4.50	0.67	Black and gray shale (?) with abundant fine-grained pyrite
76-77	5.05	0.86	Gray green to black shale (?) - some black, porous brookite-quartz at 82'
77-80	5.45	0.77	
80-82	6.15	0.51	

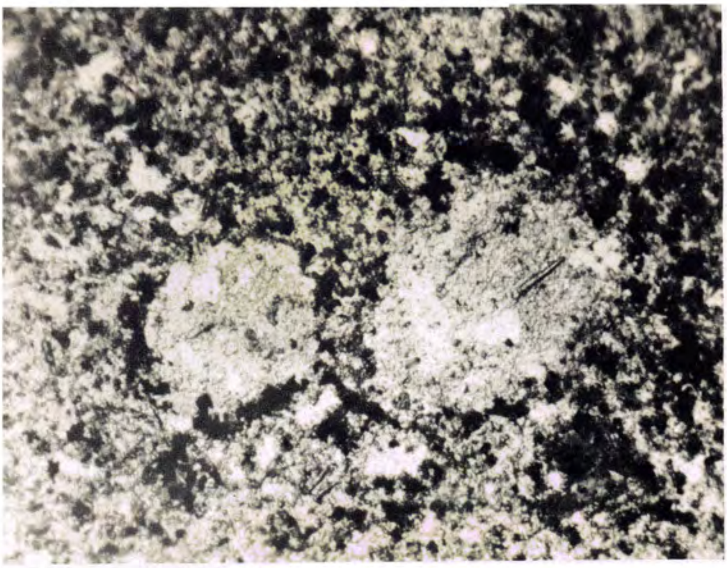
PHOTOMICROGRAPHS OF THIN SECTIONS OF ORES AND IGNEOUS ROCKS FROM THE HOT SPRING COUNTY TITANIUM DEPOSITS

Plates X through XVIII—Magnet Cove Rutile Company Deposit.

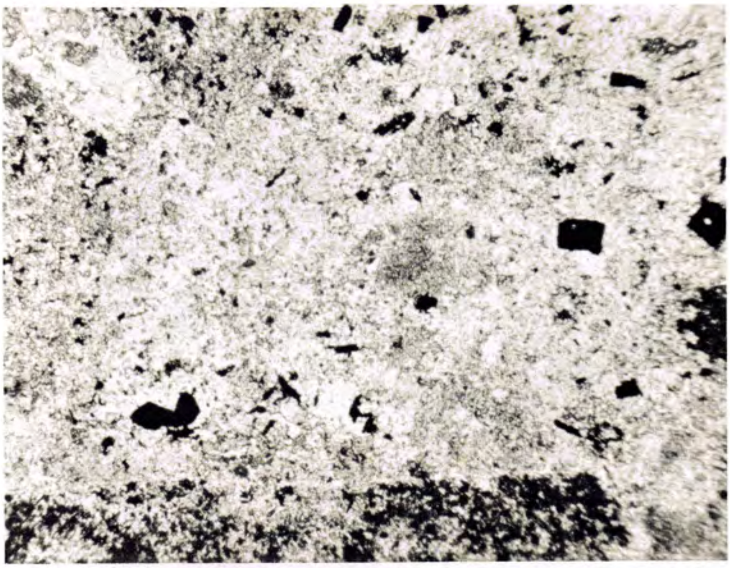
Plates XIX through XXI—Hardy-Walsh Brookite Deposit.

Plates XXI through XXIV—Christy Brookite Deposit.

PLATE X



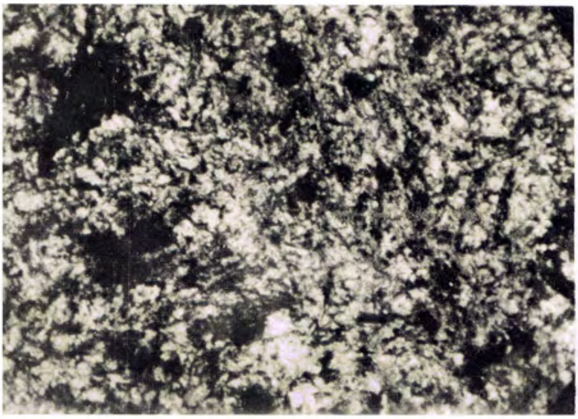
A.



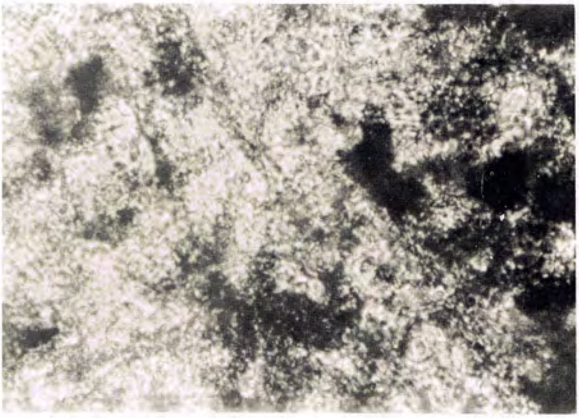
B.

PLATE XI

PHOTOMICROGRAPHS OF THIN SECTIONS OF IGNEOUS ROCKS, MAGNET COVE RUTILE COMPANY DEPOSIT



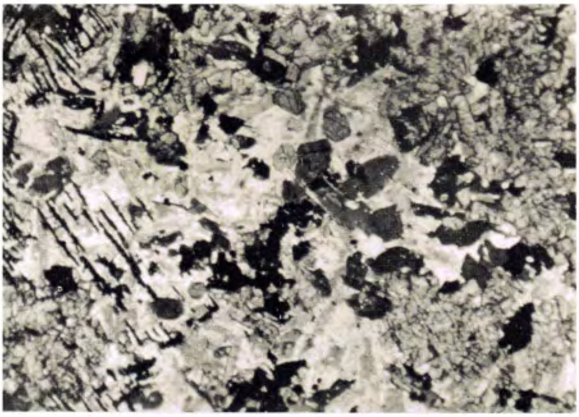
A. Thin section of aegirine phonolite porphyry. Acicular grains are aegirine. Small light gray plates are mainly biotite. Black masses are ilmenite. X 76.



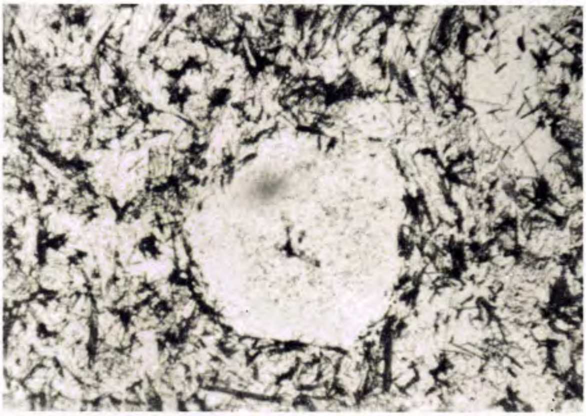
B. Thin section of aegirine phonolite porphyry showing montmorillonite alteration of the orthoclase. The small rods are montmorillonite; black areas are ilmenite and leucoxene. X 115.

PLATE XII

PHOTOMICROGRAPHS OF THIN SECTIONS OF IGNEOUS ROCK, MAGNET COVE RUTILE COMPANY DEPOSIT



A. Thin section of monchiquite from the large dike in the West Pit. Medium gray is titanaugite; dark gray is barkevikite; light gray is chlorite (?). Black is magnetite-ilmenite; white is plagioclase. Note skeleton crystals of magnetite. X 28.



B. Thin section of nepheline tinguaite dike, West Pit. Acicular grains are aegirine. Light areas are nepheline and orthoclase. The pseudomorph is after nepheline. X 100.

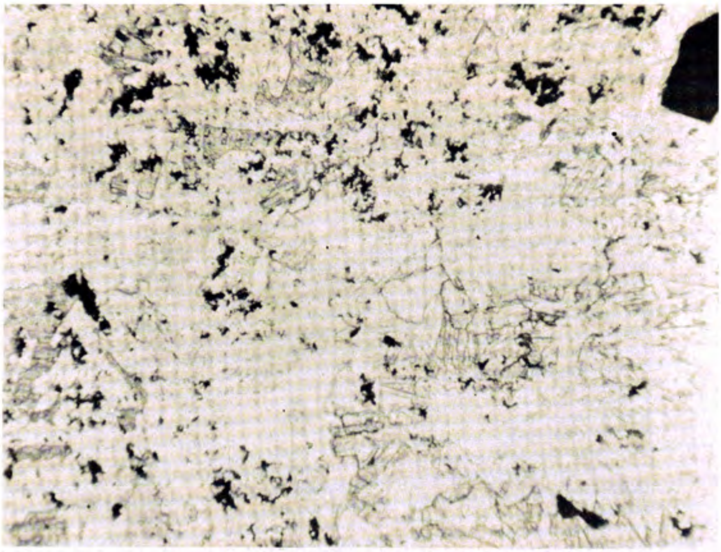
PLATE XIII

PHOTOMICROGRAPHS OF THIN SECTIONS OF VEINS, MAGNET COVE RUTILE COMPANY DEPOSIT

A. Thin section of sugary-textured albite-dolomite vein, West Pit. Dark gray areas are albite; black areas are rutile and leucoxene. X 21.

B. Same thin section as "A" with crossed nicols.

PLATE XIII



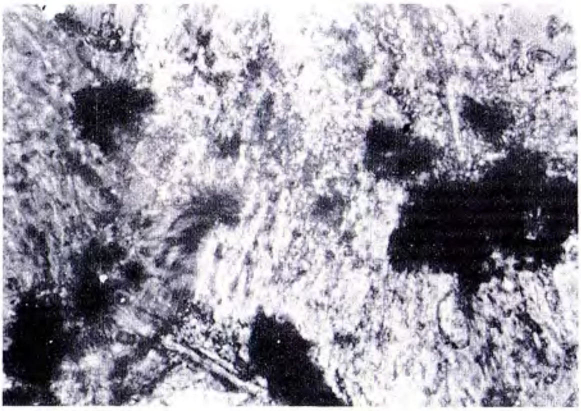
A.

B.

PLATE XIV

PHOTOMICROGRAPHS OF THIN SECTIONS OF VEINS, MAGNET COVE RUTILE COMPANY DEPOSIT

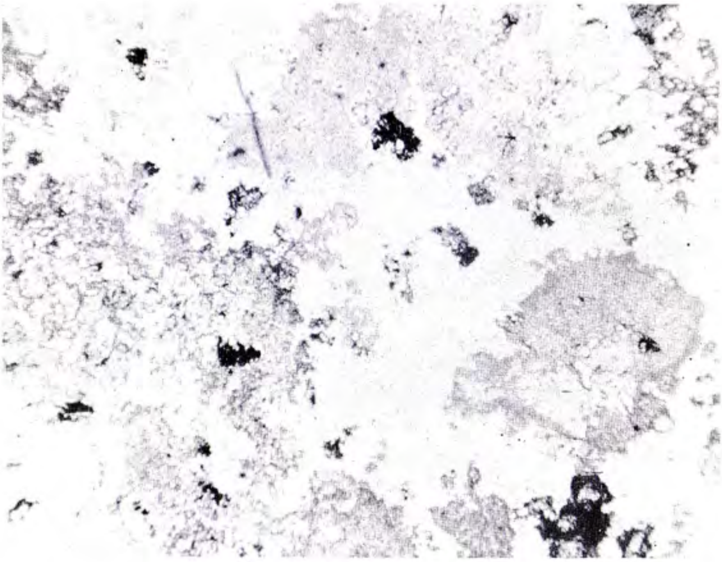
A. Thin section of sugary-textured albite-dolomite vein, West Pit, showing montmorillonite alteration of albite. Light gray is albite; darker gray streaks in albite are montmorillonite. Black grains are rutile. X 100.



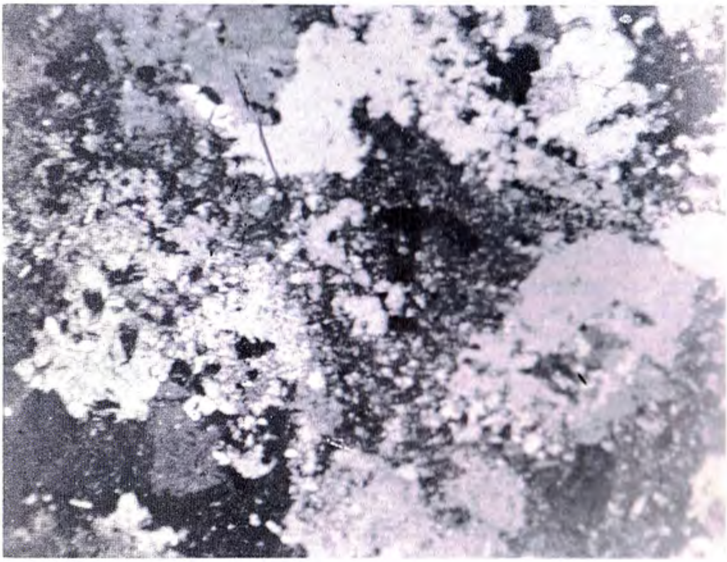
B. Thin section of sugary-textured albite-dolomite vein, West Pit, showing montmorillonite alteration of albite. White areas are remnants of albite. Black areas are leucoxene. Small rods and plates are montmorillonite. X 450. Crossed Nicols.

PLATE XV

PHOTOMICROGRAPHS OF THIN SECTIONS OF VEINS, MAGNET COVE RUTILE COMPANY DEPOSIT



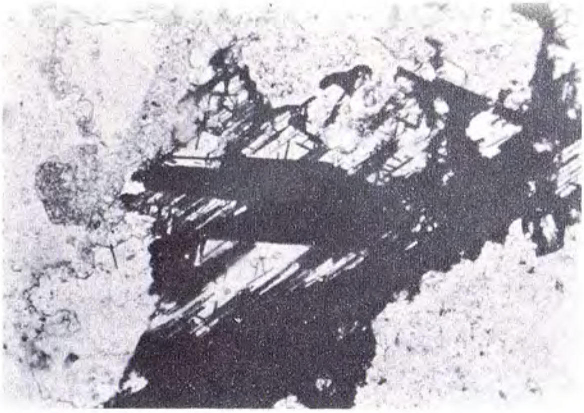
A. Thin section of microcline-calcite vein, West Pit. White areas are microcline; gray areas are calcite; black areas are rutile. X 21.



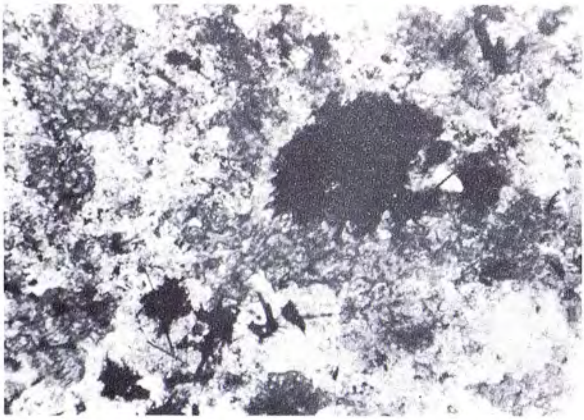
B. Same thin section as "A", with crossed nicols.

PLATE XVI

PHOTOMICROGRAPHS OF THIN SECTIONS OF VEINS, MAGNET COVE RUTILE COMPANY DEPOSIT



A. Thin section showing network of acicular rutile in microcline-calcite vein, West Pit. X 96.



B. Thin section showing variable size of rutile needles in microcline-calcite vein, West Pit. X 86.

PLATE XVII

PHOTOMICROGRAPHS OF THIN SECTIONS OF VEINS, MAGNET COVE RUTILE COMPANY DEPOSIT

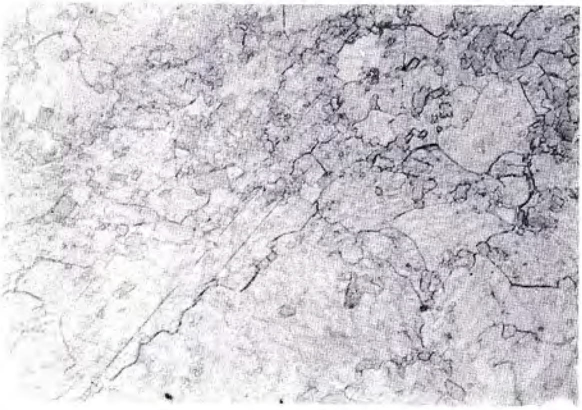
A. Thin section showing leucoxene alteration of rutile in microcline-calcite vein, West Pit. Black areas are leucoxene. Gray areas within leucoxene are residual rutile. X 72.

B. Thin section of montmorillonite-like mineral in slightly altered microcline-calcite vein, West Pit. The clay mineral is best developed along the boundaries of the microcline (light gray) grains. X 450.

PLATE XVIII

PHOTOMICROGRAPHS OF THIN SECTIONS OF VEINS, MAGNET COVE RUTILE COMPANY DEPOSIT

A. Thin section of coarse-grained albite-perthite-carbonate vein, West Pit. All grains are feldspar. Crossed nicols. X 80.

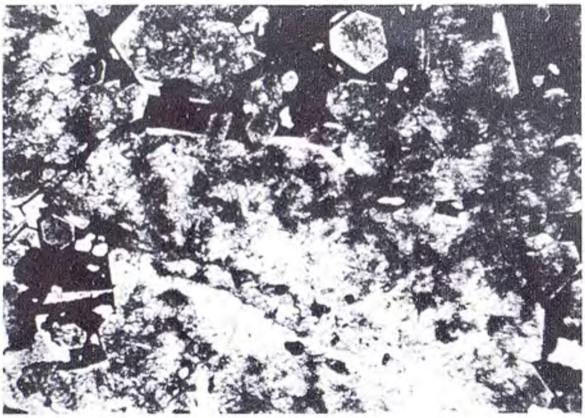


B. Thin section of dolomite-biotite vein, West Pit. Light gray areas are dolomite; darker gray plates are biotite. X 80.

PLATE XIX

PHOTOMICROGRAPHS OF THIN SECTIONS OF COUNTRY ROCK AND VEINS, HARDY-WALSH BROOKITE DEPOSIT

A. Thin section of gray quartzite. This quartzite is recrystallized Arkansas novaculite. Crossed nicols. X 24.

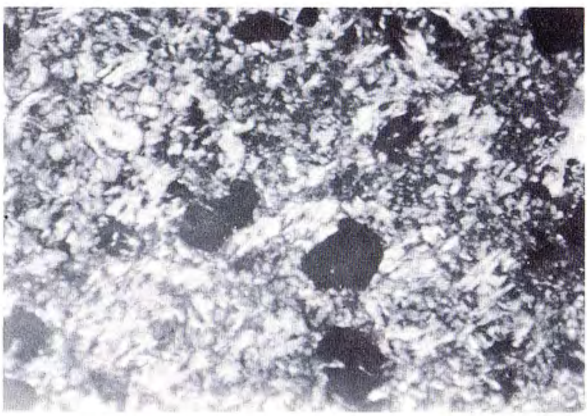


B. Thin section of quartz-goethite vein. Note rims of clear quartz around centers of quartz containing abundant rutile needles. Black areas are goethite. X 28.

PLATE XX

PHOTOMICROGRAPHS OF THIN SECTIONS OF VEINS, HARDY-WALSH BROOKITE DEPOSIT

A. Thin section showing brookite grains lying in fine-grained quartzite. The quartzite is Arkansas novaculite which was recrystallized after the introduction of brookite. X 24.

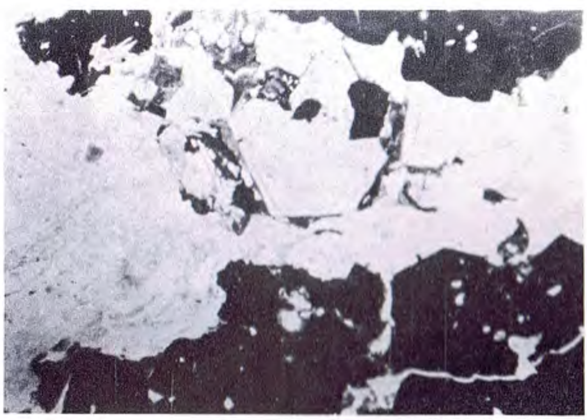


B. Same as "A" with crossed nicols. Large white areas are coarse quartz; white shreds are taeniolite; groundmass is fine-grained quartz. X .24.

PLATE XXI

PHOTOMICROGRAPHS OF THIN SECTIONS OF VEINS, HARDY-WALSH DEPOSIT

A. Thin section showing brookite lying in coarse-grained quartz. Skeleton grains are altered taeniolite. Note brookite grains (solid black areas) cutting central skeleton grain. Crossed nicols. X 24.

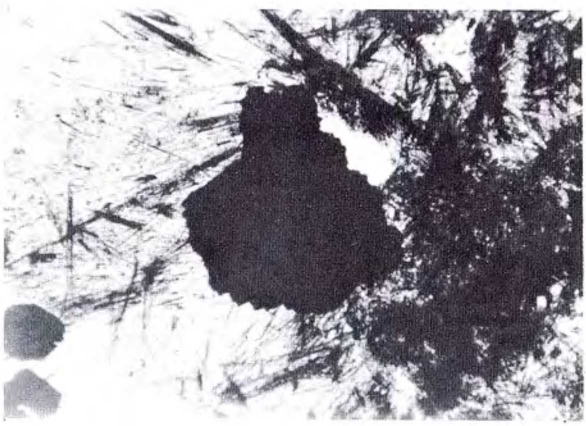


B. Thin section showing brookite-quartz vein which cuts barren gray quartzite. Black areas are brookite; white areas are quartz; gray areas are limonite-stained kaolinite. X 87.

PLATE XXII

PHOTOMICROGRAPHS OF THIN SECTIONS OF ORE, CHRISTY BROOKITE DEPOSIT

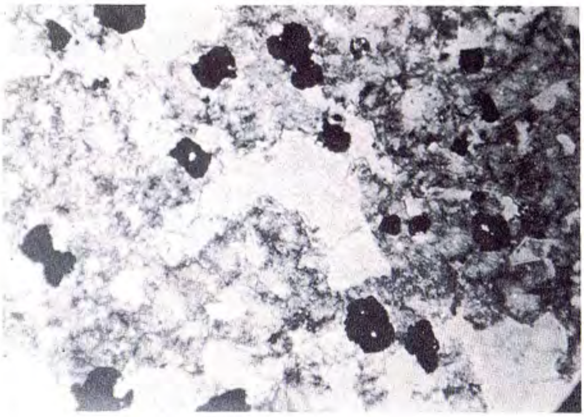
A. Thin section of dark quartzite of residual ore, Christy brookite deposit. The gray areas are quartz and black areas are brookite. The fine needles are rutile and larger acicular grains are altered taeniolite. X 24.



B. Same thin section as "A" with higher magnification. X 87.

PLATE XXIII

PHOTOMICROGRAPHS OF THIN SECTIONS OF ORE, CHRISTY BROOKITE DEPOSIT



A. Thin section of primary ore, Christy brookite deposit. Black areas are brookite; dark gray areas are clay minerals; light gray areas are quartz. X 24.

B. Thin section of primary ore, Christy brookite deposit. Large acicular grains are altered taeniolite; fine needles are rutile. X 24.

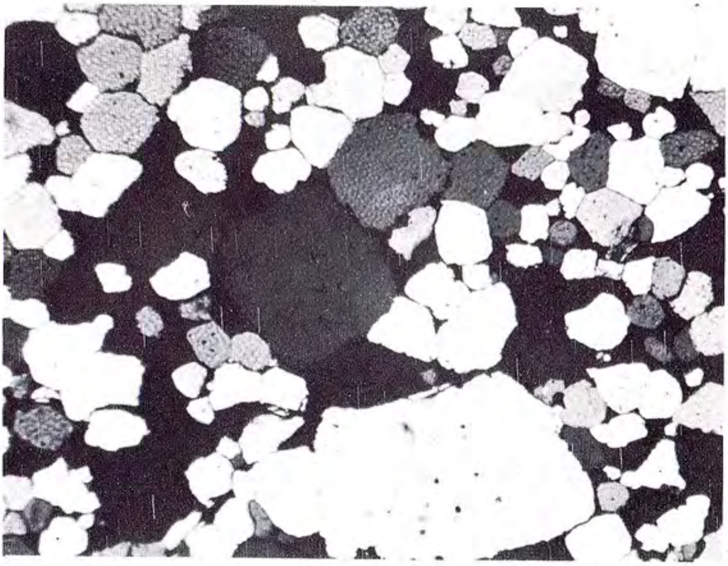
PLATE XXIV

PHOTOMICROGRAPHS OF THIN SECTIONS OF NOVACULITE AND BROOKITE VEIN EXPOSED ALONG HIGHWAY 270 AT MAGNET, ARKANSAS

A. Thin section of recrystallized novaculite. Crossed nicols. X 24.

B. Thin section showing brookite and taeniolite in recrystallized novaculite. Large black grains are brookite. White shreds are fresh taeniolite; dark shreds on left are altered taeniolite. Note that altered taeniolite is mainly restricted to coarsest quartz areas and fresh taeniolite is restricted to finer quartz areas. Crossed nicols. X 24.

PLATE XXIV



A.

B.

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