STATE OF ARKANSAS

ARKANSAS GEOLOGICAL SURVEY
William V. Bush, Director and State Geologist

BULLETIN 24

MINERAL, FOSSIL-FUEL, AND WATER RESOURCES OF ARKANSAS

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Little Rock, Arkansas

1997

STATE OF ARKANSAS
Mike Huckabee, Governor

ARKANSAS GEOLOGICAL COMMISSION
William V. Bush, Director and State Geologist

COMMISSIONERS

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PREFACE

Since the First Geological Survey of Arkansas was conducted by Dr. David Dale Owens in 1857-1858, two general reports of Arkansas mineral resources have been published by the state: Outlines of Arkansas Mineral Resources in 1927; and Bulletin 6, Mineral Resources of Arkansas, in 1942. Bulletin 6 was revised and reprinted in 1959. It was reprinted with minor revisions in 1985 and 1992.

Bulletin 24 continues the tradition of providing geologic information on Arkansas' nonrenewable mineral, fossil-fuel, and water resources. It should not be inferred that all the mineral resources described here are present in Arkansas as economic deposits. Marginal occurrences are included with the realization that rapid changes in mining and processing technologies, and the development of new uses for minerals may someday make them economically viable. The section on water has been greatly expanded to make the discussion more nearly commensurate with the importance of water in our lives. Many sections have been expanded to provide more information on the various minerals, their ores, and applications.

Unlike Mineral Resources of Arkansas, this bulletin includes a glossary and reference list. The main references for each resource follow its discussion. In addition, following the text is a list of general references covering broader aspects of the geology of the state and its mineral, fossil-fuel, and water resources. For any individual desiring more detailed information, the Arkansas Geological Commission (AGC) has available both published and open-file reports and maps relating to the geology and production histories of the commodities discussed here.

ACKNOWLEDGMENTS

We gratefully acknowledge the help of the following individuals in preparing this bulletin. Walter K. Mayfield and Vance T. Pleasant (both of the Cartography Office of the AGC) prepared the illustrations. Henry S. deLinde made helpful suggestions for improving the text. Edward J. Van Schaik (formerly of the Arkansas Department of Pollution Control and Ecology) and Terrance W. Holland (U. S. Geological Survey, Water Resources Division) suggested several changes which improved the section on water resources. Carl H. Bussey (Arkansas Oil and Gas Commission) provided guidance in the area of oil and gas conservation. Mike Hall (Superintendent, Crater of Diamonds State Park) supplied data about diamonds recovered at the park. David A. Burnett (Freeway Design Division, Arkansas Highway and Transportation Department) furnished materials statistics for the construction of Interstate Highway 40.

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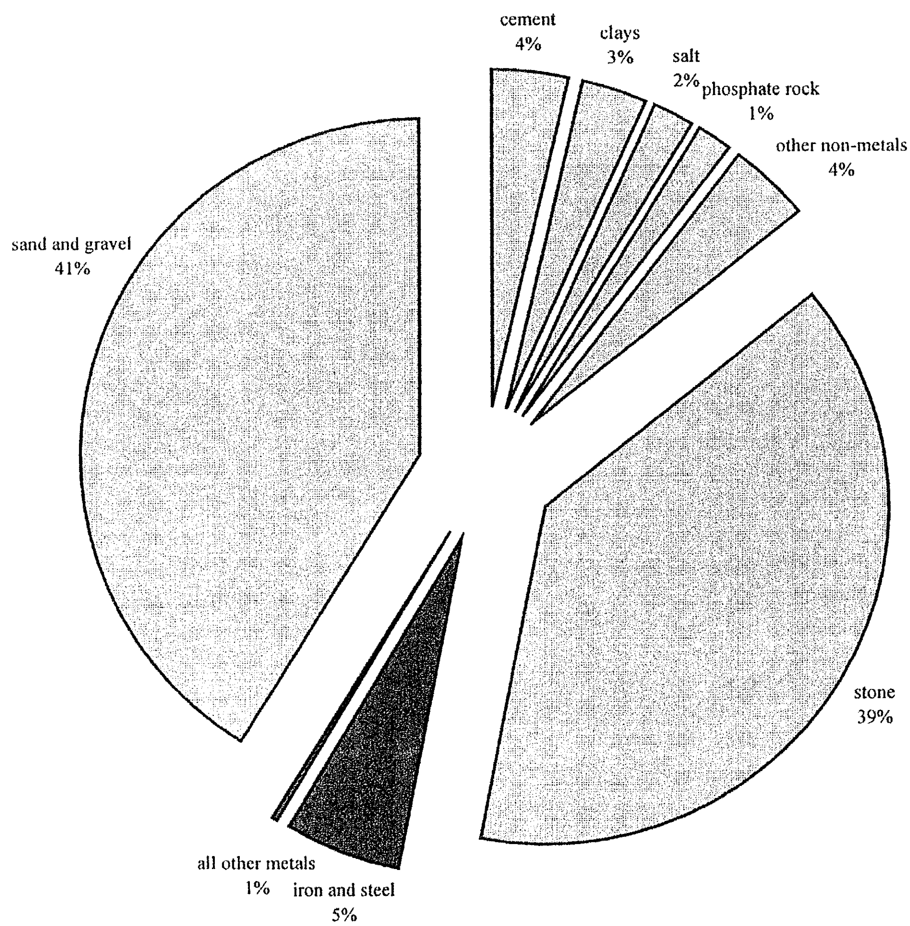


Figure 1. Relative amounts of mineral resources consumed by U. S. citizens, excluding fossil-fuels and water. Percentages calculated from data provided by the Mineral Information Institute, Inc., of Denver, Colorado. Nonmetals, gray: metals, dark gray.

MINERAL, FOSSIL-FUEL, AND WATER RESOURCES OF ARKANSAS

by

The Arkansas Geological Commission

THE NEED FOR MINERAL, FOSSIL-FUEL, AND WATER RESOURCES

Each year every inhabitant of the United States consumes a surprising quantity of non-renewable earth materials. If a citizen's yearly quota of rocks, minerals, and metals arrived as a single delivery, it would consist of 9,000 pounds of sand and gravel, 8,500 pounds of stone, 800 pounds of cement, 600 pounds of clay, 450 pounds of salt, 310 pounds of phosphate rock, 900 pounds of other nonmetals, and 1,340 pounds of metals. Every person also consumes 7,800 pounds of petroleum, 5,000 pounds of coal, 5,000 pounds of natural gas (all fossil fuels), and 1/20th of a pound of uranium – for a grand total of 20 tons! The figures are supplied by the Mineral Information Institute, Inc., of Denver, Colorado. Let's take a look at the use of 11 tons of non-fuels (fig. 1).

The first 3 materials listed make up 84 percent of the total and are used mostly to make concrete for the construction of highways, driveways, sidewalks, dams, many buildings, and the foundations of most homes and offices. Next is clay, which has a variety of end products, including bricks, many types of ceramic tile, and porcelain fixtures? Most salt is consumed to remove ice from roadways and to manufacture numerous chemicals. Phosphate rock, through processing, becomes fertilizer and a component of many detergents. In the other nonmetals, there is a diversity of rocks and minerals having special or unique properties that make them invaluable. Last are the metals, which make up only 6 percent of our total annual allotment, but are absolutely indispensable because of their myriad uses. The 9 tons of fossil fuels are used primarily to generate electric power and heat and to fuel our transportation systems.

A major use of concrete is for highway construction. An example: U. S. Interstate 40, a 4-lane highway extending 284 miles across Arkansas from the Mississippi River on the east to Oklahoma on the west. Data were supplied by the Arkansas Highway and Transportation Department (David A. Burnett, oral communication, 1996). To simplify the calculations, bridges and access and exit ramps were ignored. Construction of the 4-lane roadway required approximately 4,500,000 tons of concrete (composed of 3,920,000 tons of crushed stone and 600,000 tons of cement), 300,000 tons of steel as reinforcement and guard railing, and another 3,200,000 tons of crushed stone and 40,000 tons of asphalt (a product of petroleum distillation) for the shoulders.

Among the metals, steel is the most widely used. An example: The automobile industry is a major consumer. About 5.5 million automobiles are manufactured each year in the United States. Based on 1994 data provided by the Mineral Information Institute, an average car contains about 2,100 pounds of steel, 160 pounds of aluminum, 70 pounds of copper, zinc, manganese and other metals, and more than 200 pounds of plastics, composed in large part of petrochemicals derived from petroleum and natural gas. The car's fuel, lubricants, and antifreeze are also petroleum-derived compounds, as are the automobile's paints, tires, and most upholstery.

In years past, students were taught that Arkansas could be self-sufficient because of the state's wide variety of raw materials. This belief was more nearly true early in Arkansas' history because people's needs were simpler then. However, even Native Americans depended on trade with peoples from other parts of the country as did the early European settlers. Long gone are the days when Arkansans can realistically pretend that self-sufficiency is attainable, because people now require a much more diverse supply of raw materials to maintain present life styles. This country is not self-sufficient, much less Arkansas. Nor is any country of the world. As a nation, we depend on imports for a great many of the materials we consume, and for some products of mining we are entirely dependent on foreign supplies. This situation exists because, in Arkansas and the United States, deposits of many minerals and fuels are not commercially viable when evaluated against world markets. This is particularly true for metal-bearing ores and, to a significant degree, for petroleum. In Arkansas, for example, 12 different metals were mined at times during this century. Today not one is mined. However, Arkansas' raw materials industries yield several commodities for export. Much of the world is dependent upon our bromine and several neighboring states import gravel and crushed stone from Arkansas because they have little or no competitive sources closer. Arkansas exports crushed stone, a product made from both igneous and sedimentary rock that is applied as surface coating granules on asphalt or fiberglass-based roofing materials, throughout the southern United States. Novaculite, in the form of sharpening stones for knives and other implements, is recognized globally as a product of Arkansas.

All of the rock, mineral, and fossil-fuel resources covered in this volume are non-renewable within a human life span. When a mineral deposit or an oil field is depleted, a new one must be located. When compared with the original deposit or field, experience has shown that the replacement will be more difficult to discover, will probably occur at greater depth below the surface, and will be more costly to develop. Already in Arkansas, there has been a depletion of some of our mineral resources; the shallow lead and zinc deposits in north Arkansas are examples. Coal was once the major product of Arkansas' mining industry. The thick, more readily accessible beds have been largely mined out, so little coal is mined today even though considerable reserves of high quality remain.

Arkansas has an abundance of water compared to many other states. However, there are areas where ground water is being consumed more rapidly than it is being recharged by natural processes. More than 3,300 gallons of water per person is utilized daily in our state. About 40 percent of the water comes from surface-water sources and about 60 percent from ground-water sources (T. W. Holland, 1993). About 54 percent is actually consumed and 46 percent is returned to the hydrologic system (USGS National Water Summary, 1987).

Most people are aware of the ways in which water is used in and around our homes – for cooking, drinking, washing, laundering, bathing, to remove and transport human wastes, for watering the yard and/or garden, and for washing the car. All of these are considered domestic uses. Yet few people realize *how much* water is used. The domestic water consumption in the average household has been calculated to be about *90 gallons per person per day.*

All natural resources need to be managed and conserved. Conservation involves careful planning for the effective development and wise use of the resources – with emphasis on minimizing waste. Recycling of discarded products saves raw materials and saves the added energy for processing from a raw ore. Reclaiming of mined or otherwise disturbed lands allows them to be used for other purposes. Purifying and returning water to the hydrologic system provides for its continued availability. Arkansas' mineral and fuel wealth is directly related to its geology. The varieties of mineral resources and their distribution vary, being dependent upon existing rock types and the area's geologic history. The quantity and quality of water, both surface and underground, also bear witness to this fact. A better understanding of why mineral resources are where they are begins with an examination of the state's geomorphology and underlying geology.

GEOMORPHOLOGY

Geomorphology is the science of landforms. It encompasses the classification, description, origin, and development of the present pattern of landforms. The discussion here will be largely restricted to summaries of the various terranes (physiographic areas) present within the state. Each geographic province has undergone a unique succession of geologic events, which have imparted a specific suite of landforms (or physiographic style) so that each province is physiographically distinct from the others.

Satellite images, topographic mapping, and aerial photographs of Arkansas clearly show that the state is divided into two roughly equal-sized, but markedly different areas of sharply contrasting landform patterns (fig. 2a) along a line trending generally northeast-southwest across the state. Both areas are further divisible into smaller regions. The southeastern portion of Arkansas is in the Gulf Coastal Plain province, and the northwestern portion is in the Interior Highlands province (fig. 2b). Of Arkansas' 53,320 square miles, the highland area covers about 48 percent and the lowland region occupies about 52 percent. About 780 square miles (about 1.5 percent) of Arkansas is covered by impounded surface water.

The Gulf Coastal Plain province is topographically low and ranges from remarkably level undiversified terrain in the eastern counties to gently rolling subdued hills in the southwestern counties. The Mississippi River Alluvial Plain includes the largest tracts of irrigated cropland in the state. It is popularly referred to as "The Delta", although geologically it is not a delta. The overall gradient is southward at less than 1 foot per mile. The monotony of the plain is interrupted only by Crowley's Ridge, a prominent but narrow ridge, 2 to 11 miles wide, that extends brokenly from Phillips County northward into Missouri. It ranges in height from 100 to 200 feet above the surrounding plain. Almost all the Mississippi River Alluvial Plain is underlain by flat-lying, predominantly alluvial sediments of Quaternary age, which were deposited upon Tertiary units.

The more rolling terrain of the southwestern part of the Gulf Coastal Plain province is termed the West Gulf Coastal Plain (fig. 2b). Because it is more hilly, this area is less suitable for irrigation, but it encompasses a large part of the state's timber resources. Most of the area is underlain by unconsolidated sediments of Quaternary and Tertiary age and by weakly lithified sedimentary rocks of Tertiary age. However, a sizable area, extending from Sevier and Little River Counties eastward to Clark County, is underlain by moderately to well lithified sedimentary rocks of Cretaceous age. As much as 500 feet of relief is present in this area.

The northwestern part of Arkansas, the Interior Highlands province, is, for the most

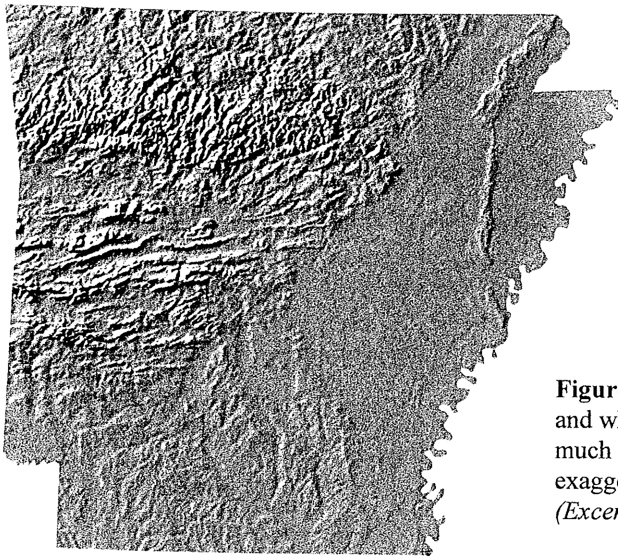


Figure 2a. A digital shaded-relief portrayal of Arkansas. A black and white photograph of Arkansas from outer space would look much like this. Scale is approximately 1: 3,500,000. Vertical exaggeration X2.
(Excerpted from Thelin and Pike, 1991)

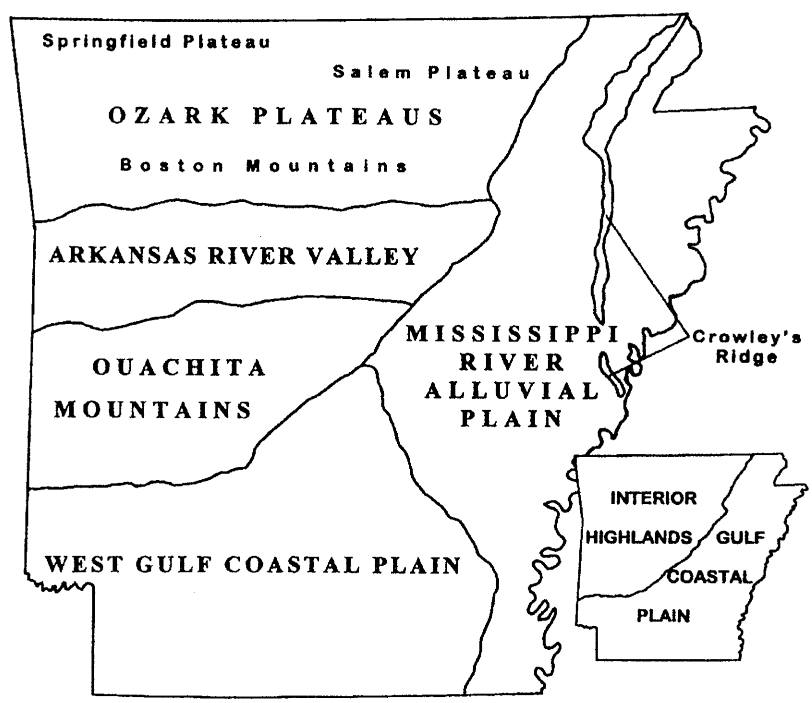


Figure 2b. The physiographic divisions of Arkansas. The two major divisions are shown on the small inset map.

part, much higher and topographically more rugged than the Gulf Coastal Plain. Within the highlands, 3 major divisions are recognized. From north to south they are the Ozark Plateaus, the Arkansas Valley, and the Ouachita Mountains. Except for the river and stream bottoms, which are occupied by relatively recent alluvial sediments, the highlands are underlain by thoroughly lithified sedimentary rocks of Paleozoic age.

The Ozark Plateaus province is a plateau, but one that has been so thoroughly dissected by stream erosion that it is barely recognizable as such to the non-geologist (fig. 2b). The Arkansas part of the province is the south flank of a broad uplift centered in southeastern Missouri. The drainage pattern is strongly dendritic. Typically, valley walls are steep and the valley floors are narrow.

Three subdivisions are recognized within the Ozark Plateaus. The northernmost of these is the Salem Plateau. Extending from southern Missouri southward into Arkansas, it is lower in average elevation and more subdued topographically than the other two subdivisions. Most of the area is underlain by dolostones and interbedded sandstones with a barely perceptible southward dip.

The Springfield Plateau occupies an irregular band separating the Salem Plateau and the Boston Mountains. It is intermediate in elevation and ruggedness between the two. Most of the Springfield Plateau is underlain by a limestone and chert unit of Mississippian age which dips very gently southward.

The Boston Mountains subdivision along the southern margin of the Ozark Plateaus is the most easily recognizable segment. It includes the highest mountains and the most rugged terrain in the Ozark area of Arkansas. The highest elevation, 2,561 feet above sea level, is Buffalo Lookout in southwest Newton County. The principal bluff-forming rocks in the Boston Mountains are almost exclusively sandstones of Pennsylvanian age which dip gently to the south.

The flat-topped hills and valleys of the dissected Ozark Plateaus and the linear fold mountains of the Ouachita Mountains are separated by the Arkansas Valley province. This low-lying area is dominated by the broad valley of the Arkansas River and, to a lesser extent, by the valley of the Petit Jean River, both of which flow eastward. The southern part of the Arkansas Valley province includes scattered mountains that rise steeply above the lowland floor. All trend essentially east-west, parallel to the mountain ridges of the Ouachita Mountains to the south. The crest of one of these, Magazine Mountain in Logan County, is the highest elevation in the state, 2,753 feet above mean sea level. Extensive areas along the Arkansas river are underlain by thick deposits of alluvium. Elsewhere the province is floored by rocks of Pennsylvanian age, gently deformed in the northern part and strongly folded in the southern part.

The southernmost division of the Interior Highlands is the Ouachita Mountains (fig. 2b). Distinctly different than the terrain of the Ozark Plateaus in form, the mountains of the Ouachitas are narrow-crested, notably linear ridges separated by relatively broad valleys (fig. 3). Mountains and valleys trend essentially east-west. A marked exception to this trend is the Zig Zag Mountains, in portions of Garland and Hot Spring Counties. Here the ridges and valleys trend northeast-southwest. Many of the ridge crests in the Ouachita Mountains are underlain by an erosion-resistant unit of Devonian and Mississippian age; others are held up by Ordovician, Silurian, and Pennsylvanian sandstone units. For the most part, the intervening valleys are underlain by less resistant shales. In contrast to the dendritic drainage pattern of the Ozark Plateaus, the drainage pattern of the Ouachita Mountains is trellis-like.

The rocks underlying the Ouachita province are predominantly sedimentary, some displaying very low grade metamorphic effects.

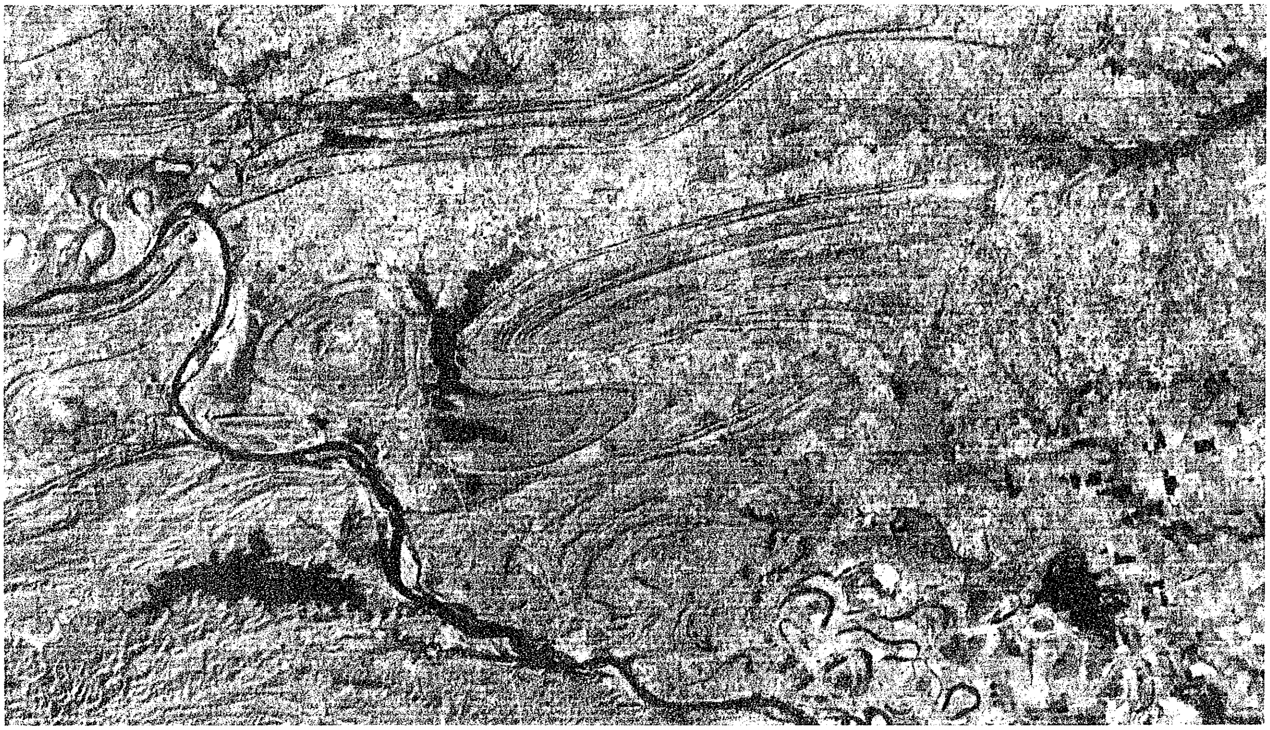


Figure 3. U. S. Satellite (Landsat) image of the eastern Ouachita Mountains and vicinity of central Arkansas. Patterns of folded sedimentary rock units typical of fold-belt mountains are notable. Lake Maumelle (lower left), Lake Conway (above and to the right).

The units have been intensely folded and faulted and range in age from Late Cambrian to Middle Pennsylvanian.

GEOLOGY

Rocks are generally arranged into 3 major categories: igneous, metamorphic, or sedimentary. Igneous rocks are those rocks that have solidified from molten or partly molten mineral matter. Metamorphic rocks are those that have been altered in the solid state from some pre-existing condition in response to significant changes in temperature, pressure, or chemical environment. Sedimentary rocks are composed of particles of sediment, which are derived by the weathering and/or the erosion of pre-existing rock. Most of the rocks at the surface in Arkansas are classified as sedimentary (fig. 4), but there are a few igneous (with adjacent contact metamorphic rocks) and very low grade regional metamorphic rocks in Arkansas as well.

A sedimentary rock can be thought of as consisting of two components: the particles and the cement that holds the particles together. However, the unconsolidated sediments of eastern Arkansas are considered sedimentary rocks even though the sediments are rarely lithified. Sedimentary rocks can be classified as either clastic, referring to those rocks made up of grains of sand, silt, and clay, or chemical, which includes rocks made up of shell fragments, saline water deposits, and other materials that are deposited from solution. The most common clastic sedimentary rocks are shales, siltstones, and sandstones. The most common chemical sedimentary rocks are limestone and dolostone

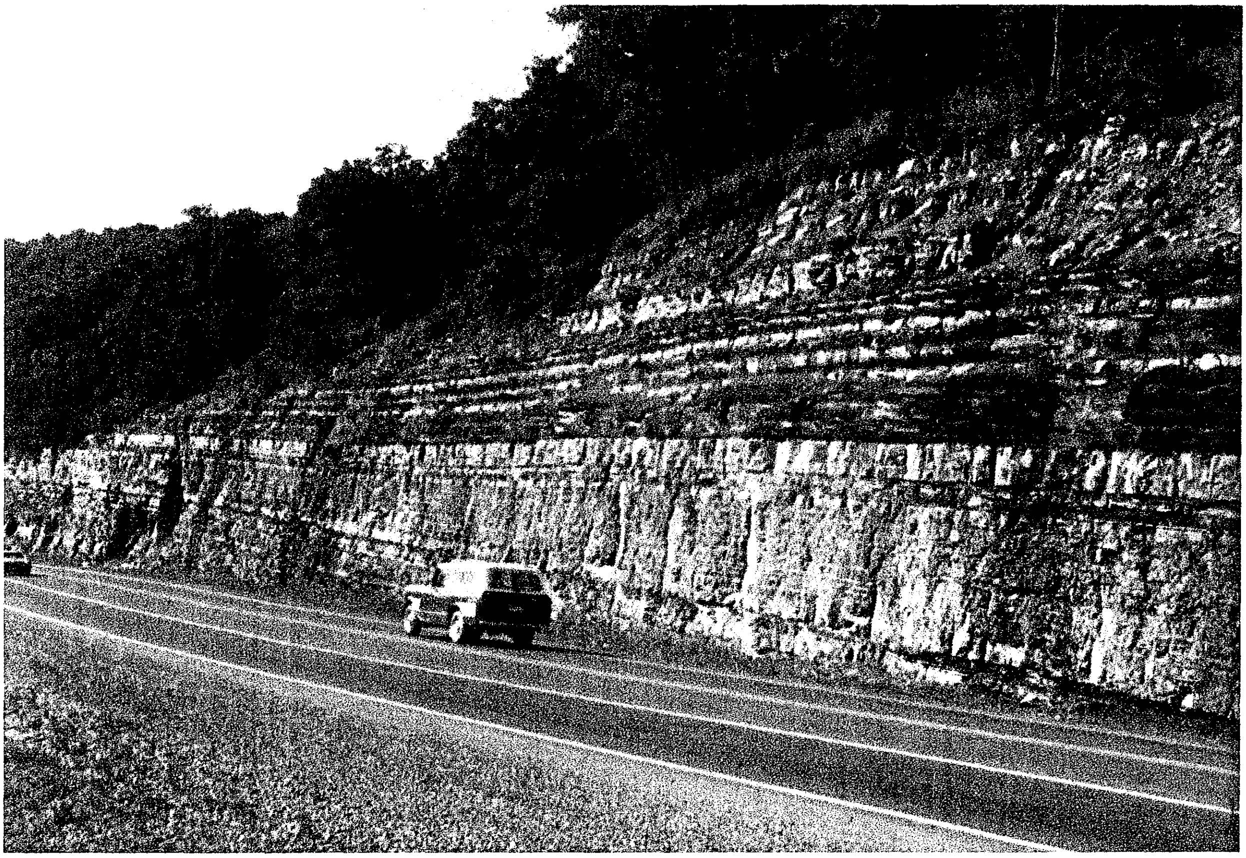


Figure 4. Interbedded flat-lying limestone and shale of the Ozark Plateaus. Lighter units are limestone, darker units are shale. Arkansas Highway 65 near Marshall, Searcy County.

In order to understand the formation of sedimentary rocks, there must be an understanding of the processes that create the original particles of sediment, the mechanisms of sediment transport, the processes of deposition or precipitation of a given sediment, and, finally, what has happened to the sediment during the vast amount of geologic time that is involved. By study of the rocks and their equivalent modern depositional systems, geologists recognize that most of the sedimentary rocks in the Paleozoic Highlands of Arkansas are marine in origin. In the southern and eastern parts of the state, the sedimentary deposits are predominantly fluvial.

The igneous rocks of Arkansas are of very limited extent and exposures make up less than 0.1 percent of the entire area of the state. Most are exposed in a total of 15 square miles, principally in Pulaski, Saline, Hot Spring, Garland, and Pike Counties. A few small igneous dikes and sills are present outside the Ouachita region, mostly in the Arkansas Valley, but one small intrusion is known in the Boston Mountains. Except for some localized contact metamorphism adjacent to the larger igneous intrusions, only very low-grade metamorphic rocks are known in the state.

Arkansas can be divided into a highland area and a lowland region, as described in the geomorphology section. The rocks in the highland area are dominated by well-lithified sandstones, shales, limestones, and dolostones of Paleozoic age. A thin drape of much younger unconsolidated clays, sands, and gravel, termed alluvium, is often found in valley floors and associated with the streams and rivers. The sediments of the lowlands consist principally of unconsolidated clay, sand, and gravel of the Quaternary Period, as well as consolidated deposits of marl, chalk, sand, and gravel of the Cretaceous, and poorly consolidated sedimentary layers of clay, sand, silt, limestone, and lignite of the Tertiary Period.

At the time that most of the sediments that make up the rocks in the highland region of Arkansas were being deposited, north Arkansas was a shallow south-sloping sea floor (continental shelf), the Arkansas River Valley was near the edge of the shelf, and the Ouachita area was a deep abyssal plain (see **summary of geologic history**, p. 9 - 10). An abyssal plain is the relatively smooth and deep (more than 3,000 feet below sea level) parts of the ocean floor where accumulating sediments have buried the preexisting topography. Toward the end of the Paleozoic Era, a broad uplift domed the Ozark strata with little structural disruption. At the same time, a collision of two of the earth's mobile continental plates compressed the sediments of the abyssal plain into the Ouachita Mountains. This multimillion-year-long process folded and faulted the Ouachita strata into a structurally complex mountain chain. The Arkansas River Valley area is the transition zone between the structurally simple Ozarks and the structurally complex Ouachitas with subdued characteristics of each region.

Today the rocks of the Ozarks are in relatively flat-lying layers (overall the sedimentary layers are slightly tilted to the south), carved by streams into dendritic drainage patterns. Because shales and siltstones erode faster than sandstones and limestones, the typical topography is flat-topped mountains with stepped flanks. The topographic expression of the Ouachitas, on the other hand, is controlled not only by the relative resistance to erosion by the different lithologies, but also by the internal structure of the strata. The strata are complexly folded and frequently faulted (fig. 5). The mountains tend to be east-west-trending ridges held up by the more erosionally resistant rocks and separated by valleys underlain by less resistant rocks. The Arkansas River Valley is characterized by much less intensely folded and faulted strata than the Ouachita region. The effects of erosional processes left the synclines as topographic highs (mountains) and the anticlines as valleys.

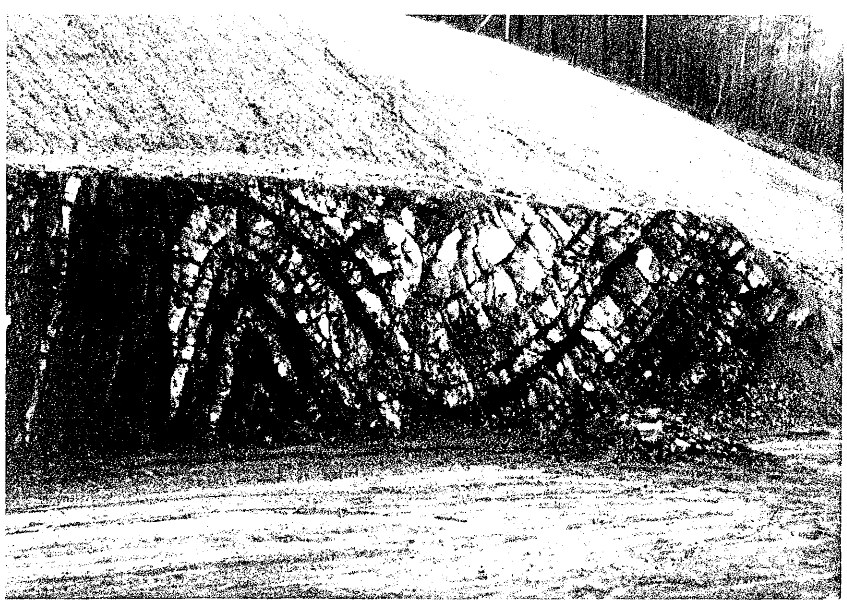


Figure 5. Folded and faulted shale and sandstone of the Ouachita Mountains. Hot Springs U. S. 270 bypass, Garland County.

The rocks and sediments of the Mississippi River Alluvial Plain and West Gulf Coastal Plain are much younger than those of the Interior Highlands. The Cretaceous-age rocks of southwest Arkansas were deposited in and along the margin of a shallow sea. The Tertiary-age materials of the southern part of the state represent marginal marine conditions, both on- and off-shore deposits. The Quaternary-age unconsolidated sediments of eastern Arkansas are dominated by material washed into the region by water released during the interglacial phases of the Ice Age and modern sediments deposited by rivers and streams. Crowley's Ridge is an isolated erosional remnant carved by rivers to either side, possibly with some structural control related to ancient seismic activity. Significant deposits of wind-blown dust (loess) were also deposited across Arkansas during the Quaternary.

Arkansas' rocks, minerals, fossils, and fossil fuels, and its water resources are the result of a long and complex history, dominated by prolonged episodes of deposition, mountain building, and erosion. The interaction of the 3 processes, along with several others, has affected different parts of the state in diverse ways and to various degrees. Long-term changes in climate also played a significant role. This long history is summarized below.

GEOLOGIC HISTORY OF ARKANSAS: A SUMMARY

Age boundaries in millions of years (Ma)

CENOZOIC ERA

Quaternary Present time to 1.6 Ma

Holocene (Present to .01 Ma): Frequent flooding of the Mississippi and other rivers results in deposition of alluvium. Sand dike injection and extrusion during major earthquakes in northeastern Arkansas. Erosion of Interior Highlands and downcutting by most streams.

Pleistocene (.01 to 1.6 Ma): Continental icesheets do not reach Arkansas, but local alpine snow packs form in the Boston Mountains and southward into the Ouachita Mountains. Repeated intervals of erosion and deposition of glacial outwash by the ancestral Mississippi and Ohio Rivers form the Eastern and Western Lowlands and Crowley's Ridge. Sand and silt winnowed from the outwash form dunes and sheet-like deposits of loess. Erosion of most of the Interior Highlands.

Tertiary 1.6 to 66 Ma

Neogene (1.6 to 24 Ma)

Pliocene: Erosion over most of the state.

Miocene: Erosion over most of the state.

Paleogene (24 to 66 Ma)

Oligocene: Erosion over most of the state. No known deposits.

Eocene: Marine and fluvial clastic sediments fill the Mississippi Embayment; transportation of some bauxite; swampy conditions favorable to the accumulation of plant debris (lignite). Erosion of Interior Highlands.

Paleocene: Shallow marine sea in the Mississippi Embayment; formation of nearshore reefs and layers rich in marine remains and accumulation of dark marine clays; development of bauxite on islands of exposed Cretaceous igneous rocks. Erosion of Interior Highlands.

MESOZOIC ERA

Cretaceous 66 to 144 Ma

Deposition of water-laid volcanic debris preceded the accumulation of sand, marl, and chalk in shallow marine seas during the Late Cretaceous. About 100 Ma, downwarping of the Mississippi Embayment and invasion of a shallow sea. Igneous activity in central, southwestern, and eastern Arkansas. Nearshore deposition of clastic and carbonate debris in the Early Cretaceous, along with deposition of gypsum and anhydrite in highly saline waters in southwestern Arkansas. Erosion of Interior Highlands.

Jurassic 144 to 208 Ma

Deposition of much carbonate sand (oolitic in part) in a shallow marine environment and some red clay and anhydrite in a shallowing sea; preceded by the accumulation of a thick sequence of salt (halite) beds, some anhydrite, and red clay and silt in shallow highly saline waters. Present only in the subsurface in southern Arkansas. Erosion of Interior Highlands.

Jurassic or **Triassic**: Intrusion of small scattered bodies of magma in southern Arkansas, which crystallized to form igneous rocks.

Triassic 208 to 245 Ma

Accumulation of predominantly red clay and silt, non-red sand and gravel, and minor beds of anhydrite in a non-marine environment. Present only in the subsurface in southern Arkansas. Age assignment indefinite. Erosion of Interior Highlands.

PALEOZOIC ERA

Permian 245 to 286 Ma

Erosion. No known deposits. Last interval of uplift of the Interior Highlands (?). Last milky quartz-vein formation.

Pennsylvanian 286 to 320 Ma

Ozark region: Shallow-water deposition of clastic sediments. Younger Pennsylvanian rocks absent. Very late northeast-southwest-trending normal faulting.

Arkansas Valley region: Rapid infilling with clastic sediments and development of growth faults along northern basin margin. As the basin shallowed, plant debris (now present as coal) accumulated in nearshore swampy areas.

Ouachita region: Extremely rapid influx of clastic sediments in a deep marine trough followed by intense deformation (folding, faulting, and, at depth, low-grade metamorphism) and uplift during the Ouachita orogeny (Late Pennsylvanian/Early Permian). Concurrent formation of quartz veins.

Mississippian 320 to 360 Ma

Ozark region: Deposition and episodic erosion of shallow-water platform carbonate debris, clay, sand and siliceous ooze.

Ouachita region: Rapid influx of clastic sediments in the Late Mississippian following the slow accumulation of siliceous ooze and clay in the Early Mississippian.

Devonian 360 to 408 Ma

Ozark region: Slow deposition of carbonate sediments, siliceous ooze, carbonaceous clay, and some sand in shallow marine water, interrupted by intervals of erosion.

Ouachita region: Slow accumulation of siliceous ooze and clay in a deep marine environment.

Silurian 408 to 438 Ma

Ozark region: Deposition of thin, shallow-water carbonate sediments, interrupted by intervals of erosion.

Ouachita region: Slow influx of sand and clay in a deep marine environment.

Ordovician 438 to 505 MA

Ozark region: Deposition of shallow-water carbonate sediment and minor sand, interrupted by intervals of erosion.

Ouachita region: Prolonged accumulation in relatively deep water of clay, sand, and carbonaceous sediment and siliceous ooze.

Cambrian 505 to 570 Ma

Ozark region: Calcareous sediment, some quartzose sand and clay accumulate in shallow water. Resulting rocks present only in the subsurface.

Ouachita region: Only the youngest rocks are presently exposed. As sediments, they accumulated as alternating layers of clay, silt, sand, and minor lime mud.

PRECAMBRIAN TIME

Precambrian events 570 to 4,600 Ma

Ozark region and northern part of Mississippi Embayment: Granitic-type igneous rocks (some as old as 1,400 Ma) have been encountered in some wells.

Ouachita region: Erratic boulders of late Precambrian igneous and metamorphic rocks and sparse tectonically emplaced bodies of metamorphosed igneous rocks (as old as 1,000 Ma) are present in Paleozoic rocks.

In the above 3 areas, there is no evidence of the succession of events during Precambrian time. Although not exposed elsewhere, Precambrian rocks are assumed to underlie the entire state.

Sources: Time scale from Palmer (1983).

MINERAL DISTRIBUTION

Arkansas' mineral resources are directly related to its varied geology. The suite of minerals present in a given region is related to the geologic history of that region and, therefore, to the types of rocks in which the minerals occur. A variety of geologic processes, active in Arkansas over geologic time, has developed a wide range of mineral deposits. This geologic diversity is largely responsible for the spectrum of mineral resources present in the state.

The Paleozoic rock units of the Interior Highlands province contain deposits of iron, manganese, antimony, mercury, quartz crystal, barite, novaculite, tripoli, coal, natural gas, "marble", limestone, dolostone, slate, shale, serpentine, sandstone, zinc, and lead.

Near the margin of the Paleozoic Highlands and the Gulf Coastal Plain in central Arkansas, masses of Cretaceous igneous rock and their adjacent weathering or alteration zones contain potentially valuable deposits of aluminum-, iron-, lithium-, titanium-, and vanadium-bearing minerals, as well as diamonds, fuller's earth, refractory clays, rare earths, and wollastonite. The igneous rock itself is an important aggregate resource.

The Cretaceous sediments of southwest Arkansas contain deposits of gypsum, chalk, marl, barite, celestine, greensand, ilmenite, and sand and gravel. Unconsolidated sediments of the Gulf Coastal Plain Province contain important deposits of sand and gravel, bloating clay, common and fire clay, and lignite. Accumulations of mineral-rich brine (notable for it's bromine), natural gas, and petroleum are present in older rocks in the subsurface.

MINING AND RECLAMATION PRACTICES

The term "mining" is used here to describe the profitable extraction, by excavation, of ore or any other rock and mineral product, including coal, regardless of the method used. It includes surface and underground operations, and dredging. However, the definition of mining does not include the extraction of fluids such as crude oil, bromine brine, natural gas, and water, nor does it include the extraction of rock material solely for the purpose of excavation, such as building footings and laying of utility lines.

By convention, the term "mine", when used without modifiers, is restricted to underground workings. Most surface excavations are called either open cuts or open pits, quarries (fig. 6), strip pits or strip mines, or borrow pits. Borrow

Figure 6. Aerial photograph of quarry operations in central Arkansas. Southwest of Little Rock National Airport, Pulaski County. Scale is 1: 20,000.

pits are the small excavations (frequently seen adjacent to roads and highways) from which road-fill material has been obtained for local use. Open cut and open pit are general terms for any operation where the material being mined is exposed for excavation simply by removing any overburden (soil and overlying rock material). A quarry is an open-pit mine, but by convention in the mining industry, the term quarry is used when mining construction materials like building stone, crushed stone, or gravel. A strip mine is also an open pit, but the term is most commonly used where coal is mined.

In surface-mining operations, two very different situations may be encountered, depending on the raw material sought. Usually, when quarrying construction materials, all the usable rock material is excavated and utilized for some type of product by crushing, sorting, and blending methods. The mining of syenite, limestone, and sandstone in the state are examples. When surface mining for a particular contained-mineral value (such as coal, bauxite, or vanadium), soil, overburden, and waste (materials which do not contain any mineral content of value to the mining operation) are removed and placed separately. With coal and bauxite, the exposed ore bed or layer is then removed and processed. Some deposits, like vanadium ores, present a more complicated situation for the miner because the waste must be separated from the ore during excavation.

The decision to use surface or underground mining methods is based on economic considerations. The primary factors are the depth of the deposit below the ground surface, the nature of the rock material in the interval to be removed, and the quality of the material or the grade of the ore being removed. If the deposit is at the surface, any cover of topsoil is removed and stockpiled for later reclamation of the site, and the deposit is directly excavated. At greater depths, the cost of removing overburden to operate as an open-pit mine must be compared to the usually higher cost of developing and operating an underground mine. The final decision whether to use open-pit or underground methods may also be affected by other factors, such as geographic location, local topography, and geology. One important geologic factor is the strength of the rock immediately above the deposit. Some rocks lack the strength to provide a safe environment for underground operations because of the danger of cave-ins and roof falls. Another factor is ground-water conditions. In some mines, ground-water seepage is so rapid that it can be removed by pumping only with great difficulty and expense. At great depths below the surface, underground mining is the only practical alternative.

Both surface and underground mining methods have been and are currently being used in Arkansas. However, the bulk of our state's mineral industry production has been from surface operations. The reason for this is obvious. Those commodities that are used in large quantities and, therefore mined in bulk, have relatively low values per ton. Examples are sand and gravel, limestone, sandstone, syenite, clay, and gypsum. As a consequence, they can be produced profitably, under most conditions, only by surface-mining methods.

Prior to 1971, the mining industry in Arkansas was essentially free of regulation. In response to increasing environmental concerns, the State Legislature passed its first surface-mining act (Act 236 of 1971). The Act required that certain steps be taken to protect the environment during mining operations, and that lands affected by the continuance of all existing and future operations be reclaimed for a designated useful purpose. Fish and wildlife habitat, grazing and cropland, recreation, shelter belts, forest land, and industrial, commercial, and residential sites are considered to be useful purposes. The Surface Mining and Reclamation Division of the Arkansas Department of Pollution Control and Ecology was charged with implementing and enforcing the regulations. In 1977, a Federal surface coal-mining law was adopted, with implementing state regulations adopted in 1979. At that time funds became available to begin the reclamation of open-pit coal mines abandoned before 1977. At current funding levels, all abandoned surface coal mines in Arkansas should be reclaimed by 2015.

Before starting to mine, operators must obtain permits from the Department of Pollution Control and Ecology. To do so, they must submit a mine plan, a reclamation plan, proof of approval by adjacent landowners, and post a bond to ensure that the plans will be fulfilled. Using a surface coal mine as an example, the typical sequence of events is:

- Removing trees and brush.
- Removing and stockpiling topsoil.
- Removing waste rock (overburden) from above the coal bed.
- Removing the coal.
- Redistributing the waste rock to backfill against any steep walls, and filling depressions to produce a surface configuration suitable for vegetation. Slope gradients are normally required to be no steeper than 1 foot vertically to 3 feet horizontally. Provisions are also made, commonly by means of man-made lakes, to control site drainage and erosion. Special attention is given to acid water, if present, so that it will not affect the environment.
- Spreading the stockpiled topsoil over the site and compacting it to retard erosion and provide a suitable seed bed. An additive, such as powdered limestone, may be added to condition and neutralize particularly acid soil types.
- Seeding as rapidly as possible with fast-growing grasses or other types of ground cover. Commonly, fertilizer and mulch are spread to hasten plant growth.
- Finally, reseeding with more permanent perennial grasses, or planting tree seedlings – if so specified in the reclamation plan.

The reclamation process is time-consuming, and because it is expensive, it adds significantly to the cost of the product – coal in this example. However, reclaimed sites are capable of serving useful purposes, and reclamation often results in the site being more productive than before mining.

THE METALS

In years past, ores of a wide variety of metals have been mined in Arkansas. As of 1997, no ores were mined for their metal content. This listing presents the last year of recorded mining.

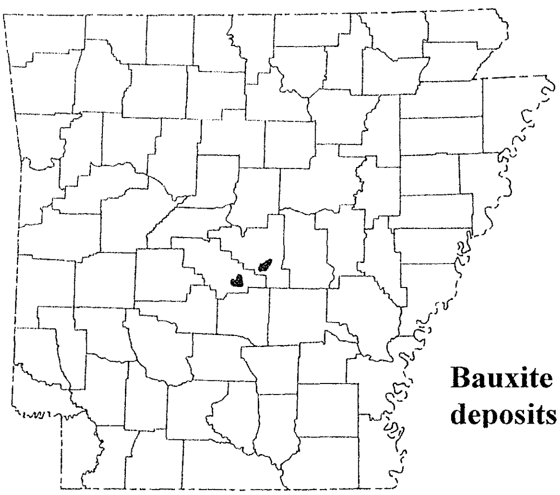
Aluminum	(1990*, 1996)
Antimony	(1947)
Copper	(1900)
Gallium	(1983)
Iron	(1965)
Lead	(1959)
Manganese	(1959)
Mercury	(1946)
Silver	(1927)
Titanium	(1944)
Vanadium	(1990)
Zinc	(1962)

*for the production of metallic aluminum

All have had a beneficial role in the state's economy, some playing a significant role in Arkansas history as well. The first metal to be mined was probably lead, as the mineral galena, which was used by early pioneers to cast bullets. To meet wartime needs, the annual production of lead increased markedly during the War between the States. During World War I, lead, zinc, and antimony were all produced in Arkansas due to higher metal prices. During World War II, the greatly expanded production of aluminum in Arkansas was vital to the military aircraft industry. However, since 1990, no ores used in the output of metals have been mined in the state. This situation is due to a number of factors, including changing world market conditions, the discovery of commercial deposits elsewhere in the world, and increasing labor, energy, and environmental costs incurred in the United States.

In addition to the metals listed above, a number of other metal-bearing minerals have been reported, but to date have not been found in sufficient quantities to qualify as ores. The metals include gold, molybdenum, nickel, niobium (columbium), the rare earth metals, thorium, and uranium. Further exploration, additional analyses, changing market conditions, and new processing methods, either alone or in some combination, may lead industry to develop and mine certain of these metals. These same conditions may also allow the renewal of mining of some metals formerly produced in Arkansas.

ALUMINUM AND ALUMINA



Bauxite deposits

The third most abundant element in the earth's crust, aluminum (Al) is, nevertheless, a relatively new metal to the human race. The commercial process allowing its recovery economically was not discovered until about the turn of the 20th century. Aluminum metal is silvery white, has a low specific gravity (2.69) and a low melting temperature. Except for iron and steel, aluminum is probably used for more purposes than any other metal. Its light weight – about one-third that of steel – and its strength when alloyed with other metals are two reasons for aluminum's versatility. Other reasons are the ease with which the metal can be cast, machined, rolled, forged, extruded, and drawn (fig. 7). It has high electrical conductivity and significant resistance to atmospheric corrosion. Aluminum paint, beverage cans, baseball bats, high-voltage power lines, house siding, boats, and airplanes are just a few examples of aluminum metal's use.

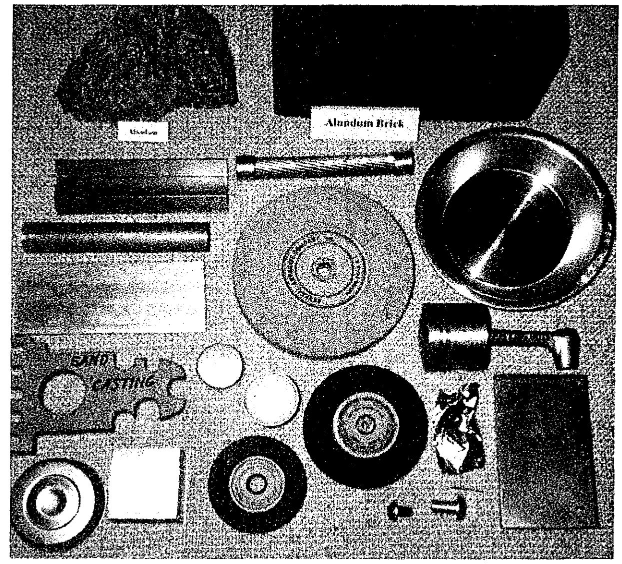


Figure 7. Various aluminum and alumina products which have been produced from Arkansas bauxite.

Another advantage of aluminum is that it can be efficiently recycled. Whereas the extraction of new aluminum from bauxite consumes huge amounts of energy (this includes the energy consumed during mining, processing the ore, and land reclamation), aluminum metal reclaimed from used products requires only 5 percent as much energy. Much of the feedstock of the aluminum metal industry now consists of used beverage cans. In 1991, for example, nearly 57 billion used aluminum cans were recycled in the United States.

The principal ore of aluminum is bauxite, a complex mixture of a number of aluminum hydroxides and hydrous aluminum oxides. The most common aluminum-bearing minerals in bauxite are gibbsite ($AlOH_3$), boehmite ($AlO(OH)$), and diaspore ($AlO(OH)$). In the Arkansas deposits, diaspore has not been reported. Free quartz along with iron and titanium oxides are common components.

Bauxite ranges in color from off-white to deep reddish brown, and structurally from a soft earthy material to a well-cemented rock. An easily recognizable oolitic (BB-sized concretions) to pisolitic (pea-sized concretions) grain texture characterizes many bauxite deposits, including those in Arkansas. Commercial bauxite usually has a minimum alumina content of 50 to 55 percent.

Many of the early-mined Arkansas bauxite deposits were exposed on the surface as outcrops or were beneath only a thin layer of sediments. Consequently, surface-mining methods were initially the most practical and economical. Before and during World War II, significant tonnages were mined underground. Some years after the war, surface operations resumed. Open-pit panel mining has been the normal surface method since the early 1960's. A strip or block of bauxite is exposed, mined, and then another panel is exposed. The first panel is normally refilled with waste rock. Several panels may be open at the same time to supply the proper blend of ores to meet the mill specifications. In recent years, major reclamation programs have begun to restore not only the recently mined land, but much of the land that was disturbed before reclamation laws went into effect.

In the bauxite refining process, the aluminum-bearing minerals in bauxite are converted in a multiple-step process to alumina (Al_2O_3). Alumina can be smelted to form metallic aluminum or it can be used as the source of many other products, including refractory materials used to line high-temperature rotary kilns and metallurgical furnaces. Alumina also is a source of many chemicals used in the paper and ceramic industries, in petroleum refining, and in some water-purification processes. Other uses are for the production of synthetic corundum for the manufacture of abrasive stones and grinding wheels, as propants in the petroleum-production industry, and as an ingredient in deodorants, antacids, and some medicines.

The Arkansas bauxite region covers about 275 square miles in the northern part of the West Gulf Coastal Plain and is divided into two mining districts. One area is in Pulaski County south and east of Little Rock and the other is in nearby Saline County, northeast and east of Benton. The bauxite is present mostly as sheet or blanket deposits in very close proximity to outcrops of the intrusive igneous rock, nepheline syenite. The deposits formed in early Tertiary time, developing as soils along the western edge of a shallow marine basin that occupied the Mississippi River Embayment. At this time, hills and knobs of syenite as islands were exposed to intense chemical weathering in a tropical or near-tropical environment (lateritic weathering). In the weathering process, leaching by rain, ground water, and perhaps by salt spray, decomposed the original igneous rock minerals (feldspar and nepheline), removed much of the silica, and concentrated the newly formed oxides and hydroxides of aluminum as the rock we term bauxite. These are residual deposits because they formed essentially in place (*in situ* paleo-soils). Many other, generally smaller deposits, consist of bauxite that was removed by erosion from its site of origin and redeposited nearby (transported deposits).

The aluminum industry has contributed significantly to the state's economy for many years. Bauxite was first mined in Arkansas as an ore of metallic aluminum in 1898, only 11 years after John C. Branner, State Geologist, first identified it in a sample brought to him by Ed Wiegel from Pulaski County. The material was being used for road surfacing. Over the years, Arkansas industry has remained the major producer in the United States, providing about 90 percent of all domestic tonnage mined (fig. 8). As aluminum became more widely available, many new uses for the metal (and for the by-products of the aluminum industry) were discovered and consumption increased rapidly. Tonnages of bauxite mined in Arkansas increased much more slowly than national consumption, however, because larger deposits supplying higher grade bauxite were readily available in the Caribbean region. In the early stages of World War II, merchant freighters carrying bauxite to the United States suffered high losses to enemy submarines. It was imperative that foreign supplies be supplemented by increased domestic production. The tonnage of bauxite mined in Arkansas quickly increased manyfold to meet wartime demands for aluminum, which was especially critical to the military aircraft industry. In 1943, more than 6 million long tons of bauxite were mined. Because of changing domestic and world economic market conditions, 1990 was the last year in which bauxite was mined in Arkansas for aluminum metal. Small tonnages continue to be mined and used in the production of a variety of alumina-based materials, including a various chemicals, abrasives, and propants.

Bramlette, M. N., 1936, Geology of the Arkansas bauxite region: Arkansas Geological Survey Information Circular 8, 68 p.

Canby, T. Y., 1978, Aluminum, the magic metal: National Geographic, v. 154, no. 2, p. 186-211.

Gordon, MacKenzie, Jr., Tracey, J. I., Jr., and Ellis, M. W., 1958, Geology of the Arkansas bauxite region: U. S. Geological Survey Professional Paper 299, 268 p.

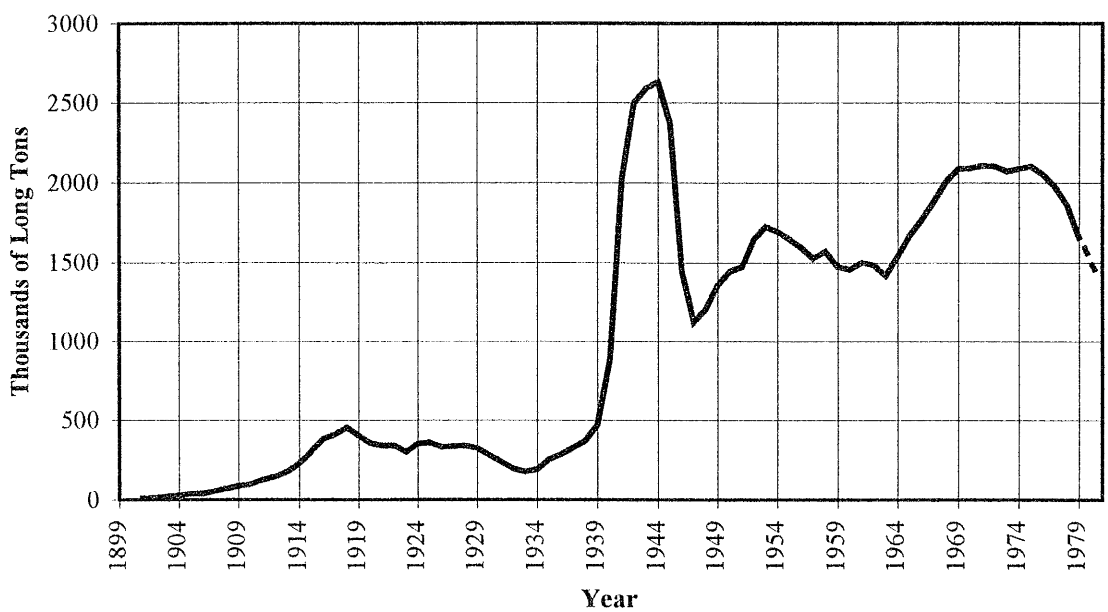


Figure 8. Bauxite production in Arkansas from 1899 to 1981. Data not available after 1981. Curve smoothed by using a 5-year moving average.

ANTIMONY

Many minerals contain antimony (Sb), a soft white metal with a low melting point. However, stibnite and antimonial lead ores are the chief sources of the metal. Stibnite (Sb_2S_3) and stibiconite ($Sb^{3+}Sb_2^{5+}O_6(OH)$) were the only minerals mined in Arkansas for this metal. Stibnite is steel gray, has a relatively high specific gravity (4.6), a metallic luster, and often forms slender prismatic crystals which may be bent or curved in habit. Stibiconite is an earthy yellow oxide formed by the weathering of stibnite.

Antimony is a hard, brittle, silver-white metal having a relatively high specific gravity (6.69) and a relatively low melting temperature. Antimony is a constituent in some alloys. The presence of this metal not only hardens the alloy, but lowers the melting point and decreases contraction during solidification. The metal's main use is to impart stiffness and hardness to lead alloys. Antimony compounds are used in medicines, in the rubber and patent-leather industries, as fire-proof coatings on clothing, for paint pigments, and in enamelware glazes.

Mining of antimony ore has been limited to northern Sevier County, although small amounts of stibnite are also present, associated with cinnabar (HgS), in Pike County. Commercial deposits occur as lenses or pockets of stibnite encased in nearly vertical quartz veins which cut steeply dipping, folded, and faulted beds of the Stanley Shale (Mississippian). The veins strike generally east-west. Sulfides of copper, zinc, iron, and bismuth may be locally associated with the antimony ores. Antimony was mined intermittently in Arkansas after its discovery in 1873. Mining activity peaked during World War I when metal prices were high. Some ore was recovered from shallow trenches excavated along the trend of the larger veins. Underground mining consisted of sinking shafts or driving horizontal entrances (adits) into surface-exposed ore bodies, driving crosscuts through the veins, and tunneling along the strike of the veins into adjacent ore bodies. There was no exploratory drilling program. The only ore reserves known during mining were those exposed on the ore face. Potential resource of the district was estimated by the U. S. Bureau of Mines at about 5,000 tons of concentrates.

Total production of antimony concentrates through 1947, the last year of mining, were estimated by the U. S. Bureau of Mines at 5,390 tons.

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Hess, F. L., 1908, The Arkansas antimony deposits: U. S. Geological Survey Bulletin 340-D, p. 241-252.

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Pittenger, G. C., 1974, Geochemistry, geothermometry, and mineralogy of Cu, Pb, Zn, and Sb deposits, Sevier County, Arkansas: Fayetteville, University of Arkansas, M. S. thesis, 75 p.

Stearn, N. H., 1935, Stibnite in quartz: American Mineralogist, v. 20, no. 1, p. 59-62.

COBALT

Cobalt (Co) is a silvery gray metal which has a relatively high specific gravity (8.9), and is hard, ductile, somewhat malleable, and magnetic. Cobalt has diverse industrial and military applications. Its principal use is in superalloys for jet engine parts. Other important uses are in permanent magnets for electrical devices and as a binder for cutting and abrasive tools, such as diamond drill bits. Cobalt chemicals are used for catalysts in the petroleum and chemical industries, drying agents for paints, varnishes and inks, additives to ground coats for porcelain enamels, and as pigments for ceramics, paints, and plastics.

Cobalt is rarely extracted from primary ores, but is recovered instead as a by-product. Most of the present Western World's demand is met by cobalt obtained as a by-product of copper production in the African countries of Zaire and Zambia. Small amounts are also recovered as by-products of platinum or nickel refining.

The United States is the largest consumer of this metal, using about 30 percent of the world's cobalt production in 1991, yet we have no domestic production. Cobalt is considered a strategic and critical mineral because of its industrial and defense-related uses.

In 1983, sample analyses of more than 140 manganese-bearing sites in the Ouachita Mountains region indicated significant amounts (0.05 to 1.2 percent, combined) of cobalt, copper, lithium, and nickel in 40 percent of the deposits sampled. In 1992, the U. S. Bureau of Mines published two studies of the west-central Ouachita manganese district, both concerned with the extraction of manganese and other metals present in these ores. In this area, manganese oxides, primarily the minerals cryptomelane ($K(Mn^{4+},Mn^{2+})_8O_{16}$) and psilomelane (massive hard manganese oxides), cement brecciated novaculite. Cobalt is concentrated in lithophorite ($(Al,Li)Mn^{4+}O_2(OH)$) Chemical analyses of initial concentrates gave values of 25 percent manganese and 0.17 percent cobalt. Magnetic separation yielded concentrates with up to 41 percent manganese and 0.22 percent cobalt with recoveries of 95 and 93 percent, respectively. No detailed resource evaluation has been done of the manganese-bearing areas of the Ouachitas, despite several brief periods of active mining. Estimates of the district's manganese potential and, therefore, its potential for recoverable cobalt and other metals, vary greatly, ranging from 1 million short tons to over 6.4 million short tons.

O'Connor, W. K., White, J. C., and Turner, P. C., 1992, Carbothermic reduction and leaching of manganese ores from the west-central Arkansas district, *in* J. P. Hager, ed., Process Mineralogy, EPD Congress, The Minerals, Metals & Materials Society, p. 379-396.

O'Connor, W. K., White, J. C., and Turner, P. C., 1992, Geology and mineral processing of manganese deposits from the west-central Arkansas district: Mining Engineering, v. 44, p. 1361-1368.

COPPER

Copper (Cu), called the red metal, is one of the first metals used by man. This is because it is often present in nature as a native element (and therefore is easy to recognize) and because it has unique properties which make it readily workable by primitive techniques. Copper is a soft metal with a relatively high specific gravity (8.9), and is highly ductile and malleable. Modern uses of copper are quite numerous, including electrical wiring, as a necessary metal in the alloys of brass, bronze, and nickel silver, self-lubricating bearings (copper powder), copper tubing, coinage, and copper sulfate ($CuSO_4$), a compound which has many chemical applications. Copper sulfate usage in agriculture to prevent the growth of algae and fungi and as a source of essential trace copper in fertilizer and animal feeds has steadily increased over the years.

Copper is present in at least 19 minerals known in Arkansas. Most of these minerals are fairly scarce, but chalcopyrite ($CuFeS_2$), malachite ($Cu_2^{2+}(CO_3)(OH)$), and native copper (Cu) are common enough to have encouraged some exploration. Copper mineralization is often present as a minor accessory mineral associated with lead and zinc deposits of the Ozark Plateaus and Ouachita Mountains. In the Ozarks, copper minerals, often associated with sphalerite ((Zn,Fe)S), are most frequently found near faults, flexures, and other structural irregularities in Paleozoic limestones and dolostones. In the Ouachita Mountains, small deposits of copper minerals are found in some quartz veins, usually in association with lead, zinc, or antimony mineralization.

All known deposits of copper minerals in Arkansas are small and considered to be uneconomic. In 1900, a small amount of copper was refined from malachite-bearing ore recovered from surface residuum at the Tomahawk mine in Searcy County. An occurrence of secondary copper minerals in Fulton County was demonstrated to be sub-economic. Copper minerals associated with lead and zinc mineralization have not generally proven to be of sufficient quantity to develop, although the potential exists that copper could be recovered as a by-product of other mining activity.

McKnight, E. T., 1935, Zinc and lead deposits of northern Arkansas: U. S. Geological Survey Bulletin 853, 311 p.

Miser, H. D., and Purdue, A. H., 1929, Geology of the DeQueen and Caddo Gap quadrangles, Arkansas: U. S. Geological Survey Bulletin 808, 195 p.

GALLIUM

Gallium (Ga) is a metal which does not form distinct minerals in nature, but instead substitutes for aluminum in the structure of many aluminum-bearing minerals. Gallium arsenide (GaAs) is the principal compound used in light-emitting diodes, photodetectors, laser diodes, and solar cells. An important potential application incorporates gallium compounds in diodes in bar-code scanners used in grocery stores.

In 1937 V. M. Goldschmidt suggested that the extraction of gallium from alkali aluminate solutions in the Bayer aluminum process might be possible. In the 1940's, chemists of the U.S. Geological Survey determined that gallium in Arkansas bauxite was enriched more than 4-fold over nepheline syenite, the parent rock of bauxite. The average content of gallium is 0.0086 percent (2.75 ounces per short ton). Gallium was recovered as a by-product of bauxite processing in Saline County from 1947 to 1983. Arkansas is one of two states in which this metal has been produced in the United States. However, no recovery figures have been released.

Goldschmidt, V. M., 1937, The principles of distribution of chemical elements in minerals and rocks: Chemical Society of London Journal, pt. 1, p. 655-673.

Gordon, Mackenzie, Jr., and Murata, K. J., 1952, Minor elements in Arkansas bauxite: Economic Geology, v. 47, p. 169-179.

Gordon, Mackenzie, Jr., Tracey, J. I., Jr., and Ellis, M. W., 1958, Geology of the Arkansas bauxite region: U. S. Geological Survey Professional Paper 299, 268 p.

GOLD

No metal has held the attention of humans throughout the ages as has gold. Gold (Au) was one of the earliest metals to be utilized due largely to its existence as a native metal. It has certain unique properties which made it workable by early man. Its bright yellow metallic luster catches the eye. Gold is relatively soft, melts at a low heat, and may be hammered, cut or drawn into fine wire. The metal has a very high specific gravity (19.3) which facilitates its recovery from ores. Gold has superior electrical conductivity and resistance to corrosion.

Worldwide, there are two types of gold deposits. *In situ* or lode deposits include disseminations of metallic gold in quartz veins, traces of gold contained in certain sulfide minerals, or extremely fine-grained particles dispersed in host rocks. Placer deposits form as the result of weathering and erosion of rocks containing gold. Gold is concentrated in nature due to its high specific gravity. Placer gold exists as fines, scales, flakes, grains, and nuggets. Native gold usually contains variable amounts of silver.

Gold is used in many ways, but over half the world's yearly consumption is in jewelry and artwork. In jewelry, pure gold is alloyed with copper and silver to increase its hardness. Purity is expressed in carats, there being 24 carats in pure gold. Therefore, 14 carat gold used in jewelry contains 14 parts pure gold and 10 parts of other metals. Gold has emerged in the late 20th century as an essential industrial metal, performing critical roles in computers, communication equipment, spacecraft, jet airplane engines, and many other applications. Gold is widely known for its use in jewelry, dental use, and for investment purposes (coins and bars).

Numerous reports and rumors of gold finds in Arkansas, beginning in the early 1880's, prompted an investigation by the Arkansas Geological Survey, which was then under the direction of the State Geologist, John C. Branner. The results of the study were released in the Annual Report of the Arkansas Geological Survey for 1888 - Volume I. The incontrovertible con-clusion was that no workable quantities of gold were found to exist in the Ouachita Mountains region. In 1923, investigations by U. S. Geological Survey geologists in the vicinity of Hot Springs, Garland County, showed the presence of very sparse amounts of silver and gold in vein material associated with igneous dikes. In summary, despite continued rumors, no payable quantities of gold have been discovered in Arkansas.

Comstock, T. B., 1888, A preliminary examination of the geology of western-central Arkansas, with especial reference to gold and silver: Arkansas Geological Survey Annual Report for 1888, v. I, pt. 2, 320 p.

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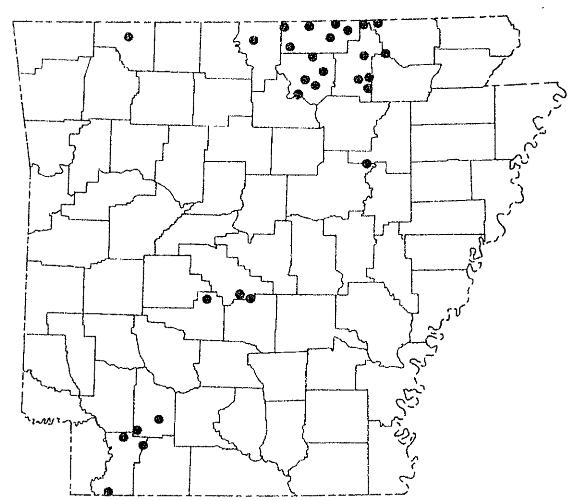
Sick, G. P., 1984, North Mountain Mine – Gold?, *in* McFarland, J. D., III, and Bush, W. V., eds., Contributions to the geology of Arkansas, v. II: Arkansas Geological Commission Miscellaneous Publication 18-B, p. 115-117.

IRON



When considering the entire composition of the earth, iron (Fe) is the most abundant element, but it only comprises approximately 6 percent of continental crust. Metallic iron is silvery-white, malleable, ductile, and may be readily magnetized. Elemental iron has a relatively high specific gravity (7.87) and high melting point. Iron is used primarily in the manufacture of iron and steel products. Also, substantial quantities of iron are consumed as paint pigments, in cement, in refractory materials as a fluxing agent used in smelting nonferrous metals, and as a constituent of some catalysts. Magnetic iron ore, magnetite, is used as shielding materials in nuclear power plants, heavy aggregate in concrete, and as a heavy-mineral medium in some metal refining mills.

The iron minerals present in Arkansas are the oxides – goethite ($Fe^{3+}O(OH)$), limonite (hydrous iron oxides), hematite (Fe_2O_3), and magnetite ($Fe^{2+}Fe_2^{3+}O_4$); the carbonates – siderite ($Fe^{2+}CO_3$) and ankerite ($Ca(Fe^{2+},Mg,Mn)(CO_3)_2$); and sulfides of iron – pyrite (FeS_2), marcasite (FeS_2), and chalcopyrite ($CuFeS_2$). Goethite is highly variable in habit and form, but is easily recognized when it forms lustrous grape-like masses having a radial internal structure and a brown streak when rubbed against unglazed porcelain. Limonite (essentially rust) varies in color from brown, black or yellow. Hematite or "red iron ore" varies in color from shiny black to blackish red to brick red. Siderite may be highly variable in color, ranging from gray to yellow, green, white, or shades of reddish-brown. Magnetite, which is black and has a metallic luster on a freshly broken surface, can be recognized by its magnetic properties. Pyrite, commonly called "fool's gold", is extremely common and may be recognized by its brassy yellow metallic luster. Pyrite is a brittle mineral and easily distinguished from native gold, which is quite malleable. Marcasite is known as white iron pyrite.

Iron minerals are common throughout Arkansas, but only in a few places are they found in sufficient quantities to be of possible commercial value. In Carroll, Lawrence, Sharp, Fulton, and Randolph Counties, secondary deposits of limonite are associated with sandstone, chert, and dolostone formations of Paleozoic age. Deposits of iron-rich concretions are pres-ent near the tops of hills and are residual in nature. Individual deposits were calculated by the U. S. Bureau of Mines to contain 5,000 to 4,000,000 tons with the majority of deposits probably containing less than 25,000 tons of iron ore. Smaller deposits are also known in Washington and Marion Counties. Past mining of these residual iron ores consisted of small-scale recovery of the harder surface-exposed material. In Hot Spring, Pulaski, Saline, and Cleveland Counties, magnetic iron ores are associated with igneous intrusions. In southern Arkansas, an iron ore-bearing area extends from northeastern Lafayette County northeast into southwest Nevada County. The iron-rich zones are present in the Wilcox Group of Tertiary age and formed as concretions of residual limonite by the weathering of zones of bedded siderite. The tops of hills in the area mentioned above have a potential tonnage of ferruginous material exceeding 100 million short tons having an average grade of 30 percent iron. Through 1965, approximately 120,000 tons of iron were produced from the Wilcox deposits, most being shipped to Lone Star Steel in east Texas. A small amount has been used as an iron-rich supplement in dog food after 1965.

Two small pig-iron furnaces were operated in Arkansas prior to 1860; one in Carroll County and the other in Sharp County. About 3,500 tons of magnetite were mined from the central portion of Magnet Cove, Hot Spring County, in the early 1950's. During the early 1960's, iron ore was open-cut mined near Falcon and Rosston in Nevada County. About 250 tons of iron ore were shipped in 1965, the last year of recorded production. In 1969, the U.S. Bureau of Mines calculated iron ore reserves in Arkansas to be 120 million long tons with an average grade of 30 percent iron. There has been no iron ore for smelting mined in the state since 1965. However, there are presently several iron and steel refineries in Arkansas, utilizing out-of-state feedstock.

Erickson, R. L., and Blade, L. V., 1963, Geochemistry and petrology of the alkalic igneous complex at Magnet Cove, Arkansas: U. S. Geological Survey Professional Paper 425, 99 p.

Penrose, R. A. F., Jr., 1892, The iron deposits of Arkansas: Arkansas Geological Survey Annual Report for 1892, v. I, 153 p.

LITHIUM

Lithium (Li) is the lightest of all the metals, having an atomic weight of 6.939 and a specific gravity of 0.534. The mineral spodumene ($LiAlSi_2O_6$), which is often present in extremely coarse-grained igneous rocks termed pegmatites, is historically the most important commercial ore mineral of lithium. In the 1960's, with the discovery of lithium in brines and in arid evaporative lakes and lake deposits (evaporites), new commercial sources of lithium became available. Lithium is present as a trace element in a variety of rocks and has been noted in significant amounts in geothermal waters and oil-well brines.

The most important lithium compounds produced commercially are lithium carbonate, lithium hydroxide, lithium chloride, lithium bromide, and butyllithium. The bulk of these compounds are consumed in the manufacture of ceramics, glass, and aluminum metal. Lithium has great potential for new and developing uses. Recently, the applications of lithium in certain metallurgical and chemical industries have been rapidly expanding and diversifying. Because lithium is electrochemically active and has other unique properties, it has few substitutes. Highly purified lithium carbonate has been successfully used in chemotherapeutic treatment of manic depression. Two new applications which show significant potential are as absorption blankets in nuclear fusion reactors and as a component in high-energy, long shelf-life batteries.

The 3 lithium minerals known to exist in Arkansas are restricted to the Ouachita Mountains. Cookeite ($LiAl_4(Si_3Al)O_{10}(OH)_8$) is present in many small hydrothermal quartz veins, most commonly filling fractures in the Jackfork Sandstone (Pennsylvanian) from Pulaski County westward through Saline and into Perry County. Taeniolite ($KLiMg_2 Si_4O_{10}F_2$) is present in smoky quartz veins in the recrystallized novaculite adjacent to the Magnet Cove intrusion (Cretaceous), Hot Spring County, and in a chalcedony-fluorite-pyrite vein in the "V" intrusive (Cretaceous age igneous dikes), Garland County. Lithiophorite ($(Al,Li)Mn^{4+}O_2(OH)$) has been reported in the manganese deposits in Polk and Montgomery Counties, and is also present as a late secondary mineral in quartz veins from many localities in the Ouachita Mountains. None of these minerals are considered economically significant sources of lithium.

The bromine-rich brines from wells in the Upper Jurassic Smackover Formation of Columbia County in southwestern Arkansas contain as much as 445 parts per million lithium. Lower values are reported in waters originating from some water wells and hot and cold springs scattered across Arkansas.

Except for lithium's potential as a by-product from the bromine brines in the Smackover Formation, no other concentrations of commercial potential are known to exist in Arkansas.

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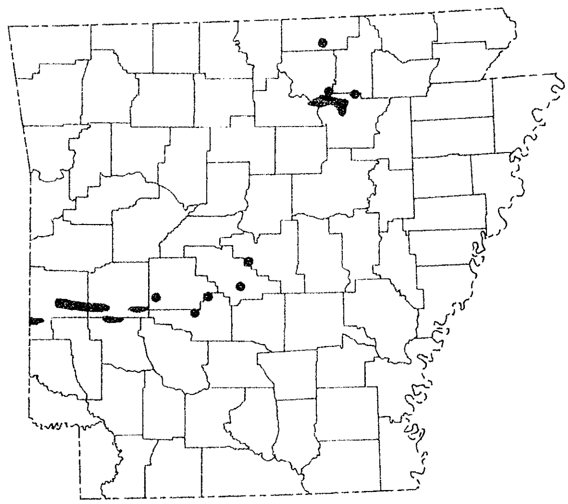
Kunasz, I. A., 1975, Lithium raw materials, *in* LeFond, S. J., ed., Industrial Minerals and Rocks, 4th ed.: American Institute of Mining, Metallurgical, and Petroleum Engineers, p. 791-803.

Miser, H. D., and Stevens, R. E., 1938, Taeniolite from Magnet Cove, Arkansas: American Mineralogist, v. 23, no. 2, p. 104-110.

Stone, C. G., and Milton, Charles, 1976, Lithium mineralization in Arkansas, *in* Vine, J. D., ed., Lithium resources and requirements by the Year 2000: U. S. Geological Survey Professional Paper 1005, p. 137-142.

Trout, M. L., 1974, Origin of bromide-rich brines in southern Arkansas: Columbia, University of Missouri, M. A. thesis, 79 p.

MANGANESE



Manganese (Mn) is a gray-white to silvery metal with a moderate melting temperature and relatively high specific gravity (7.2 to 7.4). Manganese is added to iron, along with various other metals and carbon, to make steel. Manganese never occurs as the native metal in nature, but instead in some combination with other elements.

There are over 100 minerals known to contain manganese. The most important manganese ore minerals identified in Arkansas are psilomelane (massive hard manganese oxides), hausmannite ($Mn^{2+}Mn_2^{3+}O_4$), pyrolusite ($Mn^{4+}O_2$), wad (soft, massive manganese oxides), and braunite ($Mn^{2+}Mn_6^{3+}SiO_{12}$). Other minerals such as manganite ($Mn^{3+}O(OH)$), bementite ($Mn_8^{2+}Si_6O_{15}(OH)_{10}$), and rhodochrosite ($Mn^{2+}CO_3$) have also been noted. Because of its sulfur-fixing, deoxidizing, and alloying properties, the principal use of manganese is in iron and steel manufacture. About 90 percent of the manganese consumed in the United States is in the form of an alloy known as ferromanganese, which is used in the manufacture of steel. Relatively small amounts of manganese and different manganese compounds are utilized in the manufacture of other metal alloys, animal feed, soil conditioners, dyes and paints, pharmaceuticals, dry-cell batteries, and as a coloring material in pottery, tile, and brick.

Commercially important manganese deposits are present in two principal regions in Arkansas – the Batesville district and the west-central Arkansas district. Other areas of Arkansas have been prospected for manganese and, although mineralization has been noted, quantities are presently thought to be insufficient to be economic. Mines in the Batesville district, which includes about 100 square miles located in northwestern Independence County, southeastern Izard County, and northeastern Stone County, yielded over 98 percent of the manganese ore shipped from Arkansas. The west-central Arkansas district includes portions of Pulaski, Saline, Garland, Hot Spring, Montgomery, Pike, Howard, and Polk Counties.

The ores contained in the manganese deposits of the Batesville district are classified into 4 major types: manganiferous limestone, residual *in situ* clay, clay-talus residuum, and placer. Manganiferous limestone, mostly in the Early Mississippian St. Joe and Boone Formations, is the most abundant ore; however, it is usually low grade. Residual *in situ* clay and clay-talus residual ores are present as local deposits of irregular lumps, masses, and nodules, mainly in pockets of residual clay lying in depressions in the bedrock. These latter ore types are thought to be secondary residual minerals concentrated by the decomposition and replacement of some of the rocks of the Ferndale Limestone through Cason Shale (Ordovician) strata. Placer ores and deposits containing them are derived by the transportation of residual deposits and are usually mixed with a great deal of sand and gravel.

The Batesville district manganese deposits were worked intermittently from 1849 to the early 1880's by both open-pit and subsurface methods. During the period from 1881 to 1959, manganese mining activity was almost continuous. Major production was reached in both World Wars, but the highest single-year production was during 1956 when more than 29,000 tons of manganese ore were extracted. The U. S. Bureau of Mines has calculated that almost 200 million long tons of ore containing 4 to 9 percent manganese still remain in the district. Deposits of manganese ore may be challenging to evaluate because they are generally small, scattered, and methods utilizing geophysical techniques are not usually economically feasible. Representative sampling of deposits can be especially difficult.

The west-central Arkansas manganese deposits are chiefly oxides which occur in veins and open pockets and as cement that binds breccias together in fractured zones in the Arkansas Novaculite (Devonian/Mississippian) and the Stanley Shale (Mississippian). The manganese mineralization in ore deposits ranges in thickness from a fraction of an inch to as much as 10 feet. The known deposits, although containing a large amount of low-phosphate manganese in the aggregate, are usually small and discontinuous. Exploration in the district is incomplete. A few mines and prospects are well known and minor production by both open-pit and subsurface methods was recorded in the first half of the 20th century, but the cost of mining, modest quantities of ore, and the low grade of ore has so far precluded significant development of these resources. Phosphate-free manganese ores from the west-central district were utilized during World War II to upgrade the more phosphate-rich ores of the Batesville district.

There has been no manganese ore mined in Arkansas since federal stockpile programs were stopped in 1959. The potential for manganese ore production will continue to depend primarily on the growth rate of steel production and its availability from foreign sources.

Miser, H. D., 1917, Manganese deposits of the Caddo Gap and DeQueen quadrangles, Arkansas: U. S. Geological Survey Bulletin 660-C, p. 59-122.

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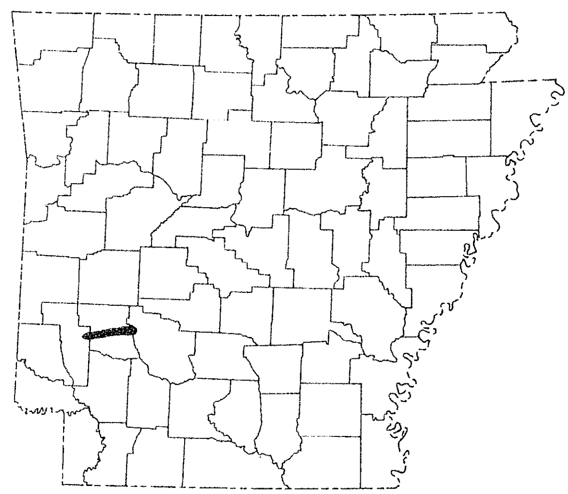
Penrose, R. A. F., Jr., 1890, Manganese: Its uses, ores, and deposits: Arkansas Geological Survey Annual Report for 1890, v. I, 642 p.

Stroud, R. B., Kline, H. D., Brown, W. F., and Ryan, J. P., 1981, Manganese resources of the Batesville district, Arkansas: Arkansas Geological Commission Information Circular 27, 146 p.

MECURY



As a mineral, elemental mercury (Hg) is relatively scarce and is formed by the weathering or oxidation of several mercury-bearing minerals. The most important ore mineral is cinnabar (HgS). Elemental mercury is a liquid at normal temperatures, freezing at -38.4° Celsius and boiling at 357° Celsius. This liquid state at ordinary temperatures led to its early use in thermometers. It will dissolve finely divided gold (dust and flour) and may then be boiled off, leaving the gold behind. Consequently, it has been used for centuries to collect gold that would otherwise not be recoverable. Mercury is present in most rock types in trace amounts.

Although mercury has been widely used in the past in a variety of applications, because it is now recognized to be highly toxic in certain forms, the market for mercury-containing products steadily declined in the 1980's. It still has important uses in the chemical and electrical industries as well as in dental applications and measuring and control devices.

The mercury-bearing district in southwest Arkansas occupies an area some 6 miles wide by 30 miles long extending from eastern Howard County through Pike County and into western Clark County. Surface rocks in the mercury district are sandstone, shale, and siltstone of the Mississippian and Pennsylvanian Systems (Paleozoic). These rocks are covered in the southern portions of the above-mentioned counties by Cretaceous clay, sand, gravel, and limestone beds. The Paleozoic rocks have been folded and faulted into steeply dipping, generally east-west trending ridges and valleys. Cinnabar and other primary minerals were deposited by aqueous solutions rising through the fractured Paleozoic rocks.

Cinnabar, the principal ore mineral, was first discovered in southwestern Arkansas in 1930. Prospecting along the major trends of larger faults in the area was conducted by examination of outcrops, pitting, trenching, core drilling, and some geochemical sampling. Mining, by both surface and underground methods, began in 1931 and mercury was recovered yearly through 1944. Minor, but rich, placer cinnabar was recovered at the Parker Hill mill site in Pike County and added to the primary ore before roasting. Cinnabar was roasted in the presence of oxygen, to break the mineral down into free mercury vapor and sulfur dioxide. These gases were then cooled and the mercury condensed as a liquid and recovered. Refining during this period yielded approximately 1,500 76-pound flasks. Mining has been negligible since 1946.

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Clardy, B. F., and Bush, W. V., 1976, Mercury district of southwest Arkansas: Arkansas Geological Commission Information Circular 23, 57 p.

Gallager, David, 1942, Quicksilver deposits near the Little Missouri River, Pike County, Arkansas: U. S. Geological Survey Bulletin 936-H, p. 189-219.

Reed, J. C., and Wells, F. G., 1938, Geology and ore deposits of the southwestern Arkansas quicksilver district: U. S. Geological Survey Bulletin 886-C, 90 p.

MOLYBDENUM

Molybdenum (Mo) is a refractory metal that is obtained primarily by processing the mineral molybdenite (MoS_2). Molybdenite is soft, lead gray, has a metallic luster, a greasy feel, and gives a greenish streak on unglazed porcelain. Molybdenite is an unusually effective dry solid lubricant. Elemental molybdenum is a hard gray metal with a relatively high melting point (4,730° F.) and a high specific gravity (10.2). Molybdenum, or "moly" as the metal is known in the trade, is used primarily as an alloying agent in iron and steel, where it enhances hardenability, strength, toughness, and resistance to wear and corrosion. Steels containing molybdenum are used both in the transportation industry and as drill steel in deep oil and gas wells. Molybdenum also has important uses in numerous chemical applications, including fire retardants, catalysts, and pigments.

Molybdenite was identified in Arkansas from Magnet Cove in Hot Spring County in 1939, where it is present in veins in a fractured igneous rock. The veins are composed mainly of orthoclase (a type of feldspar) and pyrite with minor amounts of quartz, fluorapatite, plagioclase (a type of feldspar), molybdenite, and brookite and range in thickness from less than 0.5 inch to 5 feet. The Mo-Ti prospect, as this site was named, has been explored by geophysical methods, trenching, and drilling. Molybdenum mineralization is also known from Baxter County where the lead molybdate, wulfenite, is reported to be associated with galena, cerussite, and quartz.

No molybdenum ore has been mined in Arkansas.

Erickson, R. L., and Blade, L. V., 1963, Geochemistry and petrology of the alkalic igneous complex at Magnet Cove, Arkansas: U. S. Geological Survey Professional Paper 425, 99 p.

Holbrook, D. F., 1948, Molybdenum in Magnet Cove, Arkansas: Arkansas Resources and Development Commission, Division of Geology Bulletin 12, 16 p.

McKnight, E. T., 1935, Zinc and lead deposits of northern Arkansas: U. S. Geological Survey Bulletin 853, 311 p.

NICKEL

Nickel (Ni) is the fifth most abundant element in the earth as a planetary body, but it is rare in normal crustal rocks. Elemental nickel is a silvery, hard, ductile metal with a moderately high melting temperature and a relatively high specific gravity (8.9). The chief use of nickel is as an alloy in steel and cast iron. Nickel is vital to the stainless steel industry and has played a key role since the beginning of the 20th century in the development of the chemical and aerospace industries. It also finds use in nonferrous alloys, heat- and electricity-resistant alloys, and in plating. Nickel gives its alloys toughness, strength, corrosion resistance, and special electrical, thermal, and magnetic qualities.

Nickel-bearing deposits may result from several very different geological processes. Lateritic nickel deposits form by the weathering of certain silica-deficient igneous rocks rich in iron and magnesium, concentrating nickel in the weathering product. Nickel sulfide accumulations are the result of the deposition of nickel minerals by hydrothermal (hot water) fluids. The most common nickel-bearing mineral known in Arkansas is millerite (NiS). Millerite has a metallic luster and a pale brass-yellow color with a greenish tinge. It typically forms fine, hair-like masses.

The first discovery of millerite in Arkansas was at the Rabbit Foot mine, long abandoned, located within the northwestern city limits of Benton in Saline County. Millerite in cavities and crevices in a quartz vein was exposed in a creek bed. The host rock was reported to be black shale. In 1887, 1,991 pounds of ore were sampled and assayed, showing 1.46 percent nickel and cobalt combined. Work began in 1887 and ended a short time later. The site is now lost, being covered by stream alluvium. Three minor occurrences of millerite have been noted by geologists of the Arkansas Geological Commission in north Arkansas, two in Benton County and one in Izard County. Soapstone deposits of Saline County are reported to contain traces of native nickel. Investigations of manganese deposits in the Ouachita Mountains region of west-central Arkansas also revealed the presence of nickel in the manganese ores. Analyses of manganese ore concentrates indicated nickel in the range of 0.03 to 0.39 percent. Further evaluation of the manganese deposits and their associated trace elements (cobalt, nickel, and lithium) will be necessary to determine the economic potential of these deposits. No nickel mining has taken place in Arkansas since the exploration work at the Rabbit Foot mine.

Comstock, T. B., 1888, A preliminary examination of the geology of western-central Arkansas, with especial reference to gold and silver: Arkansas Geological Survey Annual Report for 1888, v. I, pt. 2, 320 p.

O'Connor, W. K., White, J. C., and Turner, P. C., 1992, Geology and mineral processing of manganese deposits from the west-central Arkansas district: Mining Engineering, v. 44, p. 1361-1368.

Sterling, P. J., Stone, C. G., and Renfroe, C. A., 1962, An occurrence of violarite and millerite in calcite veins, Benton County, Arkansas: Economic Geology, v. 57, no. 3, p. 453-455.

NIOBIUM

Niobium (Cb), also called columbium, is a rare metal, which is steel gray, resistant to acids, and has a high melting point. Elemental niobium is a soft, ductile, malleable metal with a moderately high specific gravity (8.57). It is used principally as an additive in stainless steel and imparts creep resistance and fatigue strength in light-weight high-temperature alloys. Niobium is deemed critical because of its defense-related uses in aerospace, energy, and transportation industries.

Arkansas has 3 areas of significant niobium mineralization: Magnet Cove in Hot Spring County, Potash Sulphur Springs in Garland County, and the bauxite deposits in Saline and Pulaski Counties. The first two locations are characterized by alkaline igneous intrusions and mineralized zones of contact metamorphism and the third by the concentration of titanium minerals in bauxite. In the Magnet Cove area, there are substantial deposits of titanium minerals, rutile (TiO_2), brookite (TiO_2), and perovskite ($CaTiO_3$). Rutile and brookite crystals contain an average of 2 percent and a maximum of 5 percent niobium. Perovskite may contain up to 9 percent niobium by analysis, niobium substituting for titanium in the mineral's structure. U.S. Bureau of Mines geologists calculated that 12 million pounds of niobium are contained in the rutile-brookite deposits at Magnet Cove. The niobium of the Potash Sulphur Springs area is present as an essential element of the mineral pyrochlore ($(Ca,Na)_2Nb_2O_6(OH,F)$). Soil samples analyzed from this area contained up to 0.9 percent niobium. Another possible source of niobium in Arkansas lies in the waste material remaining from the processing of bauxite. Arkansas bauxite is reported to contain niobium values from 0.02 to 0.1 percent and average 0.05 percent. In 1954, the U. S. Bureau of Mines calculated that bauxite deposits and plant waste fines contained up to 150 million pounds of niobium metal.

Although niobium-bearing minerals have long been known to exist in the state, there has been no commercial recovery of this metal. If, in the future, any sites enriched in titanium-bearing minerals become economically viable, then niobium may be recovered as a by-product.

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Fleischer, Michael, Murata, K. J., Fletcher, J. D., and Narten, P. F., 1952, Geochemical association of niobium (columbium) and titanium and its geological and economic significance: U. S. Geological Survey Circular 225, 13 p.

Fryklund, V. C., Jr., Harner, R. S., and Kaiser, E. P., 1954, Niobium (columbium) and titanium at Magnet Cove and Potash Sulphur Springs, Arkansas: U. S. Geological Survey Bulletin 1015-B, p. 23-57.

Gordon, Mackenzie, Jr., and Murata, K. J., 1952, Minor elements in Arkansas bauxite: Economic Geology, v. 47, no. 2, p. 169-179.

Neiberlein, V. A., Fine, M. M., Calhoun, W. A., and Parsons, E. W., 1954, Progress report on development of columbium in Arkansas for 1953: U. S. Bureau of Mines Report of Investigations 5064, 23 p.

Williams, J. F., 1891, The igneous rocks of Arkansas: Arkansas Geological Survey Annual Report of 1890, v. II, 457 p.

RARE EARTH METALS

The rare earths are a family of 17 elements consisting of scandium, yttrium, and the lanthanum-group elements. The term "rare earths" is a misnomer, as some of these elements are not particularly rare and all of them are metals, not earths. The elements are similar in their chemical properties to aluminum. Among this group, however, are a few of the scarcest elements known. Perhaps best known of the group are cerium and yttrium. Monazite sand, a by-product of heavy-mineral processing, is the most important mineral source of the rare-earth group; deposits of the minerals bastnaesite and xenotime are also important sources of certain rare earths.

The rare earths were once scientific curiosities, but modern methods of separation and new applications, particularly in the fields of atomic energy and metals research, have made them commercially valuable. Rare earths are used as catalysts in automotive catalytic converters, as iron and steel additives, as ceramic and glass additives for their decolorizing properties, as lightemitting substances (phosphors), and as components in electronic devices, permanent magnets, light bulbs, and in various aspects of research. Common lighter flint contains a cerium compound.

Investigations by auger drilling the central region of Magnet Cove, Hot Spring County, revealed up to 4.3 percent combined rare earths in analyzed samples. Selected samples of bastnaesite–(Ce) ($(Ce,La)(CO_3)F$)/synchysite–(Ce) ($Ca(Ce,La)(CO_3)_2F$) mineralization collected by an Arkansas Geological Commission geologist contained over 30 percent combined lanthanides. The mineralization is present as secondary veins to 4 inches thick in carbonatite, an igneous rock composed mostly of calcite. Rare earths also are known to be associated with several igneous intrusions in Pulaski, Saline, Cleveland, and Garland Counties.

Samples collected from Independence and Izard Counties by the Arkansas Geological Commission, specifically for their rare-earth content, were submitted to the U.S. Geological Survey for rare-earth analysis. The basal phosphatic zones of the Cason Shale (Silurian-Ordovician), west of Batesville, were sampled and the analyses reported subeconomic values of rare earths. Although values are not high enough to be considered ore, should mining of the Cason phosphate deposits become economically feasible, rare earths might be recoverable as a by-product.

There has been no mining of rare earths in the state.

Barwood, H. L., and Howard, J. M., 1990, Rare earth fluorcarbonates at Magnet Cove, Hot Spring County, Arkansas (abs.): Geological Society of America Abstracts with Programs, v. 22, no. 1, p. 2.

Erickson, R. L., and Blade, L. V., 1963, Geochemistry and petrology of the alkalic igneous complex at Magnet Cove, Arkansas: U. S. Geological Survey Professional Paper 425, 99 p.

Grosz, A. E., Meier, A. L., and Clardy, B. F., 1995, Rare earth elements in the Cason Shale of northern Arkansas: a geochemical reconnaissance: Howard, J. M., ed., Arkansas Geological Commission Information Circular 33, 13 p.

SILVER

Silver (Ag) has been an important metal to humans since ancient times. Often present as a native element possessing readily workable properties of malleability, ductility, and sectility, silver was easily fashioned into ornaments, utensils, and coinage. Today silver has many important industrial uses, including photographic negative films and papers, photocopy paper, X-ray plates, and photographic off-set printing plates. All of these uses are dependent on the light-sensitive nature of silver oxide. Metallic silver has applications in electrical and electronic products due to its high electrical and thermal conductivity. In fact, silver has the highest electrical and thermal conductivity of all the metals. Silver is also used in the manufacture of batteries for special applications, especially where reduced size and weight are important, as in hearing aids and in space craft. Silver is used decoratively in jewelry and sterling ware, usually as sterling silver (92.5 percent silver and 7.5 percent copper alloy). Due to their high cost, sterling silver tea sets have lost popularity in recent years. Silver solders have important applications in the jewelry, electronic, and air conditioning industries, due to silver solder's high strength. Silver is commonly used to create the reflective backing of mirrors, as catalysts, as one of the alloy metals in dental fillings, and for investment purposes, as bars, coins, medallions, and commemorative objects.

Geologically, silver may form as a native metal in veins associated with bismuth, cobalt, and other silver-bearing minerals. Silver-bearing sulfides and sulfosalts may be associated with gold mineralization. However, the conditions under which silver mineralization may develop are far more varied than those of gold.

All significant silver mineralization in Arkansas is associated with hydrothermal lead-, zinc-, and copper-bearing quartz veins scattered throughout the Ouachita Mountain region. The deposits are present principally in small fracture-filling quartz veins which formed in tightly folded sedimentary rock of Paleozoic age. The deposits are known to be present in rocks ranging from the Collier Shale to the Jackfork Sandstone (Cambrian to Pennsylvanian). The silver is usually associated with galena (PbS) or sphalerite ($(Zn,Fe)S$). Minor amounts of freibergite ($(Ag,Cu,Fe)_{12}(Sb,As)_4S_{13}$) may be present.

The abandoned Kellogg mines in Pulaski County, a lead-, zinc-, copper-, silver-bearing deposit, were discovered in the early 1840's and mined underground intermittently until 1927. The greatest period of activity, however, was before the Civil War. In 1925, 3,118 troy ounces of silver were reported recovered from processing of galena concentrates. The silver was valued at $2,194. In 1926, mining activity recovered 70 short tons of silver-bearing lead concentrates, valued at about $6,000 (combined silver and lead value).

Prospecting of lead-, zinc-, copper-, and silver-bearing quartz veins took place in the late 1800's near the community of Silver in Montgomery County. While no commercial mining activity was reported, several tons of concentrates were processed for lead and silver as part of the exploration effort.

In the early 1980's, company exploration programs for zinc deposits in Montgomery County involved drilling of cores of the Womble Shale and Bigfork Chert, both Ordovician in age. Examination of samples revealed the presence of traces of silver and zinc mineralization. Analyses of selected Paleozoic shale units in the Arkansas Valley indicate that some lead-bearing shales also contain traces of silver. Only traces of silver have been reported by analytical work on the zinc, lead, and copper deposits of the Ozark region of northern Arkansas.

There are no known deposits of silver in Arkansas that are of commercial importance, although silver may be potentially recovered as a by-product should mining of lead-zinc ores of the Ouachita Mountain region become economically justifiable.

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Konig, R. H., and Stone, C. G., 1977, Geology of abandoned Kellogg lead-zinc-silver-copper mines, Pulaski County, Arkansas, *in* Stone, C. G., ed., Symposium on the geology of the Ouachita Mountains, v. 2: Arkansas Geological Commission Miscellaneous Publication 14, p. 5-18.

Kurrus, A. W., III, 1980, Geochemistry, geothermometry, and mineralogy of quartz and base metal vein deposits, Montgomery County, Arkansas: Fayetteville, University of Arkansas, M. S. thesis, 84 p.

STRONTIUM

Strontium (Sr) is a soft, silvery, easily oxidized metallic element with a relatively low melting point and a relatively low specific gravity (2.54) for a metallic element.

The commercial strontium-bearing minerals are celestine ($SrSO_4$), containing 56.4 percent strontium oxide, and strontianite ($SrCO_3$), containing 70.1 percent strontium oxide. Of these two minerals, celestine (formerly called celestite) is the only one found in deposits with commercial potential in Arkansas. Celestine may form in association with rocks deposited by the evaporation of sea water (evaporites) or in association with igneous rocks.

Approximately 80 percent of all strontium is consumed in glass and ceramic manufacturing, primarily in television faceplate glass, and magnets for specialty applications. About 2 pounds of strontium oxide are contained in the face plate of the picture of every color television set, where it blocks X-ray radiation and improves the brilliance and quality of the picture. Strontium-bearing magnets are used in small electric motors, loudspeakers, and in the magnetic closures of refrigerator doors. Strontium is also used in fireworks (imparts red color), tracer bullets, zinc metal processing, paint pigments, desensitizing toothpaste, aluminum-parts manufacture, optical and piezoelectrical applications, fluorescent lights, and in analytical laboratories.

Celestine in Arkansas is associated with sedimentary evaporite deposits in the DeQueen Limestone of the Trinity Group (Cretaceous), which extends from the Little Missouri River in Pike County westward across Pike, Howard, and Sevier Counties and into Oklahoma. The two best exposures of coarsely crystalline celestine are at the Briar Gypsum mine in Howard County and about 3 miles south of Dierks, Howard County. South of Dierks, celestine is present as thin layers 25 to 35 feet above the base of the DeQueen Limestone Formation. Two celestine beds have been investigated in this area. While the upper bed appears to consist of lenses, the lower bed is continuous across the area and averages 2 to 4 inches in thickness, but may range up to 6 inches in thickness. These celestine beds underlie an area of at least 3 square miles with an average thickness of 4 inches. The celestine is often intergrown with calcite.

Celestine was first reported in Arkansas in 1929 by U.S. Geological Survey geologists while mapping the southwest area of the state. In 1941, 1,500 pounds of celestine were collected and marketed by W. F. Hintze Company. During 1942 and 1943, a company conducted a prospecting and exploration project for celestine. The company dug test pits and drilled 750 test holes in an area of 30 square miles in Howard County. Subsequently, 90 tons of celestine ore were mined by open-pit methods and shipped to Nacagdoches, Texas, for processing. No further mining of celestine has been reported from Arkansas.

No mining of celestine has taken place in the United States for several decades due to the proximity of our country to the world's largest strontium-mineral producer – Mexico. Low labor costs and proximity to the U. S. market have precluded any recent consideration of development of U.S.-based mining of this commodity.

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Miser, H. D., and Purdue, A. H., 1929, Geology of the DeQueen and Caddo Gap quadrangles, Arkansas: U. S. Geological Survey Bulletin 808, 195 p.

TANTALUM

Tantalum (Ta) is a refractory metal that has a high melting temperature (2,996° Celsius), is highly acid resistant, is ductile and easily fabricated, and is a good conductor of heat and electricity. It combines readily with other refractory metals, such as tungsten, to form alloys with high-temperature strength and stability.

The major use of metallic tantalum is in the manufacture of electronic components, principally tantalum capacitors. Because of their long shelf life and reliability, these capacitors are used in computers, communication systems, and controls and instruments for aircraft, miss-iles, ships, and weapons systems. Tantalum is combined with cobalt, iron, and nickel in superalloys for aerospace structures and jet engine parts. Tantalum is also combined with carbon as tantalum carbide and with other metals to use as metal-cutting tools, wear-resistant parts, and for boring tools.

Tantalum and niobium are chemically similar and are usually present together in similar geologic environments. Niobium tends to be 10 to 20 times more abundant than tantalum. The principal ore minerals are ferrotantalite ($Fe^{2+}Ta_2O_6$) and microlite-pyrochlore ($(Ca,Na)_2Ta_2O_6(O,OH,F)$ - $(Ca,Na)_2Nb_2O_6(OH,F)$). Struverite ($(Ti,Ta,Fe^{3+})_3O_6$), which is recovered from tin-mining wastes, is another source of this metal.

Because Arkansas has known deposits of niobium (see section on **Niobium**), associated with Cretaceous igneous rocks, and because niobium is usually associated with tantalum, the potential for tantalum resources exist in Arkansas. No evaluation of tantalum potential has been made. However, the recovery of tantalum and niobium would probably be as by-products of the mining of rutile or ilmenite, both titanium-bearing minerals (see section on **Titanium**). No tantalum has been recovered from mining operations in Arkansas.

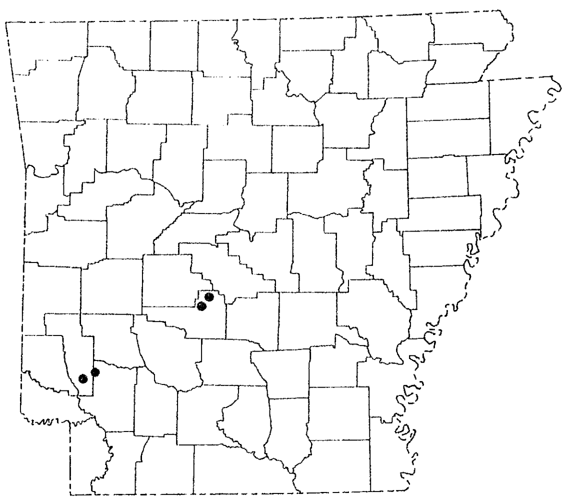
THORIUM

Thorium (Th) is a radioactive metallic element that, until the 1950's, was well known only by chemists and physicists. It is not an abundant element, but major supplies are available in sands rich in monazite ($(Ce,La,Nd,Th)PO_4$). Commercially, monazite is recovered as a by-product of the processing of titanium-bearing heavy-mineral sands. Thorium is used principally for refractory applications, but also has a role in metal technology applications, ceramics, and welding rod coatings. Thorium was formerly used in all gasoline lantern mantles, but adequate substitutes have now been developed. Thorium has had minor use as a nuclear fuel in a few foreign-based nuclear reactors.

Since thorium minerals are generally radioactive, many discoveries of thorium-bearing areas were made in the United States during uranium exploration in the early 1950's. Such was the case in Arkansas with the discovery of radioactive anomalies in the Magnet Cove area in Hot Spring County. For a discussion of radioactivity, see **Uranium**. Samples collected of the anomalous material proved to contain thorium rather than uranium. Another radioactive anomaly located at this time is the Uebergang deposit in Saline County. Here, both thorium and uranium are present in a quartz-feldspar rock. A select sample analyzed 0.019 percent uranium and 1.5 percent thorium. There has been no mining of thorium ores in Arkansas.

Erickson, R. L., and Blade, L. V., 1963, Geochemistry and petrology of the alkalic igneous complex at Magnet Cove, Arkansas: U. S. Geological Survey Professional Paper 425, 99 p.

TITANIUM



Titanium (Ti) is a lightweight metal which was discovered in 1791 and is known for its corrosion resistance and high strength-to-weight ratio. Titanium comprises about 0.62 percent of the earth's crust and is present principally in the minerals anatase, brookite, rutile (all TiO_2), leucoxene (fine-grained titanium oxides), ilmenite ($Fe^{2+}TiO_3$), perovskite ($CaTiO_3$), and titanite ($CaTiSiO_5$). In Arkansas, the most important ore minerals are rutile, brookite, and ilmenite. Rutile and brookite each have a specific gravity of over 4.1 and the same chemical formula, but differ in crystalline structure. Both are commonly black in Arkansas and are present as grains and crystals, waterworn pebbles and granules, or crystalline masses. Ilmenite is black with a metallic luster, and has a specific gravity of 4.7. It is relatively common as water-worn sand-sized grains.

Titanium is used primarily in the form titanium dioxide, although the metal is also used as an alloy. Titanium dioxide's major use is as a white pigment in paint, paper, and plastics. Minor uses of titanium minerals include ceramics, chemicals, welding-rod coatings, heavy aggregate, and steel-furnace flux. Uses for titanium metal alloys include synthetic parts for hearts and metal bone replacements for humans, eye glasses frames, and as parts for aircraft, submarine engines, golf clubs, and electric generation plants. Titanium is classified as a strategically important metal, critical to the nation's defense.

Titanium-bearing minerals in Arkansas are present in Pulaski, Saline, Hot Spring, Garland, Pike, Howard, Sevier, and Little River Counties. They are also known to be contained in alluvial sands of the Arkansas River. Titanium-bearing minerals from Pulaski and Saline Counties are related to intrusive bodies of nepheline syenite and deposits of bauxite. Ilmenite is present in association with bauxite in both counties.

Rutile, brookite, and perovskite are present at Magnet Cove, Hot Spring County. At Magnet Cove, two general types of rutile-brookite deposits are recognized: feldspar-carbonate-rutile veins in igneous rocks of the intrusion and brookite-quartz veins in the altered Arkansas Novaculite contact zone adjacent to the intrusion's rim. Perovskite is associated with late-stage carbonate-rich piercing bodies in the interior of the intrusion. Rutile was mined from open pits at Magnet Cove from 1932 to 1944; about 5,400 tons of rutile concentrates were recovered. Investigations by the U. S. Bureau of Mines show that deposits in the Magnet Cove area may contain 8 million tons of titanium-bearing material ranging from 4 to 8 percent TiO_2. However, high trace-element content, particularly of niobium, has precluded any large-scale development of the deposits. Highlevel terrace deposits south of Magnet Cove contain well-rounded placer rutile, which ranges in grain size from sand to pebble gravel. This area was explored and had minor open-pit production during the 1930's. In Garland County, sporadic titanium values were noted during active vanadium mining at Potash Sulphur Springs, but no values were recovered.

In Pike, Howard, Sevier, and Little River Counties, ilmenite is present in the upper sandy part of the Cretaceous Tokio Formation. The Tokio Formation crops out near Arkadelphia, Clark County, and extends west to the Arkansas state line, north of Arkinda, Little River County. The largest known deposits of ilmenite sands are located near Mineral Springs, Howard County. One deposit was surface-mined, but only a small amount of ilmenite was recovered. Drilling investigations by the Arkansas Geological Commission in 1992 demonstrated that some 110,000 tons of TiO_2 are contained within 50 feet of the surface in this area. During 1939 and 1940, 12.8 short tons of ilmenite were recovered by processing of sand from the Arkansas River by a company in Yell County.

Presently, no titanium ore is mined in Arkansas.

Calhoun, W. A., 1950, Titanium and iron minerals from black sands in bauxite: U. S. Bureau of Mines Report of Investigations 4621, 15 p.

Fryklund, V. C., Jr., Harner, R. S., and Kaiser, E. P., 1954, Niobium (columbium) and titanium at Magnet Cove and Potash Sulphur Springs, Arkansas: U. S. Geological Survey Bulletin 1015-B, p. 23-57.

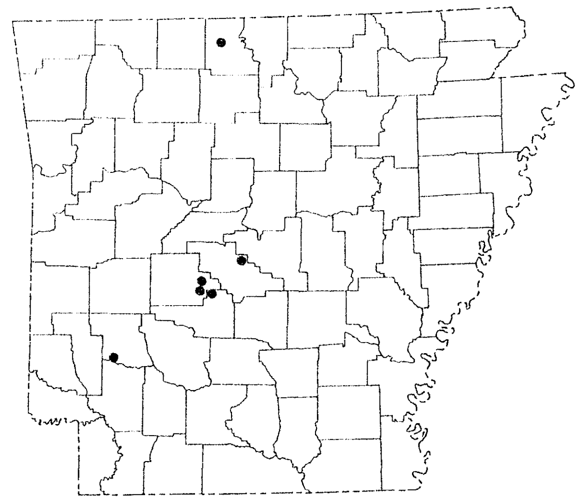
Fryklund, V. C., Jr., and Holbrook, D. F., 1950, Titanium ore deposits of Hot Spring County, Arkansas: Arkansas Resources and Development Commission, Division of Geology Bulletin 16, 173 p.

Hanson, W. D., 1997, Heavy-mineral sands of the Tokio Formation in southwest Arkansas: Arkansas Geological Commission Information Circular 33, 39 p.

Holbrook, D. F., 1947, A brookite deposit in Hot Spring County, Arkansas: Arkansas Resources and Development Commission, Division of Geology Bulletin 11, 21 p.

Holbrook, D. F., 1948, Titanium in southern Howard County, Arkansas: Arkansas Resources and Development Commission, Division of Geology Bulletin 13, 16 p.

URANIUM



Uranium (U) minerals are classified as primary and secondary. Primary uranium minerals are in the same physical state as when originally deposited and secondary uranium minerals are formed by chemical weathering of the primary minerals. The most commercially important primary mineral is pitchblende. Pitchblende, a massive form of uraninite (UO_2), has not been discovered in Arkansas. Secondary uranium minerals are normally brightly colored and may be present in any type of rock. Carnotite ($K_2(UO_2)_2V_2O_8 \cdot 3H_2O$), a canary-yellow mineral, is the most common. Both primary and secondary uranium minerals may be detected by their radioactivity, using special instruments such as Geiger counters or scintillometers. Some instruments will not distinguish between radiation emitted by uranium or by other radioactive materials of no commercial value. Therefore, a chemical assay of the radioactive substance is necessary to determine the presence and amount of uranium.

With the advent of the "atomic age" in July, 1945, the search for uranium in the United States began. Prospecting was stimulated by exploration and discovery bonuses provided by Federal atomic energy legislative acts.

In Arkansas, a number of uranium anomalies were discovered during the 1950's. Several localities yielded samples containing 0.1 percent or more uranium oxide. At many of the localities the mineralization appears to be secondary in nature or related to the presence of organic matter, but, in some instances, the actual uranium-bearing minerals have not been identified.

The Potash Sulphur Springs igneous intrusion in Garland County is probably the best known and perhaps the first site where uranium mineralization was discovered in Arkansas. The mineralization is at the contact of the Cretaceous syenite complex with folded Paleozoic novaculite and shale beds. The U.S. Geological Survey identified the uranium-bearing mineral as pyrochlore ($(Ca,Na)_2Nb_2O_6(OH,F)$), a primary mineral. Soil samples assaying up to 0.4 percent uranium were collected from this site by Atomic Energy Commission geologists.

The Rankin prospect in Pike County consists of radioactive carbonized wood fragments in the lower part of the Trinity Group (Cretaceous). The wood fragments range greatly in size, the smallest pieces containing the most uranium. The highest assay obtained was 0.24 percent uranium oxide. The uranium mineralization is secondary, but the uranium-bearing minerals have not been identified.

At the Chandler prospect in Garland County, uranium is present in gorceixite ($BaAl_3(PO_4)(PO_3OH)(OH)_6$), an uncommon mineral that coats the surface of narrow fractures in the novaculite. Samples of this mineral ran as high as 0.35 percent uranium oxide.

The radioactive material at the Bear Hill prospect in Marion County is a bitumen sparsely scattered through an outcrop of Paleozoic black shale. Samples of the bitumen assayed up to 2.0 percent uranium oxide. No uranium-bearing mineral has been identified.

At the Runyan prospect, just north of Magnet Cove in Hot Spring County, radioactive material is present in narrow smoky quartz veins that fill fractures in the host rock, novaculite. Samples assaying as much as 0.14 percent uranium oxide were collected from this deposit. The individual radioactive minerals are not known.

The Uebergang prospect in Saline County contains both thorium and uranium in a granite-like quartz-feldspar rock. A select sample contained 0.019 percent uranium. Individual uranium-bearing minerals have not been identified.

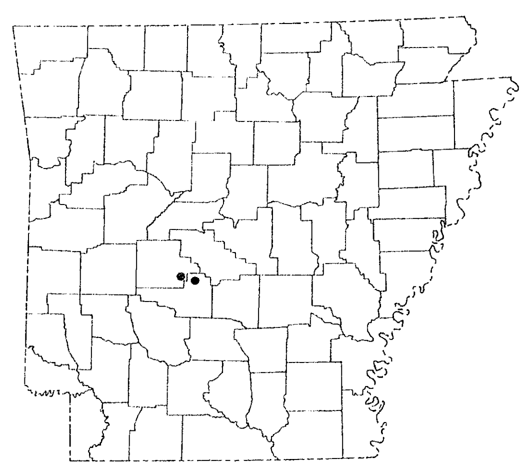
Although samples from Potash Sulphur Springs and the other prospects contain uranium-bearing minerals, no economically viable deposits have been discovered.

Erickson, R. L., and Blade, L. V., 1963, Geochemistry and petrology of the alkalic igneous complex at Magnet Cove, Arkansas: U. S. Geological Survey Professional Paper 425, 99 p.

Stroud, R. B., 1951, The areal distribution of radioactivity in the Potash Sulfur[sic] Springs complex: Fayetteville, University of Arkansas, M. S. thesis, 42 p.

Swanson, V. E., and Landis, E. R., 1962, Geology of a uranium-bearing black shale of Late Devonian age in north-central Arkansas: Arkansas Geological and Conservation Commission Information Circular 22, 16 p.

VANADIUM



Vanadium (V) is a metal with a moderate specific gravity (6.0) and a relatively high melting point, 1710° C. Vanadium is often considered to be an uncommon element, but its abundance in the earth's crust is actually comparable to that of copper, nickel, and zinc. However, in spite of its abundance, it is one of the most expensive elements to recover. Ore values generally are 1.5 percent vanadium pentoxide. Vanadium pentoxide (V_2O_5) is the principal starting material for the manufacture of all vanadium compounds.

The steel industry consumes more than 80 percent of the world's output of vanadium. Vanadium combined with iron, termed ferro-vanadium alloy, is added to steel to increase strength and improve both toughness and ductility. Such high-strength steels are used in high-rise construction, bridges, large-diameter pipelines, and automobiles because of the weight savings. High quality vanadium-steel kitchen knives are prized for their ability to retain a sharp edge. Other uses of vanadium alloys and compounds include aerospace applications and catalysts.

By 1940, chemical analyses of rocks and minerals from the Magnet Cove area, Hot Spring County, suggested that commercial concentrations of vanadium might exist in the area. During uranium exploration in the early 1950's, significant values of vanadium were reported at Potash Sulphur Springs in Garland County by geologists and chemists from the University of Arkansas. Subsequent research by the Arkansas Geological Commission, the U.S. Geological Survey, and private interests centered on uranium and niobium, but also gathered data on vanadium. In 1962, Union Carbide Corporation initiated a systematic study of the Potash Sulphur Springs igneous complex and its adjacent contact metamorphic rocks, which resulted in the discovery of several ore-grade deposits and led to construction of the Wilson Springs processing mill in Garland County.

Vanadium deposits at Potash Sulphur Springs consist of highly altered sedimentary rocks, principally the Arkansas Novaculite (Mississippian-Devonian) and altered igneous rocks in and adjacent to the contact metamorphic zone. These deposits were mined from open pits. The mineral suite is complex and includes several complex vanadium species, usually too fine-grained to readily identify in hand specimens. Vanadium ores may also include sporadic values of titanium and niobium. The Christy vanadium deposit at Magnet Cove, Hot Spring County, has also been mined by open-pit methods and the ore processed at the Wilson Springs mill. The last production of V_2O_5 from Arkansas ores was in 1990. The commercial vanadium values of the Christy deposit, adjacent to the Magnet Cove intrusion, formed in recrystallized and altered novaculite. Vanadium is contained principally in vanadiferous goethite, with some minor contribution from vanadium-bearing brookite.

Since its start-up, the Wilson Springs facility processed over 4.8 million short dry tons of approximately 1.2 percent V_2O_5- bearing Arkansas ore. Concentrate from this facility was shipped to Marietta, Ohio, for conversion to "Carvan" vanadium, a ferro-vanadium alloy.

Evans, H. T., Jr., Nord, Gordon, Marinenko, John, and Milton, Charles, 1984, Straczekite, a new calcium barium potassium vanadate mineral from Wilson Springs, Arkansas: Mineralogical Magazine, v. 48, p. 289-293.

Flohr, M. J. K., 1994, Titanium, vanadium, and niobium mineralization and alkali metasomatism from the Magnet Cove complex, Arkansas: Economic Geology, v. 89, p. 105-130.

Hollingsworth, J. S., 1974, Geology of the Wilson Springs vanadium deposits, *in* Arkansas – Texas economic geology field trip: Arkansas Geological Commission Guidebook 74-1, p. 10-16.

Howard, J. M., and Owens, D. R., 1995, Minerals of the Wilson Springs vanadium mines, Potash Sulphur Springs, Arkansas: Rocks & Minerals, v. 70, p. 154-170.

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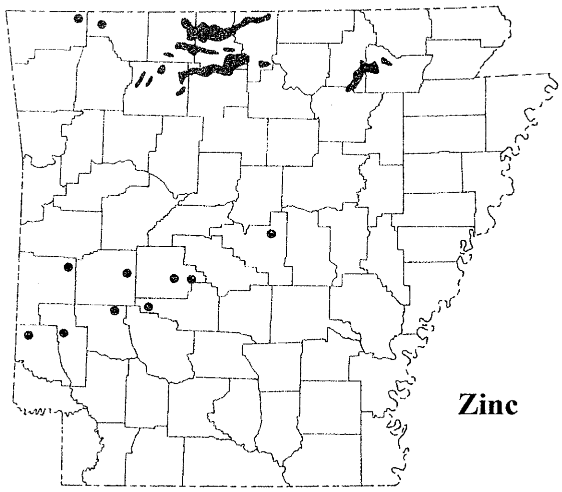
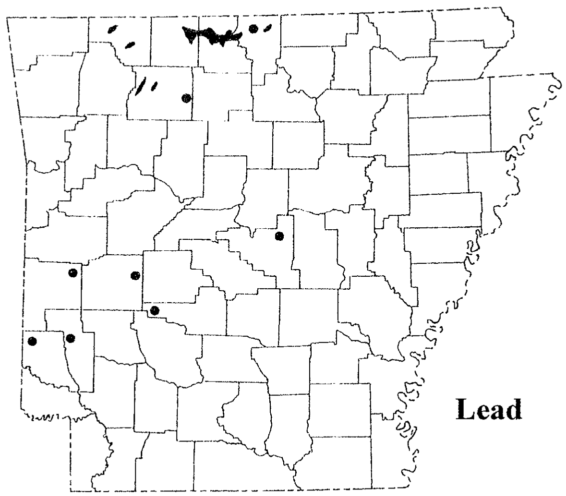
ZINC AND LEAD





Zinc (Zn) is a bluish-white lustrous metal that is brittle at room temperature, but malleable with heating. It has a low melting point (419.5°C) and a moderately high specific gravity (7.13). Lead (Pb) is a soft, ductile, malleable, bluish-white metal with a low melting point (327.4°C) and a high specific gravity (11.3). Zinc and lead have similar chemical behaviors in nature and, as primary minerals, are each combined with sulfur. Therefore, zinc and lead minerals often occur together.

People have used zinc-bearing mineral compounds for more than 2,500 years. Only iron, aluminum, and copper find more use today. The chief uses for metallic zinc are for galvanizing steel and iron, in making brass and other metal alloys, for battery electrodes, as sacrificial metal to retard corrosion of ship hulls, pipelines, and other submerged or buried steelworks, and for sheet zinc. Zinc is currently used as the core of the U. S. penny. Zinc compounds are ingredients in paints, rubber, chemical catalysts, fungus retardants, pharmaceuticals, and electronic devices.

Lead has been used for many years, being relatively easily recovered from its ore minerals. The principal use of lead today is in batteries. Lead oxides are added to glass, paint, ceramics, and other chemicals to impart special properties. Lead is alloyed with antimony, copper, and bismuth to make type metal. Compounds of lead, such as the carbonate and acetate, are used in drugs.

The zinc minerals of commercial importance in Arkansas are sphalerite ($(Zn,Fe)S$) and smithsonite ($ZnCO_3$). Sphalerite, contains 67.1 percent zinc, whereas smithsonite contains only 48 percent zinc. Sphalerite may contain small percentages of iron, manganese, or cadmium. Sphalerite is usually some shade of amber, has a resinous luster, and is transparent to translucent. Smithsonite is harder than sphalerite, has a glossy to pearly luster, usually is white to light brown, and is normally translucent. Some smithsonite with a striking yellow color and botryoidal habit is called "turkey fat" ore. Minor amounts of hemimorphite ($Zn_4Si_2O_7(OH)_2 \cdot H_2O$) were also mined in the north Arkansas zinc districts.

Galena (PbS) is the only lead mineral of commercial importance in Arkansas. Galena contains about 86 percent lead, is very heavy (density of 7.4-7.6), is gray in color with a metallic luster, and is easily cleaved. It may contain some silver as an impurity. When the silver content of the mineral is high enough, the silver may be recovered as a by-product. Galena frequently forms with sphalerite.

Zinc and lead ores are known to be present in two areas of Arkansas: the north Arkansas district, which includes Boone, Marion, Newton, Searcy, and parts of Baxter, Stone, Independence, Sharp, and Lawrence Counties, and the mineral belt of west-central Arkansas extending through and including all or parts of Pulaski, Saline, Garland, Hot Spring, Montgomery, Polk, Howard, Pike, and Sevier Counties. The north Arkansas district has been the most important commercially with more than 350 mines and prospects scattered across the Ozarks. The zinc and lead minerals in north Arkansas are present in irregular bodies in limestone, dolostone, and/or chert beds of Paleozoic age, often associated with local structural incongruities. Deposits have been mined from the Cotter, Powell, and Everton Formations (Ordovician) and the Boone and Batesville Sandstone Formations (Mississippian). They were mined largely by underground methods, although some high-grade pockets of carbonate ore were open-pit mined. In west-central Arkansas, the zinc and lead minerals are most commonly associated with quartz veins in folded Paleozoic sandstones, shales, and novaculite. The Stanley Shale, the Jackfork Sandstone, and the Arkansas Novaculite are known to host lead- and zinc-bearing quartz veins. Essentially all lead and zinc mining in the Ouachita region was by underground methods.

Although zinc is more common, lead ore was recognized and developed first in the north Arkansas district, probably because of its early use for bullets. The presence of lead in this district was mentioned by writers as early as 1818. Lead was mined locally before the Civil War, and 3 lead-refining furnaces (smelters) were in operation during the Civil War at Lead Hill in Boone County. Since that time, lead deposits were worked intermittently through 1959 when mining ceased. The history of lead mining closely parallels that of zinc, given below.

The earliest attempts to work north Arkansas zinc deposits were made at Calamine, Sharp County, in 1857 when a zinc smelter was placed in operation. Active zinc mining began in the counties farther west in 1899 and reached its peak during World War I. Since 1918, there has been only intermittent mining activity in the district, ending in 1962.

In west-central and central Arkansas, a few zinc and lead mines were worked. The Kellogg mine immediately north of North Little Rock in Pulaski County was operated sporadically from 1840 to 1940 and concentrates of lead, zinc, silver, and copper were shipped out of state to be refined. This mine remains the deepest shaft mine in Arkansas, with an inclined shaft that followed an ore vein to a depth of 1,125 feet below the surface. At Petty, 6 miles west of Gillham, Sevier County, several small lead and zinc mines were operated by the Confederate States Government in the early 1860's. Between 1,000 and 1,500 tons were mined and 3 lead furnaces were in operation. In 1899, the mines were reopened, operating for several years. During the first two years, 1,140 tons of ore were removed. The district has been essentially inactive since the turn of the 20th century.

Approximately 27,000 short tons of zinc and lead concentrates were mined from north Arkansas and about 5,000 short tons from the west-central district in total. During the entire period of lead and zinc mining in Arkansas, little ore was found by drilling, the mines being started on surface outcroppings of the ores in both regions of the state. Conservative calculations indicate that 110,000 short tons of potential shallow resources (zinc-lead ores) remain. Significant potential exists in north Arkansas for the discovery of deep (>1,500 feet) deposits of lead and zinc as the southern extension of the New Viburnum lead district in southern Missouri. Due to the high cost of deep exploratory drilling and the large commercial deposits actively being mined in Missouri, exploration in north Arkansas is presently inactive.

Branner, J. C., 1892, The zinc and lead region of north Arkansas: Arkansas Geological Survey Annual Report for 1891, v. V, 395 p.

Konig, R. H., and Stone, C. G., 1977, Geology of abandoned Kellogg lead-zinc-silver-copper mines, Pulaski County, Arkansas, *in* Stone, C. G., ed., Symposium on the geology of the Ouachita Mountains, v. 2: Arkansas Geological Commission Miscellaneous Publication 14, p. 5-18.

McKnight, E. T., 1935, Zinc and lead deposits of northern Arkansas: U. S. Geological Survey Bulletin 853, 311 p.

Miser, H. D., and Purdue, A. H., 1929, Geology of the DeQueen and Caddo Gap quadrangles, Arkansas: U. S. Geological Survey Bulletin 808, 195 p.

THE NONMETALLICS

Any rock, mineral, or sediment of economic value – exclusive of metal ores, fossil fuels, and gemstones – is designated as a nonmetallic or an industrial rock or mineral. The two terms are synonymous. Although gemstones are usually excluded, they are discussed here for the reader's convenience.

Human consumption of the industrial rocks and minerals by weight greatly exceeds our consumption of metals – at a rate of about 16 to 1. Commonly, the materials are not visible in the final product, or, if visible, may not be obvious to the unconcerned. Some of the nonmetallics are mined in large volumes in Arkansas every year and their annual value makes a significant contribution to the state's economy. Nevertheless, people tend to overlook their importance.

Nonmetallics include many very common materials, such as rock (especially limestone, dolostone, and sandstone), gravel, sand, several varieties of clay, as well as some more uncommon materials, such as bromine brine, gypsum, novaculite, syenite, and tripoli. All of the above are currently being mined in Arkansas, as are more than a dozen others.

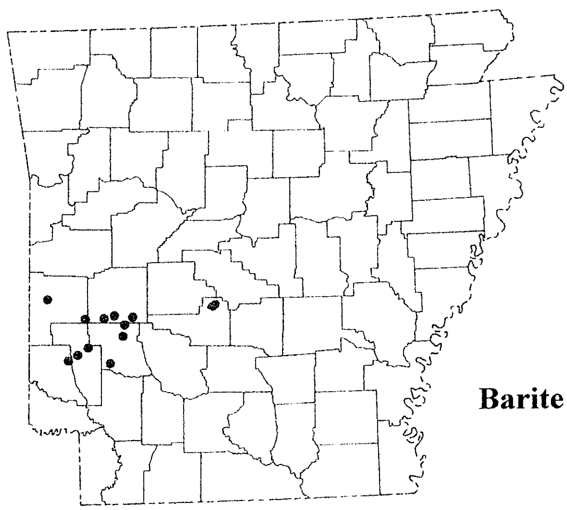
Although exact production data are not readily available, bromine brine, crushed stone (sandstone, limestone, dolostone, and syenite), sand, and gravel have been the most valuable industrial materials mined in recent years.

Unlike many metals which can be recycled profitably, few of the nonmetallics can be reclaimed and reused for the same purpose. Glass, a product in which silica sand is the main ingredient, is an obvious exception. Some materials made of nonmetallics can be salvaged and used for other purposes. Concrete is a widely used man-made material in which sand, gravel, limestone or chalk, marl, and gypsum are the principal ingredients. Demolished concrete structures are commonly reused as fill for other construction projects. Some industrial diamonds are recycled from drill bits and cutting tools. In balance, however, there is a continuous on-going search for new deposits of industrial rocks and minerals to replace those deposits being depleted.

Another major problem faced by the producers of some nonmetallics is that large tonnages are required and market prices per unit are so low that transportation costs are critical. The continuing expansion of suburbs around major market and urban areas and an ever-increasing number of environmental constraints have forced many operators to move to more distant sites, thereby increasing transportation costs and prices paid by consumers.

BARITE

Barite ($BaSO_4$) is a nonmetallic mineral used primarily as a weighting agent in drilling muds in the oil and gas industry, due to its relatively high specific gravity (4.5) for a nonmetallic mineral. The bulk of Arkansas' barite was used for oil-field drilling fluids. In 1990, 90 percent of the world's production was consumed in



drilling fluids. Barite can also be used for the manufacture of lithopone, a white paint pigment, and as a filler in paint, paper, rubber, linoleum, and cloth.

Barite deposits in Arkansas are present in the Ouachita Mountain province, specifically in Hot Spring, Montgomery, and Polk Counties, and near Dierks in Howard County in the Gulf Coastal Plain.

Barite was first discovered in 1888 in Arkansas in Montgomery County and in 1900 was recognized near Magnet Cove in Hot Spring County. Barite was produced in Arkansas from 1944 to 1981 (fig. 9). Mining of the Chamberlain Creek deposit in Hot Spring County began in 1939. From 1944 to 1966, the Baroid Division of The National Lead Company and Magnet Cove Barium Corporation (Magcobar) mined enough barite for Arkansas to lead the nation in annual production. In the 1970's and early 1980's, barite was mined from the Fancy Hill district west of Hopper, Montgomery County. During this time, other barite mines were active near Pigeon Roost Mountain northeast of Glenwood. Limited barite mining has also taken place east of Dierks, Howard County. In 1981, the cost of extracting and processing barite ore exceeded the product's value because the nation began importing ore from less expensive overseas sources. Most of the barite mining operations in the United States ceased.

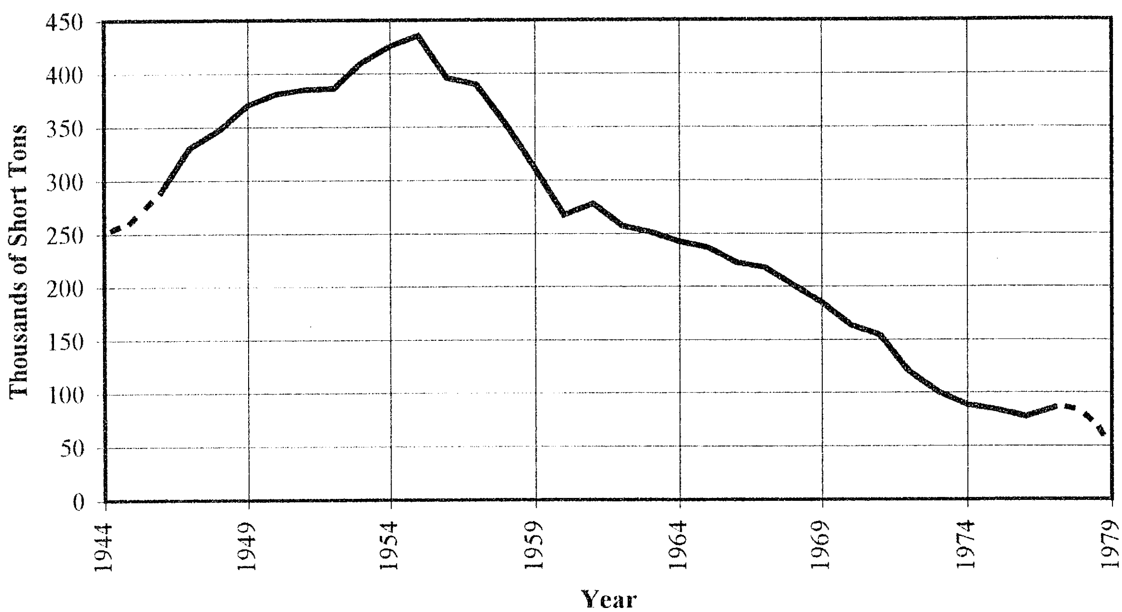


Figure 9. Barite production in Arkansas from 1944 to 1981.
Curve smoothed by using a 5-year moving average.

Barite in the Ouachita Mountains is present primarily as bedded intervals, locally over 100 feet thick, and less commonly as nodules or veins. The mineralization is near the base of the Stanley Shale (Mississippian). Minor quantities of barite may also be present in the middle part of the Arkansas Novaculite. The barite is typically a grayish to white, granular to finely crystalline rock, and is easily identified by its relative softness, high density for a nonmetallic mineral, and by a sulfurous odor when hit by a hammer or scratched with a knife blade.

In the Dierks district of the West Gulf Coastal Plain, the barite consists of a fine- to coarse-grained crystalline cementing material in the sands and gravels of the Cretaceous Trinity Group. Along the margins of these deposits are barite "roses" in the sandy weathered residual zone.

Most of Arkansas' bedded deposits were worked solely by open-pit methods, but the Chamberlain Creek deposit was mined by both open-pit and underground techniques. Ore in the deeper parts of the syncline was mined underground to as much as 500 feet below the ground surface. Most of the barite was processed at flotation mills at Magnet Cove and Malvern, both in Hot Spring County. A small quantity of barite ore was mined and test-milled by Milchem Corporation at Hopper, Montgomery County, before economics forced closure of the facility. The flotation mills typically utilized barite ore containing about 50 percent barite. The result was a concentrate composed of 92 to 94 percent barite. Total production of Arkansas barite concentrates is 9 million short tons (1939-1983 inclusive) – 8 million short tons from the Chamberlain Creek deposit alone.

The geologic origin of most of the barite beds and cemented barite deposits has been the subject of much debate. Both sedimentary and replacement origins have been discussed for years. Recent research has persuaded many geologists to favor theories evoking sedimentary origins related to possible deep-sea hot-springs activity, particularly for the deposits in the Stanley Shale. The age of the deposition of the barite in the Trinity sands and gravels is obviously post Early Cretaceous since it forms the cementing agent of the sediments.

Reserves of barite in Arkansas are estimated to be in the order of millions of tons, but further mining awaits barite's expanded use. Increased domestic oil-field drilling activities and a shortage of cheap foreign ores could make Arkansas barite a viable mineral commodity again.

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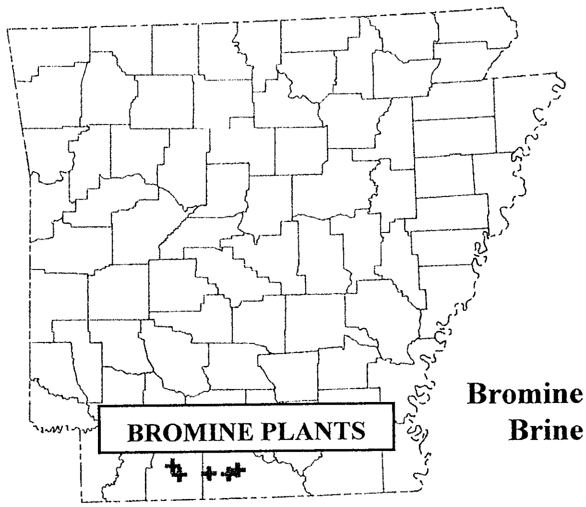
BROMINE BRINE

Elemental bromine (Br) is a highly corrosive, reddish-brown, volatile liquid which, along with fluorine, chlorine, and iodine, forms a closely related family of elements known as the halogens. Bromine is the only nonmetallic element that is a liquid at normal temperature



and pressure. As a liquid, bromine is extremely corrosive, yet when combined with other elements into compounds or chemicals, it becomes the basis for a large number of useful and marketable products. About 85 percent of the bromine recovered is consumed at the production site by the bromine producers. Major products include fire retardants, ingredients in bug and fungus sprays, antiknock compounds in leaded gasoline, and oil-well completion fluids. The remainder, as elemental bromine, is shipped to various chemical processors for use in chemical reagents, disinfectants, photographic preparations and chemicals, solvents, water-treatment compounds, dyes, insulating foam, and hair-care products.

Bromine and iodine are extracted from sea water by seaweed and plankton. In Arkansas, decomposition of organic debris during the Jurassic Period released both bromine and iodine to the forming brines. However, iodine is thought to have escaped from the system into the atmosphere through the process of oxidation. During the active processes that produced the hydrocarbons composing petroleum and natural gas, bromine became even more concentrated in the associated salt brines. In Arkansas, it is thought that brines in the Louann Formation migrated through the overlying Norphlet Formation and into the Smackover Formation.

Bromine is present in abnormally high concentrations in salt brines of the Smackover Formation (Jurassic) in south-central Arkansas. The original analyses that led to the development of Arkansas' bromine industry were performed by a chemist with the Arkansas Geological Commission on brines from 4 oil fields developed in the Smackover Formation. The analyses showed bromine concentrations ranging from 4,000 to 4,600 parts per million, or about 70 times the bromine concentration of normal ocean water. Between 1.5 to 1.8 pounds of bromine are recovered from every barrel of brine processed. U. S. Bureau of Mines data for 1993 show that 35 percent of Arkansas' non-fuels mineral value was due to bromine recovery.

The first commercial recovery of bromine in Arkansas was from Union County in the year 1957, and production has been continuous since then. Arkansas' industry continues as the world's leading producer of bromine, averaging 40 percent of the world's production for the 5-year period between 1986 and 1990, inclusive. During the same period, the average rate of growth of Arkansas' bromine recovery was more than 20 million pounds per year. U. S. production in 1990 was 389.4 million pounds; Arkansas' output accounting for 97 percent of this figure. Bromine presently is recovered from brines in Columbia and Union Counties by several major companies.

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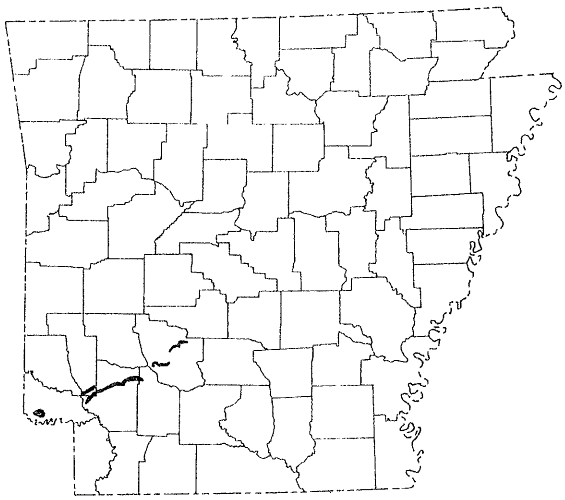
CHALK



Chalk is a sedimentary rock composed chiefly of the skeletons of microscopic organisms composed of calcite ($CaCO_3$). It is readily distinguished by its white or light color, crumbly nature, and emission of carbon dioxide gas (it fizzes) when in contact with weak hydrochloric acid. Chalk, when strongly lithified, becomes limestone. Arkansas chalk is used primarily in the manufacture of Portland cement and as a neutralizing agent in the treatment of acid soils. Chalk may also be used as a whiting agent, as asphalt filler, and as a chemical neutralizer for the control of gaseous emissions from some industrial plants.

In Arkansas, chalk is the major constituent of two extensive Cretaceous formations: the Annona Chalk and the Saratoga Chalk. These sedimentary deposits are exposed in a trend extending northeasterly from Foreman in Little River County to Arkadelphia in Clark County and dip gently to the south-southeast.

The Annona Chalk is a hard, white, thick-bedded, massive chalk containing few macrofossils. It is exposed 2.5 miles north of Columbus in Hempstead County westward to Foreman, some 35 miles across Hempstead, Howard, and Little River Counties. North of Columbus, the chalk is less than 1 foot thick and pinches out to the east. The best exposures of the Annona Chalk are in the vicinity of Foreman and at White Cliffs Landing on the Little River, both in Little River County. At White Cliffs Landing, the chalk has a maximum exposed thickness of about 100 feet.

The Saratoga Chalk is a very fossiliferous, hard, sandy, glauconitic chalk interlayered with beds of chalky marl and chalky sands. It is exposed in Clark and Hempstead Counties. The Saratoga has an average thickness of about 40 feet, but thickens on the east side of Lake Millwood in Hempstead and Howard Counties to about 70 feet. This thickening may be due to local faulting. The Saratoga Chalk is well exposed at Saratoga Landing on Lake Millwood, along Arkansas Highway 4 between the communities of Washington and Ozan in Hempstead County, and west of Columbus along Arkansas Highway 73 in Howard County. The Saratoga, though widespread, is apparently too thin to interest industry in its potential.

In 1929, a cement-manufacturing plant was erected in southwest Arkansas near Saratoga. A second plant was built near Foreman in 1958. Both mined the Annona chalk from open pits. The plant near Saratoga closed in the early 1990's after about 60 years of operation. For a brief period, the Annona chalk also was mined by open-pit methods at White Cliffs Landing for cement and whiting, but the chalk proved to contain too much silica and mining ceased. In 1969, the Arkansas Geological Commission and the U. S. Bureau of Mines, using outcrop data, calculated chalk reserves of 700 million tons in the Annona Chalk in Sevier and Howard Counties.

Chalk, used for the manufacture of cement, continues to be mined near Foreman by Ash Grove Cement Company. The plant near Foreman is the 28^{th} largest facility (by capacity) in the United States. No production figures are readily available, but it is estimated that over 1 million tons of cement rock are mined in Arkansas annually.

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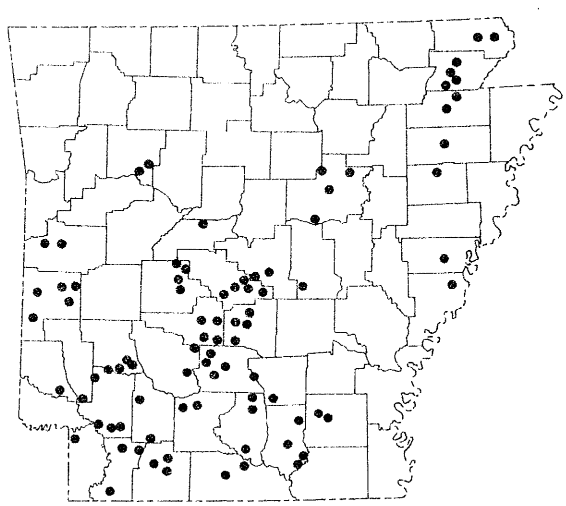
CLAY



The term clay is used in 3 different ways: to designate a diverse group of fine-grained minerals, as a rock or sediment term, and as a particle-size term. Clay is generally defined as any very fine grained, natural, earthy material, which is generally plastic at appropriate water contents and hardens when dried or fired. Despite the lack of a standard definition for clay among geologists, agronomists, engineers, and soil scientists, the term clay is generally understood by all who use it. As industrial minerals, clays are a complex group that encompasses several mineral commodities, each having somewhat different mineralogy, geologic occurrence, manufacturing technology, and uses.

Mineralogy

Mineralogically, clays are divided into 3 principal groups – kaolinite-serpentine, illite, and smectite. There are some 30 separate minerals included in the 3 clay groups. Certain other minerals are included with the clays as a group and may consist of a clay mineral regularly interstratified on an atomic level with sheet-type non-clay minerals, usually micas. Rectorite is an example; it consists of interlayered smectite (clay) and mica (non-clay). Such clay minerals do not easily fit into the general 3-fold classification.

Most clay minerals are the result of weathering of some pre-existing rock. The great bulk of clay present in sedimentary rocks was derived by the weathering of silicate minerals composing igneous rocks. Some clay minerals are hydrothermal in origin (dickite, rectorite, and halloysite), whereas others form from the alteration of other types of clay (example – nontronite). Nine clay minerals have been reported in Arkansas. When we add rectorite to the list below, we have a total of 10.

<u>Kaolinite-Serpentine Group</u>
- Antigorite
- Dickite
- Halloysite
- Kaolinite
- Nacrite

<u>Illite Group</u>
- Illite

<u>Smectite Group</u>
- Beidellite
- Montmorrillonite
- Nontronite

Classification by Use

In nature, clays rarely are present as pure minerals, but typically are mixtures of the different clay types, one group or type normally being dominant. The physical properties of clays, which determine their commercial value, depend on whether or not they are admixed, what types of clays are present and their percentages in the mixture, the percentage and composition of non-clay materials present, and other factors. Important physical properties include, but are not limited to, firing temperature, shrinkage or swelling percentage on firing, plasticity index, bloating character-istics, firing color, percentage of fines (slack) produced upon crushing, and fired strength.

Utilization of clay as a resource material requires that the clay have a restricted range of properties for each industry. Therefore, the brick manufacturer wants a large-volume source of moderately uniform clay that has a low shrinkage/swelling percentage, consistent firing color, relatively low firing temperature, and good strength after firing. A lightweight aggregate manufacturer desires a clay which upon firing, bloats or swells to become a cellular frothy mass. A paper manufacturer has a specific whiteness test that a kaolinite must pass before it can be used as a surface coating for high-quality paper. Because individual clay deposits can be unique due to their specific modes of formation and physical characteristics of any given blend of clays, industry usually classifies clay by the properties which determine its usage (fig. 10). This type of classification includes ball clay, bentonite, bloating clay, brick clay, common clay, fuller's earth, pottery clay, fire or refractory clay, high purity kaolin, and several others.

Clay is a relatively heavy, low-value commodity so transportation costs are a significant economic factor in the commercial development of any deposit. The presence of local and regional markets for either the raw material or for a manufactured item often determine the commercial viability of a given deposit. Most clay deposits in Arkansas have been mined from open pits.

Each type of clay from Arkansas will be discussed by actual use, rather than by mineralogy alone. In our state, there are several industries which either manufacture products directly from clay or utilize clay in their processing.

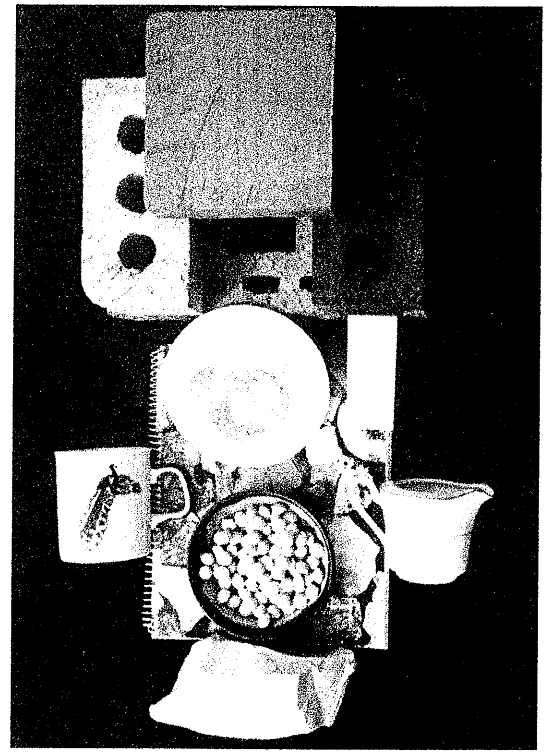


Figure 10. Various everyday items produced from or containing clay. Small pellets (in bowl) are bentonite.

Bentonite

The principal clay mineral composing bentonite is smectite. Smectite is most often used as a group name, encompassing a number of very fine grained minerals which possess certain ion-exchange characteristics. Bentonite's commercial value is due to its ion-exchange ability, which determines the clay's physical expansion and colloidal properties. Sodium-rich bentonites are valuable for well-drilling muds which must flow when shaken or stirred, but harden when left undisturbed (the property of thixotropy).

Bentonite occurs as bedded deposits and as a hydrothermal mineral. Bentonite beds that originated as an alteration of waterlaid volcanic ash, deposited in either fresh or saline water, are commercially the most important source of this resource. In the Gulf Coastal Plain of Arkansas, beds of bentonite are present, particularly in the Midway Group (Paleocene).

A number of these bentonitic beds contain fuller's earth. Bentonite has not been mined in Arkansas, although specific deposits of certain clays that have the desired properties after treatment have been mined.

Bloating Clay

Bloating clay may be defined as any fine-grained clayey material which, upon firing, expands or bloats into a frothy mass with closed cellular texture within a limited temperature range. In practice, the definition can be extended to include some shales, slates, and mine wastes. After being ground to fine size and mixed with water, some of these particles are suitably clayey and can be used as feedstock for making lightweight aggregate. The property of expansion upon firing is desired because bloated material, when used as an aggregate in concrete, reduces the weight of the final product. Two conditions are necessary to bring about bloating of a clay. During firing, when the bloating temperature is reached, the general clayey mass must be in a plastic condition and, at the same time, gases must be evolving throughout the mass. Plasticity is developed by the fluxes that start a fusion and, in this state, the gases can not readily escape. The result is a mass of thin-walled cells, resembling pumice in appearance. After firing, the expanded clay is ground or broken to various sizes and is used in concrete structures, lightweight building block, and precast or prestressed concrete structural members. The use of lightweight aggregates results in considerable monetary savings in structural steel and foundation design on new and existing structures, and in some applications, strength is greater that it would be if heavier rock aggregate were used. Other applications include loose insulation, plaster and stucco aggregate, mulching agents for horticultural applications, bases for sports tracks, and refractory (high temperature) materials.

For a few years, beginning in the early 1950's, clay was expanded for lightweight aggregate at Poyen, Grant County. Alluvial clay suitable for lightweight aggregate has been mined near England, Lonoke County, and is presently being mined in Crittenden County. Most of the physiographic provinces of the state contain major resources of this material. In the Ozark region, black fissile shales of the Atoka Formation (Pennsylvanian) constitute a major potential resource. In the Arkansas Valley, clays derived by the weathering of shales in the Hartshorne Sandstone are potentially useful. The bloating-clay resources of the West Gulf Coastal Plain are known to include tuffaceous sediments of the Woodbine Formation (Cretaceous), Brownstown Marl (Cretaceous) and some clays of the Wilcox Group (Eocene). Smectite clays in Arkansas have received some attention for use as commercial grade "kitty litter". Such clays are common in the Midway Group (Tertiary) in central Arkansas and in several Cretaceous formations in southwestern Arkansas. High bloating characteristics with a medium firing range result in a frothy porosity which is ideal for a high-absorbancy product. The Mississippi River Alluvial Plain contains major resources, including surficial alluvial (recent stream) deposits and the loess (wind-blown dust) deposits of Crowley's Ridge. Few detailed studies have been done concerning actual reserves of individual deposits, but it is felt that Arkansas' potential reserves of clay (and shale) that qualify for bloating are large. A potential source of lightweight aggregate in Arkansas is tripoli (see **Tripoli**).

Common Clay

Clay suitable for the manufacture of heavy clay products, such as building and paving bricks, drain tile, and sewer tile, are present in several areas of the state and have been utilized for many years. Many deposits of kaolin, ball clay, and fire clay are suitable for heavy clay products. To manufacture heavy clay products, the natural material must possess certain working and drying properties, the most important of which include plasticity when wet, little shrinkage when drying and being fired, and good strength as both a green (unfired) and fired product. The fired color of the clay is important to the consumer and, therefore, of major concern to the manufacturer. A building-brick clay that fires white may be developed commercially because, by the addition of various minerals, the color may be modified to meet whatever is popular among consumers at any given time. Clay from another deposit, otherwise comparable in size and clay quality, that fires to a red to orange color may not be commercially suitable for the brick industry, but may be considered usable by the manufacturer of unglazed clay flower pots.

Geologically and volumetrically, the most important source of clay in Arkansas is the Wilcox Group (Eocene). Wilcox clays, alone or mixed with clay from other geologic units, are usable for most ceramic products, especially refractory brick and heavy clay products. Deposits in the Wilcox in Hot Spring, Ouachita, and Hempstead Counties have been particularly important. Some building brick has also been manufactured from surface clays and shales in other regions of the state.

Fuller's Earth

Fuller's earth, or natural bleaching clay, is any natural or treated clay which, when used as a filter, effectively removes color and clarifies various mineral and organic oils. Mineralogically, fuller's earth is predominantly smectite (calcium montmorillonite), but typically includes some kaolinite and attapulgite. The importance of fuller's earth to industry is due its bleaching properties. Deposits of fuller's earth were mined by underground methods near Olsen Switch, 7 miles south of Benton in Saline County, between 1901 and 1922. The deposits were formed by the weathering of igneous dikes of Cretaceous age. The original igneous rock was altered to a depth of 200 feet, probably in early Tertiary time, while bauxite was forming nearby. Several deposits of bentonite, which upon treatment with weak acid have good bleaching or clarifying properties, are reported in Pulaski and Saline Counties. These bedded deposits are in both the Midway and Wilcox Groups (Paleocene and Eocene, respectively).

High-purity Kaolin

Kaolin has many industrial applications and new uses continue to be discovered. It is a unique industrial mineral due to several properties, including chemical inertness over a wide range of acid-alkaline conditions, white color, good covering or hiding power when used as a pigment or extender in coated films and in paper-filling applications, softness and non-abrasive properties, low conductivity of heat and electricity, and lower cost than most competitive materials. Some uses of kaolin require very rigid specifications including particle-size distribution, color and brightness, and viscosity. Other applications require none of these, an example being the use of kaolin in the manufacture of cement. Nationally, the higher grades of kaolin make up the bulk of the tonnage sold and have the highest unit value. Many grades are designed for specific uses, particularly for the paper, paint, rubber, plastics, and ceramics industries. Deposits of high-purity kaolin have been and will continue to be searched for in Arkansas. At this time, no deposits have been discovered that are suitable to the paper industry, but continuing research into the uses and applications of kaolin may result in expanded use of this Arkansas resource.

Pottery Clay

Clays used for pottery and stoneware are principally kaolin and/or ball clay. To be successfully worked and dried, the clay must be plastic when wet, must shrink little while drying, and must resist warping and breaking after being dried before firing. At this stage, it is known as "greenware". After firing, the final product must be hard, strong, nonporous and of a suitable color. Household items manufactured using pottery clays include porcelain sinks and waterclosets (toilets), some chinaware, various types of ovenproof cookware, stoneware and other kitchen and dinnerware, ceramic floor and wall tile, and decorative items. Pottery has been manufactured from red-orange residual clays in the Ozark Plateaus region of Arkansas. Clays having the properties necessary for pottery and stoneware use are present in the Ouachita Mountain and Arkansas Valley regions as deposits formed by the weathering of shales in the Atoka Formation and Stanley Shale (Pennsylvanian and Mississippian, respectively). Most Cretaceous clays in southwest Arkansas are calcareous and are not suitable for ceramic purposes. Ceramic and pottery clays are present in southeastern Arkansas, primarily in the Midway Group (Paleocene), and the Wilcox and Jackson Groups (both Eocene) and, to a smaller extent, in Quaternary and Recent sediments.

Refractory Clay

Refractory clays exhibit high melting temperatures which make them useful wherever high-temperature applications exist. Refractory bricks line the roasting and processing furnaces of various high-temperature processing plants and ceramic kilns. Crucibles, condensers, and many types of laboratory glassware are made from refractory clays. The white ceramic insulator portion of gasoline engine spark plugs are manufactured from refractory clay and coated with vitrified kyanite (Al_2SiO_5). In addition to the high melting temperatures, refractory clays must have good greenware strength and exhibit minimum shrinkage and warpage. Kaolinite, flint clay, plastic fire clay, ball clay, and various calcined materials, such as bauxite, qualify as refractory resources. The product is generally hard and may vary in porosity. In the Ozark region of Arkansas, some shales in the Atoka Formation (Pennsylvanian) have the firing properties necessary to manufacture refractory materials such as fire brick. Clays generated from weathered Pennsylvanian strata in the Arkansas Valley constitute abundant fire-clay resources. These clays are often underclays associated with coal beds. Although the shale units of the Ouachita Mountain region are highly varied, fire clay resources are present. In the Gulf Coastal Plain region, fire clays have been mined from kaolin deposits in the Tokio Formation (Cretaceous) in Pike County. Some fire clays (as underclays), associated with lignite, are locally present in the Wilcox Group. Some Wilcox clays in Ouachita and Hot Spring Counties are suitable for manufacturing fire brick. High-alumina clays, associated with bauxite deposits in Pulaski and Saline Counties in central Arkansas, are potential sources for refractory materials.

Clay resource

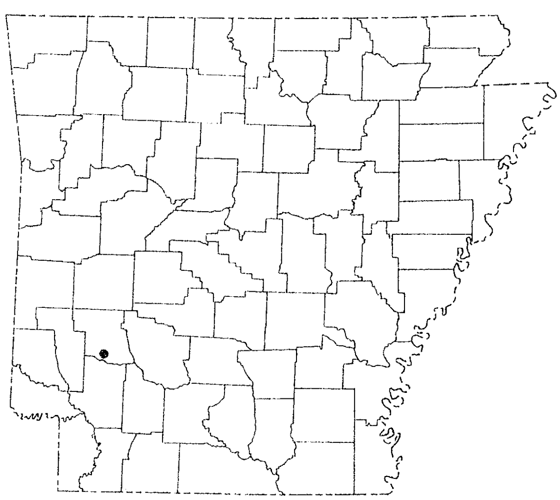
Clay is a major industrial mineral resource in Arkansas. Combined industry output in 1995 amounted to over 1.05 million tons of raw clay, valued at over $1.2 million. In 1995, Arkansas ranked 4th in the nation in production of both kaolin and fire clays, and 9th in common clays. Few data concerning tonnage and grade of individual clay deposits in Arkansas are available, but it may be said that the amount of potentially useful clay in the state is great. Many changes have taken place in the various clay industries in recent years. Some changes are due to technological advances, changing economic conditions, opening new markets, shifts in demand, and increases in both domestic and export markets. Changing conditions which affect the clay industry in Arkansas include increasing freight rates and energy costs, increasing production and marketing costs, and increasing governmental control and recent changes in mining laws. An example of this changing situation involves the public's attitude pertaining to landfills. At one time, rubbish disposal did not require containment of the liquid products of any landfill. It now does. Clay liners are commonly required during landfill construction. The types of clay used vary according to the type of material the landfill will contain. Untreated clays used industrially as clay liners include kaolinite, smectite, and palygorskite. Each clay has very different physical and chemical properties, allowing their use as liners in differing situations.

Branner, J. C., 1908, The clays of Arkansas: U. S. Geological Survey Bulletin 351, 247 p.

Miser, H. D., 1913, Developed deposits of fuller's earth in Arkansas: U. S. Geological Survey Bulletin 530, p. 207-220.

Williams, N. F., and Plummer, Norman, 1951, Clay resources of the Wilcox group in Arkansas: Arkansas Resource and Development Commission, Division of Geology Information Circular 15, 98 p.

DIAMOND (INDUSTRIAL)



Diamond is an unusual mineral. It is the hardest known substance, being composed of very densely packed carbon (C). Diamond has unique physical and chemical properties, aside from its brilliance and "fire" when properly faceted into a gemstone, which make it one of the most important minerals to industrialized society. Due to their superior hardness, industrial grade diamond powders are often used to cut and polish all types of gem-grade stones. Along with its abrasives applications, other uses include heat sinks in electronic components, infrared windows in heat detectors, surgical blades, glass-cutting and engraving tools, wire-drawing dies, metal-cutting tools, and drill bits. When tungsten carbide cutting tools were introduced during World War I, industrial diamond use increased greatly, principally for grinding and sharpening these tools. During World War II, demand for all industrial applications of diamond again increased dramatically. In 1955, General Electric Company announced the development of an industrial process for the manufacture of synthetic diamond. This was followed by a similar announcement in 1959 by De Beers Consolidated Mines Ltd. Today, the production of industrial grade synthetic diamond (336 million carats or 148,151 pounds) outstrips the world's mined output of natural diamond. In 1989, natural industrial diamond counted for 55 percent of the world's diamond production. Since diamonds were discovered over 2,000 years ago, only about 380 tons of natural (industrial and gemstones, combined) diamond have been recovered.

Evidence provided by the conditions required to grow artificial diamonds and studies of minerals included in natural diamonds indicate that diamond is only formed at depths greater than 120 miles below the earth's surface and at temperatures of more than 2,000° F. Under these conditions, diamond is the stable form of carbon and is thought to have been captured and swept upward by igneous intrusions. These igneous rocks are called lamproites and kimberlites.

One of the few places in North America where diamonds are present in their host rock and the only place the public may hunt for diamonds is the Prairie Creek pipe in Arkansas. It is roughly triangular in surface outcrop, covers about 83 acres, and is situated 2.5 miles southeast of Murfreesboro in Pike County. The site has been known to geologists since 1842. It is a breccia-filled volcanic pipe of Cretaceous age, which was formed by a series of gaseous explosions, as are several other smaller pipes nearby.

Various rock types are present in the diamondiferous pipes. Magmatic lamproite is a dark-colored igneous rock with a texture that has two distinct grain sizes (porphyritic). Some of it was broken into smaller pieces explosively as it neared the earth's surface. This broken rock material is lamproite breccia tuff. Rarely have diamonds been reported in the soils formed by the weathering of magmatic lamproite; most have been recovered in the lamproite breccia tuff or in the thin residual soils overlying this rock. Microdiamonds, however, have been recovered from the magmatic rock by special techniques. Epiclastic rock, which is a rock formed by the mechanical mixing of tuffaceous volcanic material and local Cretaceous sediments, has only recently been recognized by geologists.

Diamonds were first discovered in Arkansas in 1906 when two stones were picked up by John M. Huddleston near the mouth of Prairie Creek southeast of Murfreesboro. Following this discovery, diamonds were reported from two small areas 2 miles to the northeast of the Prairie Creek pipe. Through the years, various efforts were made to mine diamonds on a com-mercial basis, but without sustained success. In 1919, the Arkansas Diamond Corporation was organized and a washing plant was erected which processed 18,000 loads of surface-mined diamond-bearing material in 1920. The corporation discontinued operations after 9 months. Early in 1940, the property was taken over by The Diamond Corporation of Arkansas. Their 2,000-ton washing and concentrating plant began operation in 1948, but shut down a year later. Howard A. Millar operated the "Crater of Diamonds" tourist attraction on part of the Prairie Creek pipe for a number of years in the 1950's and 1960's. This volcanic pipe and some surrounding acreage became Crater of Diamonds State Park in 1972 when the State of Arkansas purchased it for $750,000 from General Earth Minerals. From 1972 to 1996 inclusive, 1,840,003 guests have visited the Park.

Recovery figures are incomplete, but it is estimated that about 100,000 diamonds, thought to average 0.25 carats in weight, have been recovered by commercial efforts and by tourists. Since the Prairie Creek pipe became a state park in 1972, the state has maintained records of the number of diamonds discovered and reported. From 1972 to 1996 inclusive, 20, 396 diamonds weighing a total of 4,065.19 carats were reported (Mike Hall, personal communication). It is not known what percentage of the stones from Arkansas are of industrial grade.

In the early 1990's, drill-hole data on the Prairie Creek pipe indicated that about 78 million tons of diamond-bearing rock are present to a depth of 650 feet. Several other nearby diamond-bearing lamproite pipes are known to exist northeast and east of the state park, all on private property. For information concerning gem-quality diamonds, see the diamond section in **Gemstones** (below).

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Miser, H. D., and Purdue, A. H., 1929, Geology of the DeQueen and Caddo Gap quadrangles, Arkansas: U. S. Geological Survey Bulletin 808, 195 p.

Miser, H. D., and Ross, C. S., 1922, Diamond-bearing peridotite in Pike County, Arkansas, *in* Contributions to economic geology, pt. 1: U. S. Geological Survey Bulletin 735, p. 279-322.

GEMSTONES

As used here, a gem is any jewel, whether mineral, rock, pearl or the like, having value and beauty that are intrinsic. A gemstone or gem material is a stone or material from which a gem may be cut. Gems are used for personal adornment, display, or in manufactured objects of art because they possess beauty, rarity, and durability.

Arkansas has within its boundaries several stones or materials which, by popular definition, are considered gemstones. They are: amber, diamond, fresh-water pearls, onyx, quartz (several varieties), and turquoise. In 1995, Arkansas ranked 3rd in the nation in value of gemstones produced.

Amber

Amber is brittle, yellowish to brownish, translucent to transparent, fossilized tree resin. It may trap and enclose insects and other organisms. Gem-quality amber takes a high polish. Gem-grade amber is often used to make faceted beads and irregularly shaped polished drops. Larger pieces may also be manufactured into mouth pieces for pipes or cigarette holders, although less expensive plastics now substitute almost entirely for this market.

Amber has a low specific gravity (1.0-1.1) and is soft (2-2.5 Mohs scale). Because it is a hydrocarbon in composition, amber burns with a strong "tar" odor. Amber is also soluble in some petroleum-based solvents, such as acetone.

Worldwide, amber is recovered from alluvial soils, clays, and recent sediments, from beds of lignite, and along some seashores where offshore deposits are disturbed during storm activity, as in the Baltic Sea. In Arkansas, amber is associated with lignite beds of Tertiary age uncovered during the mining of brick clay south and east of Malvern in Hot Spring County. Although no gem-grade amber has been reported in these deposits, paleontologists have discovered several new species of insects in Arkansas amber.

Diamond

The Arkansas General Assembly passed Act 128 of 1967, which designated diamond as the official gem of the State of Arkansas. To qualify as gem grade, the mineral diamond must meet several criteria. It should be large enough to cut a stone whose value is enhanced by more than the cost of cutting. An octahedral-shaped diamond allows the production of the largest brilliant round cut with the least waste. Even when faceted to this ideal shape, which possesses the most fire for the finished weight, a given diamond crystal will lose about 50 percent of its weight. The rough or uncut stone must be clear and devoid of major inclusions or flaws. Diamonds not meeting the grader's standards are termed industrials. Total lack of color is usually considered to be of the highest value. However, some particularly strong or unusual colors are highly valued, such as canary yellow, pink, or blue. Pale yellow, brown, and green are considered inferior colors for gemstones.

With these qualifications in mind, a number of diamonds recovered from the volcanic pipes near Murfreesboro qualify as gem-grade material. The largest diamond discovered in North America came from this site and was recovered by commercial methods (fig. 11). Named the "Uncle Sam", this diamond was discovered in 1924. It weighed 40.23 carats in the rough, and was faceted into an elongate emerald-cut gemstone weighing 12.42 carats. It has a faint rose color and is presently owned by Peiken of Fifth Avenue, New York. The best known diamond recovered by a tourist is the "Star of Arkansas", a white 15.33-carat crystal which was faceted to a flawless 8.27-carat marquise-shaped gem (fig. 12). This stone was auctioned at Christie's of New York in 1994 and brought $145,000. The largest diamond discovered since the beginnings of Crater of Diamonds State Park in 1972 is the "Amarillo Starlight", weighing 16.37 carats. This stone was faceted to a 7.54-carat marquise-shaped gem, valued at between $150,000 and $175,000.

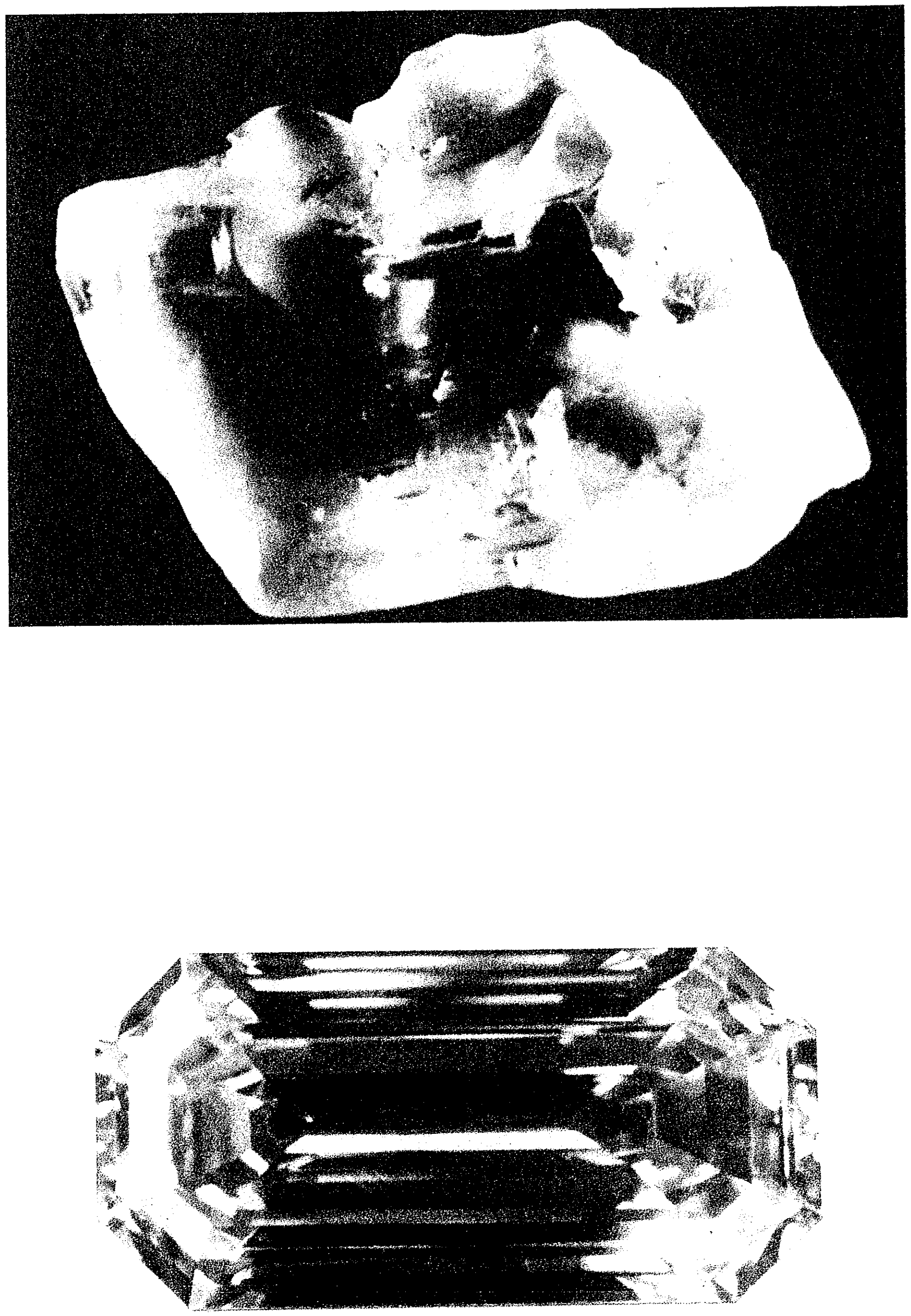

Figure 11. Uncle Sam diamond, uncut (above). The largest diamond discovered in North America, weighing 40.23 carats. Recovered in 1924 by the Arkansas Diamond Corporation during commercial mining. Uncle Sam diamond, cut weight 12.42 carats (below). Both photographs greatly enlarged. *Courtesy Arkansas Department of Parks and Tourism.*

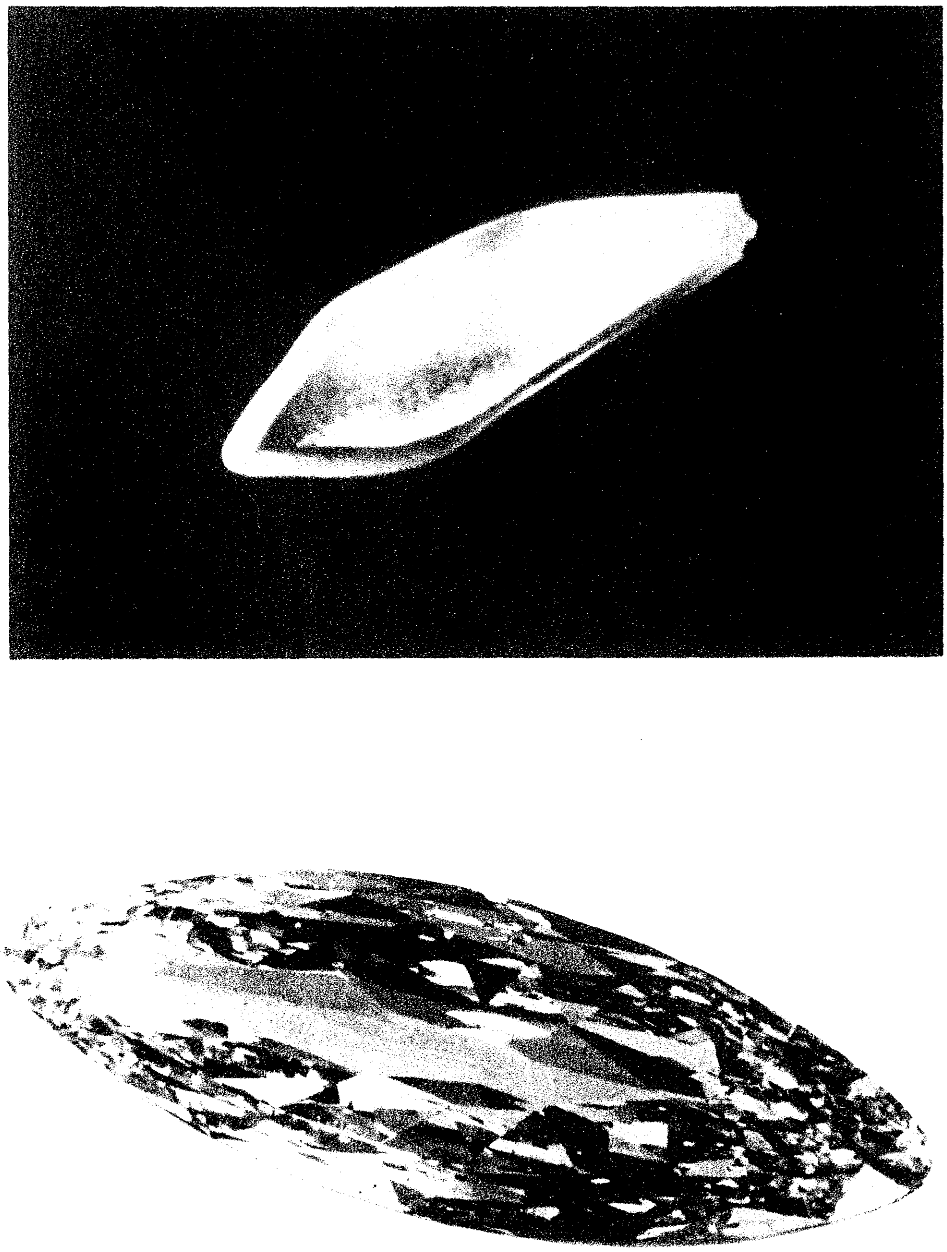

Figure 12. Star of Arkansas, uncut (above). Weighing 15.33 carats, it was discovered in 1956 by Mrs. A. L. Parker of Dallas, Texas. Star of Arkansas, cut weight 8.27 carats (below). Both photographs greatly enlarged. *Courtesy Arkansas Department of Parks and Tourism.*

Numerous smaller stones from Arkansas have been cut or left as natural crystals and utilized in jewelry. During the 1992 Presidential Inaugural Ball in Washington, DC, the First Lady, Hillary Clinton, wore a natural diamond crystal set in a gold ring. This diamond crystal weighs 4.25 carats, is strong canary-yellow in color, and possesses a brilliant natural luster.

Records of the diamonds discovered at Crater of Diamonds State Park for the period of 1972 to 1996, inclusive, indicate that 591 diamonds were reported that weighed over 1 carat each (Mike Hall, personal communication). An unknown percentage of these stones would qualify as cuttable gemstones.

One notable find of a gem-grade diamond is reported near Searcy in White County in 1926. A young girl picked up a pretty stone while working in a cotton field. It was later identified as a 27.21-carat gem-quality diamond (fig. 13). In 1946, the finder, Mrs. Pellie Howell, sold this uncut stone to Tiffany & Company of New York for $8,500. Still in Tiffany's possession, it is of a fine cape (pale yellow) color, has not yet been cut, and is the third largest diamond so far discovered in the United States. It is thought that this single stone was originally discovered by a Native American at or near the Prairie Creek pipe and dropped near Searcy where it was later found. There are no known geologic or geophysical indications of diamond-bearing pipes in northeast Arkansas.

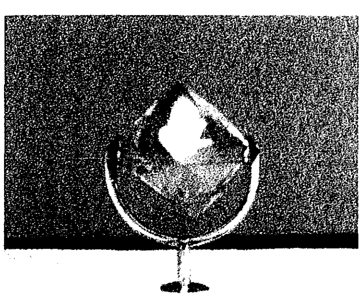

Figure 13. Searcy diamond, uncut weight 27.21 carats. The third largest diamond discovered in the United States. Photograph enlarged by about 50 percent. *Courtesy Tiffany and Company, New York.*

Onyx

Onyx is a variety of banded calcite ($CaCO_3$) deposited by water in caves. Inexpensive carved figurines, table tops, and interior decorative items are the stone's principal uses. There are numerous caves in northern Arkansas. However, it is illegal to remove or disturb cave formations in the state. Arkansas has no recorded history of use of this resource.

Pearl

A pearl consists of concentric layers of the mineral aragonite ($CaCO_3$) formed as nacre secreted by a mollusk to cover an internal irritant. Pearls are recovered from both fresh- and salt-water bi-valve shellfish. In Arkansas, fresh-water mussels of the genus *Unios* are the principal source of pearls. A pearl's value depends on a number of factors, including its weight, luster, perfection of shape (sphericity), color, translucency, and stability in air. The luster and translucency are controlled primarily by the thickness of the nacre. It is difficult to grade the value of any given pearl without considerable experience.

Although pearls were occasionally collected by Arkansas' fishermen, little notice was taken until 1895, when a survey party recovered pearls from fresh-water mussels in the White River. When this collection of pearls sold for $5,000, many people began to search for the gems in the White, St. Francis, and Arkansas Rivers and their tributaries. Within a year, nearly every major stream in Arkansas had yielded pearls. The highest quality and most extensive collections came from the White and Black Rivers in north-central and northeast Arkansas. The pearling industry was centered at Black Rock, Independence County, where, at one time, more than 1,000 people were gathering pearls within 20 miles of the town. The Black River proved to be the nation's richest pearling region. During the early years of pearling excitement in Arkansas, a large percentage of the choice pearls were discovered loose, lying in mud along lakes formed by cutoff meanders and river backwater shorelines. At the height of the excitement in 1897, many people purchased unopened mussels, speculating on the discovery of valuable gems. Between 1895 and 1898, over $500,000 worth of pearls were recovered by Arkansas' pearling industry.

Individual Arkansas pearls have sold for as much as $25,000, but pearls valued up to a few hundred dollars are considered to be exceptionally good finds. The above-mentioned $25,000 pearl was round, weighed 103 grains (almost one-quarter ounce), and was discovered in the Black River in 1904. A necklace displayed at the St. Louis World's Fair in 1904 was composed of 16 Arkansas pearls having a combined weight of 861 5/8ths grains (nearly 2 ounces). A pearl found at Newport, Arkansas, is set in one of the Royal Crowns of England. Usually fresh-water pearls do not compare with salt-water pearls, but the exceptional luster and color of some fresh-water pearls do command high prices.

Presently, Arkansas has one commercial pearl business in Jackson County. Arkansas continues to be second in commercial freshwater pearl recovery in the United States, Tennessee being first.

Quartz Varieties

Gemstone varieties of quartz (SiO_2) present in Arkansas include the cryptocrystalline varieties (agate, jasper, chalcedony, banded chert) and crystalline varieties (rock crystal, amethyst, smoky quartz). Another material potentially usable by lapidaries is silicified petrified wood. Opal, an amorphous variety of silica is discussed in this section also.

Arkansas is often thought of as offering little material for the lapidary, other than quartz crystal and diamond. However, for the hobbyist interested in tumble polishing and cabochon making, much useful material is present (fig. 14).

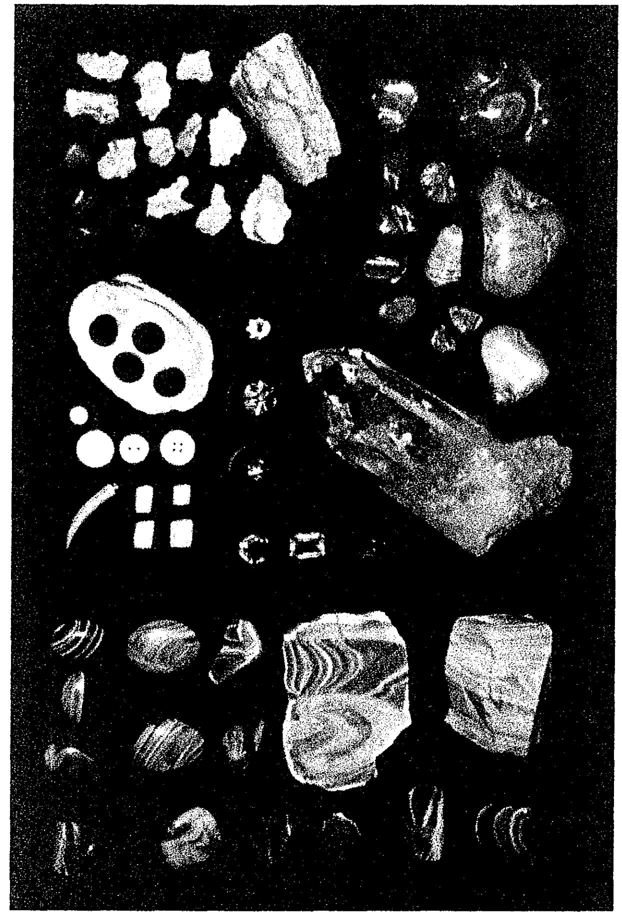

Figure 14. Various Arkansas lapidary materials. Turquoise (upper left); polished agates (upper right); mother of pearl (center left); rock crystal and faceted stones (center right); polished, slabbed, and rough banded chert (lower one third).

Agate

Agate is variety of cryptocrystalline quartz which displays distinct banding and is translucent. Most agate collected in Arkansas is present in gravel deposits on Crowley's Ridge, although there is a chance of finding agate wherever gravel is present. Crowley's Ridge extends north-south from Clay County to Phillips County in a gentle eastward-facing arc (fig. 2b). The agates in this area are different shades of tan, light brown, and yellow due to the penetration and oxidation of trace amounts of iron. The gravels of the Crowley's Ridge deposits were transported from the north to their present position by the ancestral

Mississippi River. Identically banded, light bluish-gray agate is present in Missouri in the Potosi Formation (Upper Cambrian). This rock unit appears to be the source of the bulk of the agate in the Crowley's Ridge deposits, oxidation of the gravel-bearing units having altered the original blue-gray color to shades of brown and yellow. Rarely, a specimen may appear similar to the agate from the Great Lakes area of the northern United States. Agate is also moderately common at the Crater of Diamonds State Park, where it sometimes displays a lace-like pattern. The agate is present as blocky rectangular pieces weighing up to several pounds and is present in the major drainages of the diamond-search area. Most is somewhat sugary or porous in texture, rendering it unusable to the lapidary. However, good-quality pieces are not uncommon and yield attractive cabochons in a variety of colors. Some of this material is also suitable for tumble polishing.

Amethyst

Amethyst as a gem material is a violet to purple, transparent, crystalline variety of quartz. The Crater of Diamonds State Park, 2.5 miles southeast of Murfreesboro in Pike County, is the only area in Arkansas known to contain crystals of amethyst large enough to be of use to the lapidary. Amethyst veins, reported to be up to a foot wide, are sometimes located by collectors during the periodic plowing of the diamond search area. The amethyst is present as stubby strongly colored crystals up to 1 inch across, filling cavities in calcite veins. Individual specimens are scarce and the amethyst crystals may be zoned or contain tiny inclusions of goethite (an iron mineral), strongly resembling the amethyst of Brazilian geodes. Although an unknown percentage of this amethyst may be faceting quality, most of the rough is suitable for producing tumbled stones.

Chalcedony

Chalcedony is a light-colored, translucent, nonbanded variety of cryptocrystalline quartz which has a waxy luster on a broken surface. It is often nodular in form and sometimes is fluorescent green in ultraviolet light. Cream-colored masses of chalcedony reportedly have been recovered from the gravel deposits of the Saline River in Saline County.

Chert

Chert is an opaque to translucent cryptocrystalline variety of quartz, which ranges considerably in color and suitability for lapidary use. Although the Ouachita Mountains contain major beds of sedimentary chert, little of this material is of cuttable quality. Major sedimentary units in northern Arkansas do contain banded translucent nodules of chert that will take a high polish when tumbled or cut into cabochons. Nodular chert in the Cotter Formation (Early Ordovician) and in the residuum formed by its weathering is often available in attractively banded pieces. Large unfractured examples are somewhat scarce, but abundant tumbling-quality material is available, particularly in Marion County, and also in portions of Carroll, northern Boone, Baxter, Fulton, Randolph, Sharp, and Izard Counties. This is the major outcrop area of the Cotter Formation. Some chert which will take a high polish is also present in the Penters Formation (Devonian) and, locally, in the Boone Formation (Mississippian) and its residuum in north Arkansas. All of these materials are present in shades of brown, tan, cream, and gray. Large quantities of tan to brown chert are also present in the gravel deposits along Crowley's Ridge.

Jasper

Jasper is a red variety of chert. Two companies, one in Pike County and the other in Hempstead County, have reported the recovery of small quantities (less than 1,000 pounds yearly) of jasper the past several years. The suitability of this material for lapidary use is unknown. The source of the jasper may be the basal gravel deposits of the Cretaceous formations or Quaternary deposits which contain reworked gravels derived from the Cretaceous units. The jasper probably originated as red novaculite. Jasper is also present at the Crater of Diamonds State Park, Pike County, as rounded reddish-brown to red surficial gravels in the diamond search area. The jasper takes a high polish and may be used for both tumbling and for making cabochons.

Opal

Opal is a poorly crystalline variety of the mineral cristobalite (SiO_2), which may be present anywhere ground water has circulated. Opal usually contains an indeterminate quantity of water in it; the chemical formula usually is written as $SiO_2 \cdot nH_2O$. A colorless transparent variety called hyaline is relatively common in Arkansas as late-formed glassy blebs or crusts coating other minerals. Hyaline is commonly fluorescent green due to traces of uranium salts. Two locations for opal are notable in the state, but neither have yielded significant material for lapidary use.

At the Potash Sulphur Springs intrusion in Garland County, late secondary opal was discovered in the zone of contact metamorphism as both greenish-yellow veins having black dendritic (fern-like) patterns and as gray, opalized replacements of the contact rocks. In the North Wilson pit at this site, paper-thin films of fiery precious opal were noted in a very restricted zone in the vanadium orebody.

In southern and eastern Arkansas, wherever petrified wood is present, there is the possibly of discovering late-formed hyaline opal. See the section on **Petrified Wood** below.

Petrified Wood

Silicified petrified wood is present in Quaternary gravel deposits in eastern and southern Arkansas. Because most specimens are cream to white in color, little interest has been expressed by hobbyists in cutting and polishing the material. A fossilized "logjam" of this type of petrified wood was reported in a stream drainage at the golf course of the El Dorado Country Club in Union County. Many people in southern Arkansas use light-colored petrified wood as flower-garden decoration pieces or borders. Late-formed hyaline is often present as colorless botryoidal infillings of cavities or fractures in the petrified wood. Some petrified wood in the gravel deposits along Crowley's Ridge ranges in color from tan and brown to black and takes a high polish. This material is suitable for cabochon making and tumble polishing. Numerous small pieces and sometimes large logs of petrified wood are collected in the creeks that drain Crowley's Ridge from Forrest City in St. Francis County northward to Wynne in Cross County.

Rock Crystal

Rock crystal (quartz crystal) that qualifies as a gem material is transparent, colorless and should contain no visible flaws. This material is relatively abundant at many of the quartz crystal dealerships in Arkansas and price varies with size of the rough stock. When used for faceting stones or beads, carving figures or decorative items, or manufacturing spheres, it is not necessary that the crystal's exterior be undamaged as with prime specimen material. Because of the low price of surface-damaged rock crystal, it is a popular material to use when learning faceting techniques. Faceted rock crystal is sold at many tourist-based businesses in Arkansas under the trade name, "Hot Springs diamond". Slender, clear, undamaged single quartz crystals are known locally as jewelry points and are used in the manufacture of relatively inexpensive necklace drops, pendants, and earrings, often set in sterling silver settings. Rock crystal for this use ranges from $30 to more than $150 per pound, depending on its perfection, transparency, luster, and length of the crystals.

Smoky Quartz

Smoky quartz as a gem material is light- to medium-brown in color, transparent, and of best quality when of uniform color (unzoned). In Arkansas, most smoky quartz is present in two areas: near Jessieville in Garland County and adjacent to the Magnet Cove intrusion in Hot Spring County. Southwest of Jessieville, one mining operation occasionally recovers some pale- to medium-brown smoky quartz. These crystals range up to 3 inches in length and 1.5 inches across and have milky bases or areas near their attachment points to the vein walls. Most crystals exhibit faint zoning (alternating light and dark banding), but some crystals qualify as faceting material. Zoned and unzoned smoky quartz crystals to 6 inches long were mined in the late 1960's at a site on the north shore of Lake Ouachita, west of Jessieville in Garland County. The area has since been closed to collecting by the U. S. Army Corps of Engineers. The deposits of smoky quartz at Magnet Cove have been known for over a century. The host rock, the Arkansas Novaculite (Mississippian-Devonian), is the source of the silica forming the crystals. In this area, smoky quartz crystals have been discovered up to 15 inches in length and 6 inches across. Most of the smoky quartz from this area has internal fractures or mineral inclusions, is zoned, or has sufficient internal stress as to render it useless for faceting stock. Small pieces are sometimes cut into attractive gems. An unknown percentage of this material might be useful for tumbled stones. A site which yielded a small amount of faceting-grade smoky quartz was discovered by Ben Clardy, Arkansas Geological Commission, and investigated by state geologists in the 1970's. It was a highly weathered quartz syenite dike in a bauxite mine in Saline County. Although about 50 pounds of rough smoky quartz pieces were collected, less than a pound was determined to be faceting quality.

Most mineral dealers and rock shops in Arkansas have samples of "smoky quartz" on display. Natural rock crystal may be subjected to gamma radiation in a reactor, resulting in crystal from specific locations being changed from colorless to almost black. Irradiated "smoky" quartz from Arkansas produced by this process has been marketed for many years for decorative purposes.

Turquoise

The mineral turquoise is the end member ($Cu^{2+}Al_6(PO_4)_4(OH)_8 \cdot 4H_2O$) of a mineral series in which copper is substituted for iron; chalcosiderite is the other end member. Intermediate in composition in the series between these two minerals are the minerals planerite and rashleighite. However, to the lapidary, any and all of these minerals are considered turquoise if the material will cut and polish. Handcrafted turquoise and silver jewelry has become increasingly popular with the general public.

In Arkansas, the turquoise minerals are present in the Ouachita Mountains, usually associated with the secondary mineralization present in lead-, zinc-, and copper-bearing quartz veins as thin fracture-filling seams in the sandstone or shale host rock. In some places turquoise is present as hard, translucent bluish films where no primary copper mineralization is evident. In these instances, the host rock is almost always the Arkansas Novaculite (Devonian-Mississippian) or the Bigfork Chert (Ordovician). Planerite is often associated with either secondary aluminum phosphates or manganese mineralization. Three localities of "turquoise" mineralization are notable in Arkansas.

In 1974, a turquoise prospect on Porter Mountain in Polk County, was tested by a company based in Denver, Colorado. The company reported that about 200 pounds of fair to good gem-quality turquoise had been processed from this location, of which about 10 pounds were sold for $100 per pound. The host rock is tripolitic novaculite. The site, named the Mona Lisa mine, was intermittently mined by open-pit methods, with a reported total recovery of over 1,000 pounds, until the late 1980's. Much of the output of the Mona Lisa mine was dyed, stabilized, and compressed into cylinders for shipment to China as carving stock. Some treated and untreated gem material was marketed in New Mexico and Arizona. Final reclamation took place on this site between 1989 and 1991.

Another "turquoise" locality in Polk County is the old Coon Creek manganese mine. Planerite is moderately abundant as thin green films coating novaculite boulders and cobbles. However, no gem- or cutting-grade material has been reported on this claim.

Planerite was also rather abundant at the Montgomery County quarry, now abandoned, on Mauldin Mountain, Montgomery County. Planerite formed as thin coatings and crusts on Bigfork Chert, often in association with wavellite, an aluminum phosphate. No gem material has been mined at this location.

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GREENSAND

Greensand is the name commonly applied to a sandy rock or sediment containing a high percentage of the mineral glauconite. Glauconite ($(K,Na)(Fe^{3+},Al,Mg)_2(Si,Al)_4O_{10}(OH)_2$) is a greenish-black to blue-green mineral which forms as a mineral in shallow marine sediments after their deposition. Because of its potash and phosphate content, greensand has been marketed for over 100 years as a natural fertilizer and soil conditioner. Greensand is recommended by organic gardeners as a mulch, top dressing, and soil-conditioning additive for both potted plants and vegetable gardens. The slow release rate of plant nutriments (potash and phosphate) minimizes the possibility of plant damage by fertilizer "burn" while the retention of moisture by the mineral aids soil conditioning. Early in the 1900's, glauconite was recognized to have chemical exchange properties when in water solutions, which led to its use as a water softener.

In southwest Arkansas, greensands are abundant in the Cretaceous Nacatoch and Ozan Formations. Greensands in the Nacatoch Formation are more extensive, contain higher percentages of glauconite, and are richer in potash (2.8-4.5 percent) than the Ozan Formation. These formations extend from the Oklahoma-Arkansas state line near Foreman in Little River County northeastward to Arkadelphia in Clark County and dip gently to the south-southeast. Greensands of the Nacatoch are exposed intermittently from Columbus, Hempstead County, to Terre Noire Creek in Clark County. Notable exposures are present near Washington, Hempstead County, and along the banks of a branch of Moore's Creek in Clark County. Outcrops of the Ozan Formation are scattered, extending from western Little River County near Foreman to north-central Hempstead County. The glauconite is present in a sandy micaceous marl near the base of the formation. This basal sand may be 3 to 15 feet thick and contain up to 50 percent glauconite.

Markets for greensand consist of small- to medium-sized water treatment companies providing domestic and small water-system services and designers and manufacturers of medium to large water-treatment systems who service their installed facilities. Also, potential exists for marketing Arkansas greensand at organic garden supply stores as a bagged commodity. Presently, in the United States, economically viable greensand deposits contain at least 90 percent glauconite. The deposits must not contain more than 2 to 3 percent clay matrix and must show no evidence of weathering. There has been no mining of greensands in the state.

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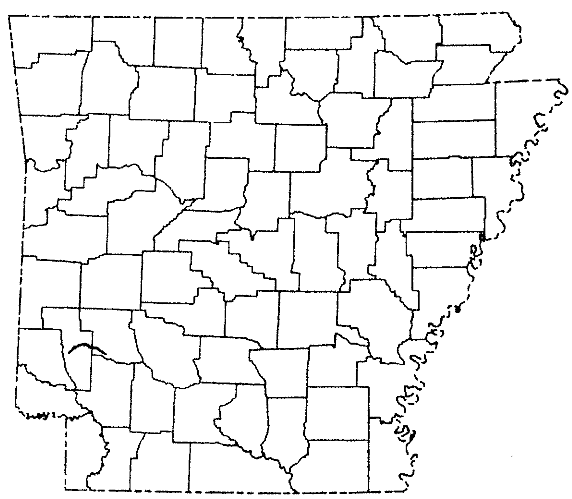
GYPSUM



Gypsum ($CaSO_4 \cdot 2H_2O$) has a hardness of 2 and specific gravity of 2.32. Gypsum forms by the process of evaporation of seawater, which leads to the precipitation of various salts in evaporite deposits, gypsum being one.

Three varieties of gypsum are known in Arkansas: selenite, satin spar, and saccharoidal (alabaster). Saccharoidal, the most important commercially, resembles lump sugar and occurs as massive beds. Satin spar is fibrous in appearance, has a satiny luster, and forms thin discontinuous layers. Selenite is a transparent, often colorless, crystalline variety.

Raw or uncalcined gypsum is used as a cement additive, fertilizer and disinfectant, in the manufacture of paper and paint, and in metallurgy. Calcined or dehydrated gypsum, also known as plaster of paris, is manufactured into wall plaster or wallboard (commonly called sheetrock), accounting for about 75 percent of the nation's production. Small amounts of very pure gypsum are used as fillers, in glass making, and in pharmaceutical applications. The gypsum mined in Arkansas is used primarily in the manufacture of wallboard and as a cement additive. When added to cement, gypsum slows the setting time or crystallization of cement in concrete, allowing mixed concrete to be trucked longer distances. Calcium sulfate deposits (the combination of gypsum and another mineral, anhydrite) throughout the world account for the largest reserve of sulfur resources known to mankind. However, gypsum is rarely used as an industrial source of sulfur because sulfur is generally available from non-gypsum resources at a lower cost. The single most important factor in the evaluation of a gypsum deposit is its location in respect to potential markets for the product. Consequently, most gypsum produced is used by the manufacturing companies, who own and operate the mines, to make products for established nearby markets.

Gypsum deposits are mined by open-pit methods in southwest Arkansas from the DeQueen Limestone (Early Cretaceous). The formation is exposed in a narrow belt extending from the Little Missouri River in Pike County westward through Howard and Sevier Counties. It dips gently to the south. The greatest known thickness of a single gypsum bed (12 feet) is at Plaster Bluff in Pike County. In a major operation near Briar, Howard County, 5 beds of sacchroidal gypsum with an aggregate thickness of as much as 20 feet are mined. Satin spar is interbedded with clay units as thin layers (0.5 to 2.5 inches in thickness), both above and below the 5 minable layers of alabaster. The thin layers of satin spar are wasted during mining as it is intermixed with clay during stripping operations that expose the commercial beds. Small amounts of selenite are present also in the commercial gypsum mines of Howard and Pike Counties. Selenite is also present locally in Paleocene and Eocene sediments of the Gulf Coastal Plain region.

The first recorded mining of gypsum in Arkansas began in 1922. Continuous gypsum production started in 1936. By 1961, yearly production had risen to 166,698 tons. In 1963, Dierks Forest, Inc. opened the Briar Gypsum plant in Howard County. This mining and manufacturing facility, now operated as James Hardie Gypsum, is one of the 10 largest producers of wallboard in the world. In 1993, 1,175,000 cubic yards of overburden was removed at the mine and 630,000 tons of gypsum was mined. From this, 660 million square feet of wallboard was produced. Another mine operator, Highland Gypsum Company, operates a smaller mine near the community of Highland in Pike County. All of Highland Gypsum's output is used locally as a cement additive. In 1995, Arkansas ranked 9th in the nation in the production of crude gypsum.

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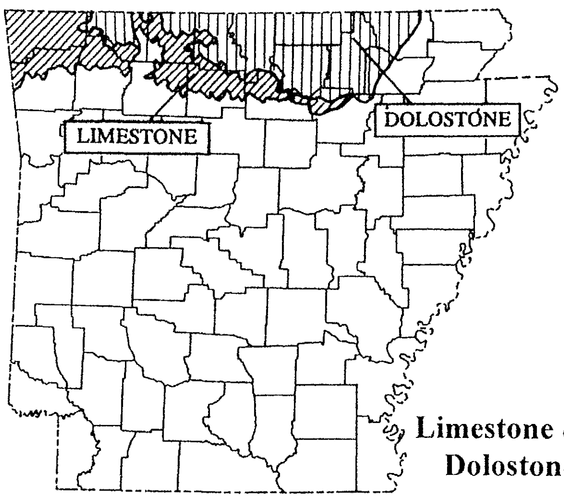
LIMESTONE AND DOLOSTONE

The principal mineral of limestone is calcite ($CaCO_3$), a form of calcium carbonate. Dolostone is quite similar to limestone, but is composed mostly of the mineral dolomite ($CaMg(CO_3)_2$). Both are sedimentary rocks that occur as thin to massive beds of fine- to coarse-grained rock. Their color is typically some shade of gray, but may be white, tan, yellow, pink, purple, reddish brown, brown, or black. Calcite that composes limestone readily reacts with hydrochloric acid, the reaction producing carbon dioxide (CO_2) as a gas.

Dolostone is less reactive and normally must be in powdered form to react visibly. Pure dolomite contains 54.28 percent calcium carbonate and 45.72 percent magnesium carbonate. Dolostone is commonly referred to by its mineral name, dolomite.



Limestone & Dolostone

Limestone is composed of material derived by both chemical and biological activities. The particles of sediment that make up a typical limestone are frequently recognizable as fossil fragments. Most dolostone, on the other hand, is crystalline and thought to be the result of replacement where magnesium in pore water is substituted for some of the calcium in the original limestone. Dolomite sediment can also be deposited by direct precipitation. Most limestones of commercial importance accumulated in a relatively shallow marine environment. Carbonate rocks form about 15 percent of the earth's sedimentary crust and are widely available for utilization.

Often, little distinction is made between limestone and dolostone and, for many purposes, they can be used interchangeably. Both are frequently sold under the name of limestone. Perhaps no other mineral commodities discussed here have as many uses as limestone and dolostone. These two rocks are the basic building blocks of the construction industry. The principal uses are in the manufacture of quicklime (CaO) and other chemical feedstock items, crushed stone, riprap, building and dimension stone, cement, and agricultural limestone. The most important use of dolostone for which limestone cannot be substituted is in the manufacture of refractory dolomite and in the preparation of heat-insulating materials. At the present time, the dolostone quarried in Arkansas is used as crushed stone, agricultural limestone, and building stone. Limestones and dolostones high in silica have been used in the manufacture of mineral or rock wool for insulation, and some Arkansas rock is suitable for this purpose. Some high-purity limestones in northern Arkansas have been used as source material for calcium-based food supplements.

All the dolostone and most of the limestone in Arkansas are Paleozoic in age and are present in the Ozark region of the state. A small amount of Paleozoic limestone in the Ouachita Mountains has been quarried. A Tertiary-age limestone in the Midway Group is present in the Gulf Coastal Plain between Little Rock in Pulaski County and Benton in Saline County.

Crushed limestone, used largely as concrete and asphalt aggregate, is the major product of limestone mining in Arkansas. Several companies in northern Arkansas mine and crush the stone, most operations being in Benton, Independence, and Lawrence Counties (fig. 15). The bulk of the crushed material is used in road construction, concrete aggregate, and as agricultural limestone. Some limestone- and dolostone-bearing formations are quarried for building or ornamental stone, mostly in Independence County. At the present time, one company produces quicklime (CaO) from its facility near Batesville in Independence County. The raw rock is hand sorted and transported a short distance from the quarry to the kilns by a narrow gauge railway.

Limestone and dolostone are quarried from open pits and, to minor extent, from underground mines.

Figure 15. Limestone quarry, Ozark region, Independence County. Benches approximately 40 feet in height.

The usual mining method involves drill-ing and blasting to release the stone from the outcrop and provide the first-order breakage. The rubble is then hauled to a crushing facility where the stone is further crushed, screen-sorted into size classes, and stored. Limestone needed for high-purity applications (quicklime, food supplements) is usually hand-sorted at the mine. In the manufacture of quicklime, limestone is crushed to lump size (usually 5-8 inches) and heated in a kiln to temperatures of around 2,000° F. The process is called calcination and works by driving off carbon dioxide (CO_2) from the calcite, forming quicklime. Limestone used as a source of nutritional calcium is simply ground into a powder, mixed with other supplements and binders, and reformed into pills or capsules. Stone that is to be used for its ornamental qualities is extracted from the bedrock by saws and wedges rather than by blasting. Then the rock is either sawn or carved to obtain its final shape. A polish may or may not be used to finish the product.

Branner, G. C., 1941, Limestones of northern Arkansas: Arkansas Geological Survey, 24 p.

Corbin, M. W., and Heyl, G. R., 1941, Tertiary limestones of Pulaski and Saline Counties, Arkansas: Arkansas Geological Survey Information Circ. 13, 28 p.

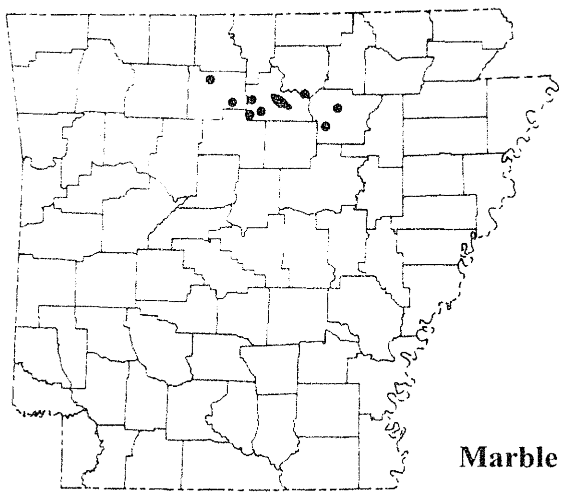
Croneis, Carey, 1930, Geology of the Arkansas Paleozoic area, with especial reference to oil and gas possibilities: Arkansas Geological Survey Bull. 3, 457 p.

Holbrook, D. F., 1965, High-calcium limestones in Independence and Izard Counties, Arkansas: Arkansas Geological Commission open-file report, 21 p.

Hopkins, T. C., 1893, Marbles and limestones: Arkansas Geological Survey Annual Report for 1890, v. IV, 443 p.

MARBLE

Marble is a type of rock composed of calcite ($CaCO_3$) or dolomite ($CaMg(CO_3)_2$). It is fairly soft as stone goes and easily worked. From a scientific standpoint, marble is a metamorphic limestone or dolostone. However, in



commercial terminology a marble is any crystalline calcareous rock that will take a polish. Even serpentine (a hydrous magnesium silicate metamorphic rock) is sometimes considered a marble because it is often cut by veins of calcite or dolomite and will take a high polish. The marbles mined in Arkansas are all unmetamorphosed limestones or dolostones (see location map in the section describing **Limestone**). Marble is used primarily as a building and ornamental stone but also has uses as monuments, table tops, wash basins, statuary, and other decorative applications.

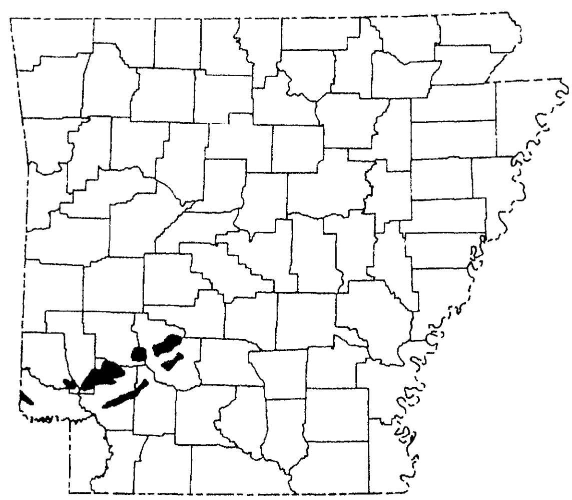
Several types and grades of marble have been mined from quarries in the state. The crystalline texture of Arkansas marbles varies from coarse to fine and the colors may range from light gray to black, tan to yellow to rust, and be of one uniform color or variously shaded. Often, primary sedimentary structures or structures produced by the actions of organisms (or both) add uniqueness and interest to the stone, making it more marketable. Marble is mined exclusively from limestones and dolostones of Paleozoic age in north Arkansas. Principal "marble"-producing formations include the Plattin, Kimmswick, and Fernvale of Ordovician age, the St. Clair of Silurian age, and the St. Joe, Boone, and Pitkin of Mississippian age. Other stratigraphic units are sometimes quarried for stone when exploration reveals a unique quality that is in demand.

The first export of marble from Arkansas was in 1836, the year Arkansas became a state. A large block of Early Mississippian limestone was quarried near Marble Falls in Newton County and sent to Washington, DC, to be used in the construction of the Washington Monument. Marble production has been intermittent throughout most of its commercial history, but in recent years the use of products made of Arkansas marble has steadily increased. Most current mining operations of commercial marble in Arkansas are located near Batesville, Independence County.

Hopkins, T. C., 1893, Marbles and limestones: Arkansas Geological Survey Annual Report for 1890, v. IV, 443 p.

Parks, Bryan, and Hansell, J. M., 1932, Black marbles of northern Arkansas: Arkansas Geological Survey Information Circular 3, 51 p.

MARL



Marl is a sediment or sedimentary rock that is a mixture of clay and calcite ($CaCO_3$). Arkansas marls may also contain glauconite, sand, and marine shell deposits. Marl is used in the manufacture of cement and for agricultural purposes.

Commercially, the most important marl-bearing formation in Arkansas is the Marlbrook Marl, a dark blue-gray, fossiliferous, chalky sedimentary unit of Cretaceous age. In places, it may contain minor sand, glauconite, or phosphate grains. The Marlbrook, which may be up to 220 feet in thickness, dips gently to the south-southeast at about 80 feet per mile. Exposures may be seen from near Arkadelphia, Clark County, southwestward to Foreman in Little River County. Particularly notable exposures of the Marlbrook are present in and near Ozan Creek south of the community of Ozan along Arkansas Highway 4 in Hempstead County. The Ozan Formation, another marl-bearing unit, and the Brownstown Formation are sandy marls containing glauconite, some phosphate nodules, and invertebrate shells. The Arkadelphia is chiefly marl and marly clay containing sandy clay and limestone, and impure chalk. All of these Cretaceous formations dip gently to the south-southeast and crop out along the same trend.

In Arkansas, the Marlbrook Marl is presently used as a source of silica in the manufacture of cement. Ash Grove Cement Company mines marl near the community of Foreman, Little River County.

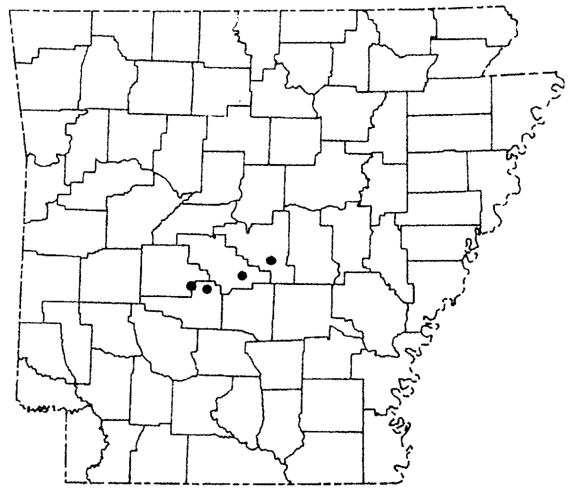
Branner, J. C., 1898, The cement materials of southwest Arkansas: American Institute of Mining Engineers Transactions, v. 27, p. 53.

Dane, C. H., 1929, Upper Cretaceous formations of southwestern Arkansas: Arkansas Geological Survey Bulletin 1, 215 p.

Hill, R. T., 1888, Neozoic geology of southwestern Arkansas: Arkansas Geological Survey Annual Report for 1888, v. 2, 319 p.

Taff, J. A., 1902, Chalk of southwestern Arkansas with notes on its adaptability to the manufacture of hydraulic cements: U. S. Geological Survey 22d Annual Report, 1900-1901, pt. 3, p. 687-742.

NEPHELINE SYENITE



Nepheline syenite is a medium to coarse-grained, light- to medium-gray, igneous rock composed predominantly of a silicate mineral called orthoclase ($KAlSi_3O_8$) and has a granite-like appearance (fig. 16). It may be distinguished from granite by the fact that it contains little or no quartz (SiO_2). In Arkansas, nepheline syenite has been intruded into the sequence of Paleozoic sedimentary rocks. Locally, quarrymen describe two varieties of this rock – "blue granite" and "gray granite".

Much of Arkansas' nepheline syenite have high strength and weather-resistant properties and are crushed for use as roofing granules, road materials, riprap, and asphalt and concrete aggregate. Fines are used as a colorizing and fluxing agent in the manufacture of brick and as compaction fill. In the past, this rock has been used as building stone, pavement stone, for monuments, and as material for construction of railroad beds. Syenite has also been used extensively as riprap for the protection of river banks and road embankments. Arkansas' syenite deposits have been studied as a potential source of the mineral nepheline, which is used in the manufacture of glass. However, the inclusion of fine-grained iron-bearing minerals results in too high an iron value to manufacture low-iron glass. The development of new sepa-

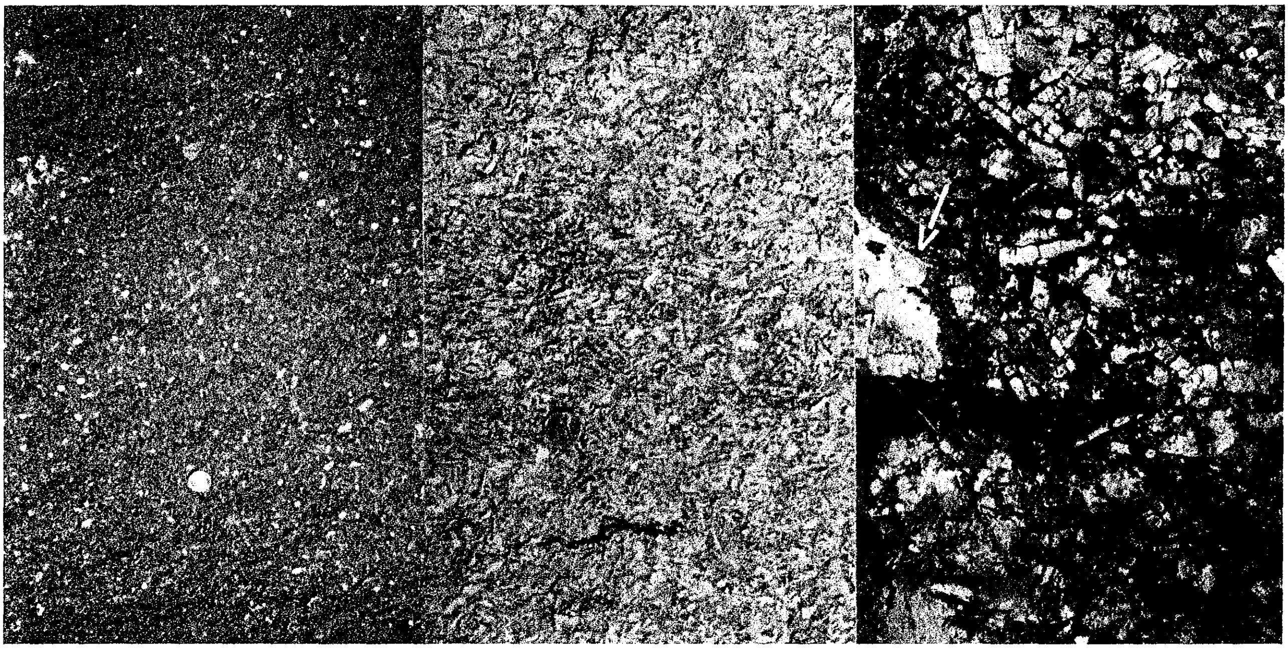


Figure 16. Various textures and grain sizes of syenite from central Arkansas. Left: bright cleavage reflections of feldspar in pulaskite. Center: flow-aligned tabular feldspar crystals in nepheline syenite. Right: coarse-grained texture of feldspar (light) and nepheline (dark) in nepheline syenite. Penny in each photograph for scale.

ration technology may allow the use of Arkansas nepheline concentrates for specialty markets. Several syenite deposits have been examined for potential use as low free-silica (contains little quartz) sand-blast abrasive.

Nepheline syenite and its associated igneous rocks are exposed in 4 areas of the state. These are: south-central Pulaski County between Little Rock and Sweet Home, Saline County in the vicinity of Bauxite, Garland County at Potash Sulphur Springs, and Hot Spring County at Magnet Cove. The total surface exposure of syenite in Arkansas is about 13 square miles.

Nepheline syenite is quarried at Granite Mountain in Pulaski County by several companies. It is crushed and sized for a number of aggregate uses. Crushed, sized roofing granules, colorized to builder's specifications, are produced at a plant east of Little Rock, using syenite from a nearby quarry. Nepheline syenite has also been quarried near Bauxite in Saline County and at the Diamond Jo quarry in Magnet Cove, Hot Spring County. Mining of nepheline syenite exceeds 5 million short tons annually.

Gordon, Mackenzie, Jr., Tracey, J. I., and Ellis, M. W., 1958, Geology of the Arkansas bauxite region: U. S. Geological Survey Professional Paper 299, 268 p.

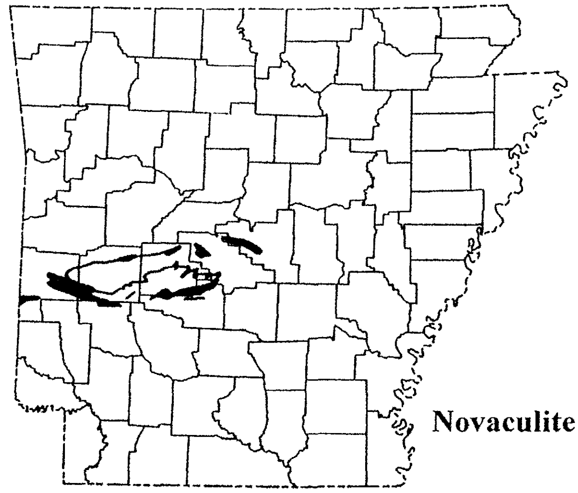
Morris, E. M., 1987, The Cretaceous Arkansas alkalic province; A summary of petrology and geochemistry, *in* Morris, E. M. and Pasteris, J. D., eds., Mantle metasomatism and alkaline magmatism: Geological Society of America Special Paper 215, p. 217-233.

Smothers, W. J., Williams, N. F., and Reynolds, H. J., 1952, Ceramic evaluation of Arkansas nepheline syenite: Arkansas Resources and Development Commission, Division of Geology Information Circular 16, 21 p.

Williams, J. F., 1891, The igneous rocks of Arkansas: Arkansas Geological Survey Annual Report for 1890, v. II, 457 p.

NOVACULITE

Novaculite is a sedimentary rock composed almost entirely of microcrystalline quartz (fig. 17). By some definitions it is a slightly recrystallized variety of chert. It is dense, hard, white to grayish-black in color, translucent on thin edges, and has a dull to waxy luster. It typically breaks with a smooth conchoidal (shell-like) fracture. The word novaculite is derived from the Latin word **novacula**, meaning razor stone.



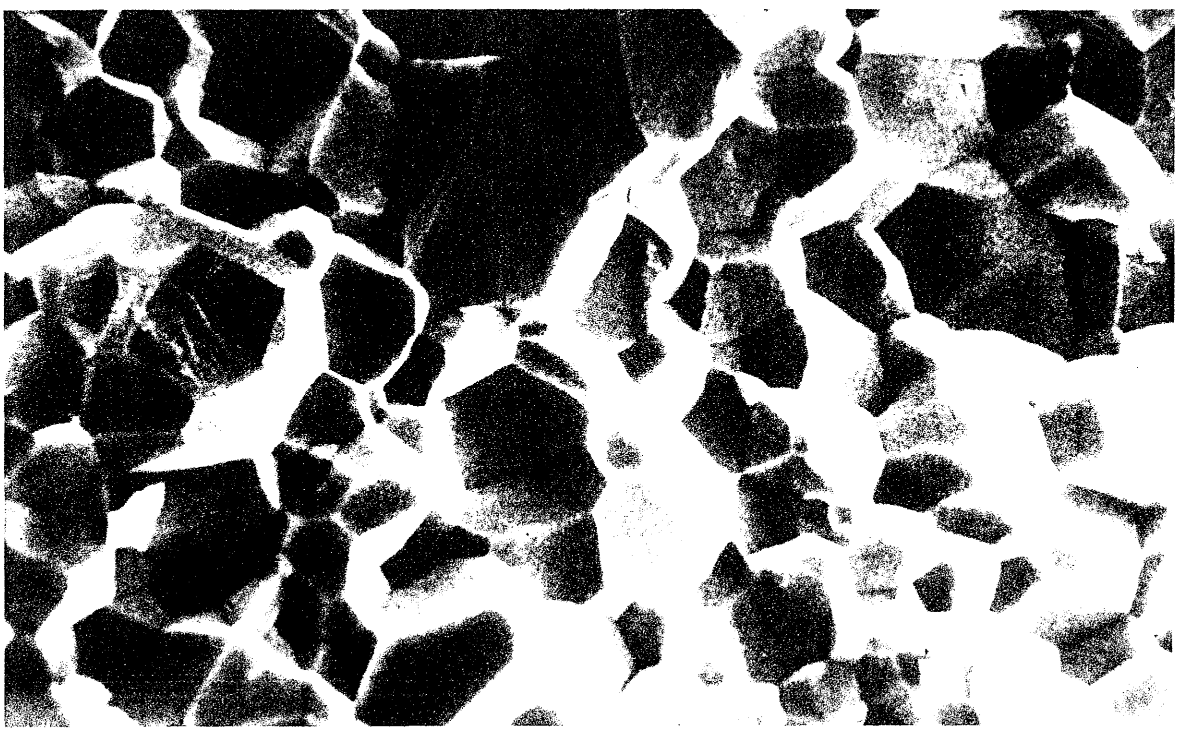


Figure 17. Scanning electron micrograph (SEM) of novaculite from the Arkansas Novaculite. Average grain size is about 0.0003 inches. The sharp edges and corners of the quartz grains show why the novaculite is a very effective whetstone. *SEM courtesy of W. D. Keller, University of Missouri-Columbia.*

Novaculite is widely distributed in the Ouachita Mountains of Arkansas. Because it is highly resistant to erosion, it forms prominent ridges. The Arkansas Novaculite is a formation of Devonian and Mississippian age that consists of novaculite interbedded with shale. It ranges in thickness from about 250 to 900 feet (fig. 18).

Figure 18. Outcrop of homogenous, well-jointed, bedded siliceous Arkansas Novaculite, West Mountain, Hot Springs National Park, Garland County. Staff is marked in 1-foot intervals.

Arkansas novaculite is recognized worldwide for its use as whetstones and oilstones, which are especially well suited for sharpening knives, surgical instruments, and wood-carving tools. Early Native Americans who lived in Arkansas gathered novaculite boulders and, in the vicinity of Hot Springs in Garland County, quarried the stone for use in making weapons and tools. It was noted in 1818 that a quarry of honestone near Magnet Cove in Hot Spring County had been worked for several years by early settlers. Records show that novaculite mining in Arkansas was intermittent from 1885 to 1905, but has been continuous since.

Novaculite for abrasives is mined mostly in Garland and Hot Spring Counties. It is classified by the abrasives industry into two categories: "Arkansas" stone and "Washita" stone. "Arkansas" stone is extremely fine-grained, uniform, and has a waxy luster. It is typically white or light gray. "Washita" stone is less dense, more porous, and has the dull luster of unglazed porcelain. When quarrying novaculite for whetstones, little to no explosive is used because blasting, combined with the brittle nature of the stone, tends to cause excessive fracturing, reducing the amount of useful stone. Rough novaculite blocks are cut by circular diamond saws, using large amounts of degradable lubricant as a coolant. The preformed stones are lapped (smoothed) on horizontal rotating grinding machines, using industrial abrasive grits, such as silicon carbide.

Commercial whetstone mines were very active for years in Arkansas until the development of less costly synthetic abrasives. In recent years, however, the demand for natural honestones and oilstones has again increased, resulting in increased quarry output. In 1990, there were 9 companies that mined and processed whetstones in the Hot Springs area. The tonnage of novaculite mined for abrasives applications is withheld to avoid disclosing company proprietary data.

Large tonnages of novaculite are also quarried each year for use as concrete aggregate, road construction material, railroad ballast, riprap, high-silica refractories, and, intermittently, for the recovery of silicon metal. The massive novaculite of the Upper and Lower Divisions of the Arkansas Novaculite is a source of high-purity silica (>99 percent). Individual quarries for novaculite extend from Little Rock in Pulaski County westward to Hatton in Polk County.

There is an extensive, uncalculated, resource of novaculite in the Ouachita Mountains. However, top-quality whetstone-grade material is mined almost exclusively from the massive Lower Division of the formation in Garland and Hot Spring Counties. The available tonnage is quite variable from deposit to deposit. The market for natural whetstones and oilstones should continue to increase, but competition from other abrasives – both natural and manufactured – may prevent rapid expansion of markets. In 1995, Arkansas ranked 1st in the nation in silica-stone (abrasives) production. The production of aggregate from novaculite should continue to grow, depending upon transportation costs. There exists a potential for the use of high-purity novaculite in other markets, including raw material for the manufacture of ferro-silicon and fire bricks, as plastic additives, and as polishes for finishing machined metal parts. Use of novaculite as a crushed aggregate is discussed in the article on crushed stone.

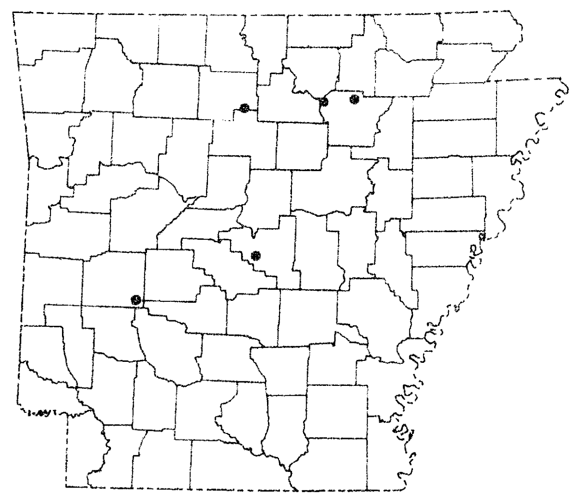
Griswold, L. S., 1892, Whetstones and the novaculites of Arkansas: Arkansas Geological Survey Annual Report for 1890, v. III, 443 p.

Holbrook, D. F., and Stone, C. G., 1978, Arkansas Novaculite – a silica resource: Oklahoma Geological Survey Circular 79, p. 51-58.

Miser, H. D., and Purdue, A. H., 1929, Geology of the DeQueen and Caddo Gap quadrangles, Arkansas: U. S. Geological Survey Bulletin 808, 195 p.

Steuart, C. T., Holbrook, D. F., and Stone, C. G., 1984, Arkansas Novaculite: Indians, whetstones, plastics, and beyond, *in* McFarland, J. D., III, and Bush, W. V., eds., Contributions to the geology of Arkansas, v. II: Arkansas Geological Commission Miscellaneous Publication 18-B, p. 119-134.

PHOSPHATE ROCK



Phosphate rock can be any rock or sediment with sufficiently high concentrations of some form of the mineral fluorapatite ($Ca_5(PO_4)_3F$) to be of commercial value. Fluorapatite composes the mineral part of vertebrate bones and teeth. Collophane is the name given to the massive fine-grained variety of apatite minerals present in phosphate rock. Commercial phosphate rock is usually sedimentary in origin and is used primarily as a plant nutrient, either by direct application to the soils as a powdered product or in the manufacture of superphosphate or triple super-phosphate fertilizer. Elemental phosphorus and phosphoric chemicals are also derived from phosphate rock and are used in detergents, insecticides, matches, fireworks, and many other products.

Phosphate rock was first recognized in Arkansas in 1895. During the early 1900's, several thousand tons were mined by both underground and surface methods in Independence County and shipped to a plant in North Little Rock for processing into super-phosphate fertilizer. This operation ceased when higher grade material from Tennessee and

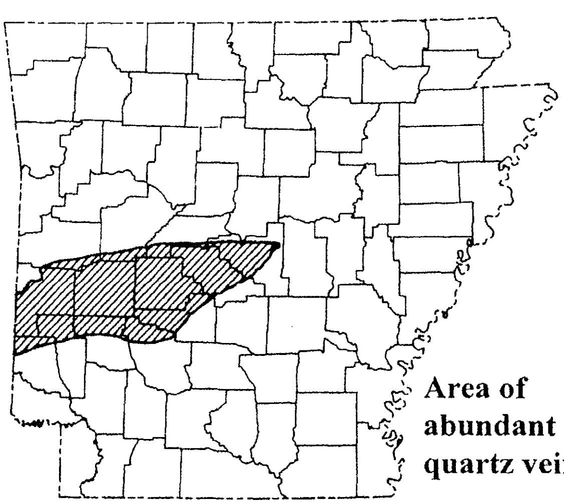
Florida entered the market. Potential commercial deposits are present in the Cason Shale (Ordovician-Silurian) along the White River Valley and nearby areas in Independence, Stone, Izard, Searcy, and Marion Counties. A deposit in Upper Mississippian rocks along the Searcy-Van Buren County line a few miles south of Leslie was mined for a few years during the 1960's. Other minor phosphate rock deposits are known, but have not been explored or tested.

Because, under normal conditions, phosphate rock for any use is a low-cost commodity, certain cost-limiting conditions must be met for a deposit to be minable. A typical phosphate mining operation uses open-pit methods, is a large volume producer, and requires large amounts of water for upgrading the raw material. Low-cost transportation to markets is also essential. Current economic conditions preclude commercial utilization of the Arkansas phosphate rock, but calculated reserves suggest that local deposits may become important when the current supplies from other states are exhausted.

Branner, J. C., 1897, The phosphate deposits of Arkansas: American Institute of Mining Engineers Transactions, v. 26, p. 580-598.

Wells, C. J., 1949, Hickory Valley phosphate deposit in Independence County, Arkansas: Arkansas Resources and Development Commission, Division of Geology Bulletin 19, 37 p.

QUARTZ (INDUSTRIAL)



Quartz, or silica (SiO_2), is a hard, brittle, usually colorless or white, nonmetallic mineral that exhibits considerable resistance to weathering. Because quartz is composed of the two most abundant elements (silicon and oxygen) in the earth's crust, it is an exceptionally common mineral on the earth's surface. Hydrothermal quartz crystals and milky "bull" quartz veins are a common and striking geologic feature of the Ouachita Mountain region of Arkansas. Quartz as both single crystals and groups or clusters of clear rock crystal from Arkansas are widely known for their esthetic beauty. The mineralogical profession has recognized Arkansas quartz crystal as some of the best and purest in the world. Because of this, and the popularity of quartz with the many tourists who visit Arkansas every year, the Arkansas General Assembly of 1967 established Act 128, which designated quartz crystal as the official State Mineral.

In recent years, large quantities of quartz crystals have been mined from open pits in two districts in Garland and Montgomery Counties and, to a lesser degree, in Saline and Pulaski Counties. Specimens are sold mostly to tourists, museums, schools, and private collectors in this country and overseas. By paying a small daily mine fee, tourists are allowed to collect quartz crystal. This has become a popular recreational activity. The U.S. Forest Service has a free quartz crystal collecting site named Crystal Vista in the Ouachita National Forest south of Mount Ida in Montgomery County.

Most of the crystal deposits mined in the Ouachita Mountains formed as veins which filled cavities or fractures in the Crystal Mountain and Blakely Sandstones (both Ordovician). Individual quartz crystals up to 5 feet long and weighing over 500 pounds and clusters to 15 feet long by 10 feet wide, weighing over 10 tons, have come from Arkansas' mines. Exquisitely developed large single crystals and quartz clusters may be valued at thousands of dollars.

Clear, colorless, untwinned quartz crystals have had important uses as oscillators in radio equipment and in periscopes, gun sights, and other optical equipment, particularly during World War II. More recently, quartz has been mined for use in electronics, fiber optics, and as the source of silica in the production of synthetic quartz crystals. One company produces the chemical feedstock (lasca) for synthetic quartz growth. Annual production varies from 450 to 570 tons. The milky quartz is mined from veins in an open pit near Paron, Saline County, and trucked to the processing plant near Jessieville, Garland County. There it is crushed, washed, cleaned in an acid bath, then hand sorted to 4 different grades. The quality of lascas produced from Arkansas is equal to or slightly superior to lascas produced in Brazil, and is usually less variable. Some crushed milky quartz was mined in Saline County and used as decorative surface aggregate in precast concrete.

Milky "bull" quartz veins in the Ouachita Mountain region are up to 60 feet wide and hundreds of feet in length. They may strike in any direction, but generally trend across the structure of the host rock. These veins occur in highly deformed shale sequences in the Ouachita Mountains region. Milky quartz veins have been investigated by several companies and individuals for their industrial quartz potential.

Radiometric dating of adularia, a hydrothermal potassium feldspar present in some quartz veins, yields Late Pennsylvanian to Early Permian ages for the mineralization, placing the major period of quartz vein form-ation at the end of the Ouachita Mountain orogenic (mountain-building) cycle.

In the Ozark region of north Arkansas, minor deposits of clear to white, stubby quartz crystals are present, associated with lead and zinc deposits and lining small cavities, nodules, or concretions, in some Ordovician and Mississ-ippian sedimentary units.

With the increasing demand by tourists, collectors, museums, and the new commercial applications of synthetic quartz, the price for clear quartz crystal and processed milky quartz should continue to rise.

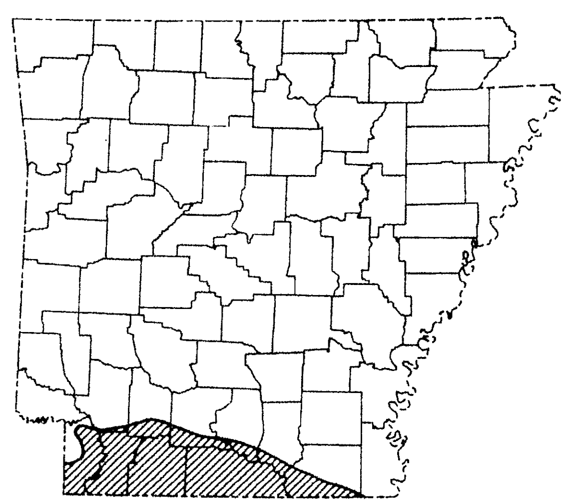
Engel, A. E. J., 1952, Quartz crystal deposits of western Arkansas: U. S. Geological Survey Bulletin 973-E, p.173-260.

Howard, J. M., and Stone, C. G., 1988, Quartz crystal deposits of the Ouachita Mountains, Arkansas and Oklahoma, *in* Colton, G. W., ed., Proceedings of the 22nd Forum on the Geology of Industrial Minerals: Arkansas Geological Commission Miscellaneous Publication 21, p. 63-71.

Miser, H. D., 1959, Structure and vein quartz of the Ouachita Mountains of Oklahoma and Arkansas, *in* Cline, L.M., and others, eds., The geology of the Ouachita Mountains – A symposium: Dallas Geological Society and Ardmore Geological Society, p. 30-43.

Miser, H. D., and Milton, Charles, 1964, Quartz, rectorite, and cookeite from the Jeffery quarry, near North Little Rock, Pulaski County, Arkansas: Arkansas Geological Commission Bulletin 21, 29 p.

SALT (INCLUDING CHLORINE)



Salt (the mineral halite – NaCl) is one of society's basic needs. Its use goes back in time to earliest recorded history (3,500 B. C.), and probably well before that. Pure halite consists entirely of sodium and chlorine in an atomic ratio of 1:1. Rock salt is the solid form; when dissolved in water it makes saltwater – or brine if the salt content is high.

Salt has so many uses in modern society that it is one of the most important raw materials of industry. It is the starting material for the manufacture of the bulk of elemental sodium and chlorine used in industry, and most compounds of either element. Among other things, sodium is used to make caustic soda, large quantities of which are used in the pulpwood and metallurgical industries. Chlorine is used to manufacture polyvinylchloride (PVC, an important plastic) and muriatic (hydrochloric) acid, as a water purifier, and as a bleaching agent. Huge tonnages of rock salt are used to de-ice highways, streets, and sidewalks. Much salt is used as a flavor-enhancer and a preservative in the food-processing industry. A volumetrically minor, but very important product, is the table salt used in most homes as a seasoning agent.

The most important commercial source of salt is rock salt. It occurs as evaporite layers that were deposited by the evaporation of water from oceans or saline lakes. Commonly, rock salt is interbedded with shale, gypsum, and anhydrite. Because rock salt may flow when under pressure, it also occurs in domes cored by salt that has been forced or extruded upward into younger sedimentary rocks. Salt is often mined underground or recovered by the evaporation of water obtained from the seas, saline lakes, and brine springs or wells.

In Arkansas' past, Native Americans and the early settlers obtained salt by evaporation from small bodies of saline water and brine springs in several counties, mostly in the central part of the state.

Although there are major deposits of both rock salt and brine in the subsurface of south Arkansas, there has been no commercial recovery of salt or chlorine from the subsurface to date. The salt-bearing Louann Formation (Jurassic) in southern Arkansas extends in the subsurface from Miller and Hempstead Counties in the west to Chicot County in the east. The Louann in south Arkansas represents the northernmost edge of salt-bearing units in the Gulf Coast Basin, the largest of 4 major basins containing salt in the United States. Some deep wells have encountered more than 1,000 feet of salt in the Louann. It may someday prove economically feasible to utilize these bedded deposits by deep-well injection of water into the salt-bearing units and extraction the resultant brines for processing. The remaining cavity may then have value for storage.

Oil-field brines, most notably those in the Smackover Formation (Jurassic), are present throughout southern Arkansas. A collection of 284 Smackover brine samples was analyzed for chlorine and determined to average more than 171,000 ppm, or nine times the chlorine content of typical seawater. Presently, the oil-field brines in southern Arkansas remain a little-investigated potential source of halite and other salts.

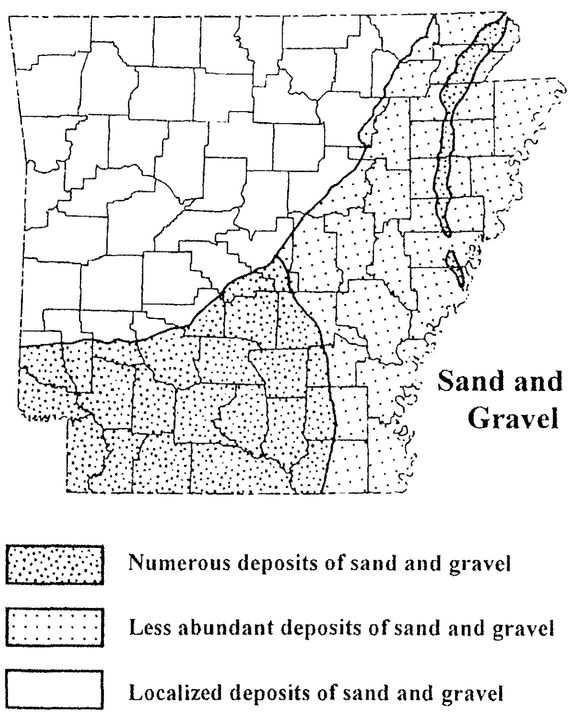
Bell, H. W., 1933, Discovery of rock salt deposit in deep well in Union County: Arkansas Geological Survey Information Circular 5, 24 p.

Collins, A. G., 1974, Geochemistry of liquids, gases, and rocks from the Smackover Formation: U. S. Bureau of Mines Report of Investigations 7897, 84 p.

Imlay, R. W., 1949, Lower Cretaceous and Jurassic Formations of southern Arkansas and their oil and gas possibilities: Arkansas Resource and Development Commission, Division of Geology Information Circular 12, 64 p.

SAND AND GRAVEL

Sand and gravel can be defined as continuously graded unconsolidated material (that is sediment) present on the earth's surface as a result of the natural disintegration of rocks. Following this definition, stone or rock that is crushed to gravel size – and commonly called gravel – will not be discussed here (see section on **Stone, Crushed and Dimension**). Both sand and gravel are composed predominantly of the mineral quartz, although gravel may also consist of various resistant rock types, such as novaculite, chert, and sandstone. Sand and gravel usually occur together, but in a wide variety of types and size classifications (fig. 19). Sand-sized material ranges from 0.0625 mm to 2 mm, whereas gravel is defined as ranging from 2 mm to 256 mm.



The Arkansas State Highway and Transportation Department sets specific standards, relating to the performance of construction materials, for sand and gravel used in Arkansas' highway projects. Use of specific deposits of sand and/or gravel depends on the performance of these materials in standardized engineering tests, including, but not limited to, size distribution, abrasion resistance, grain shape (roundness), and percentage of admixed fines (silt or clay). The major uses for construction sand and gravel are shown here.

- Concrete aggregate
- Concrete products, including block, brick, and pipe
- Aggregate in asphalt and other bituminous mixtures
- Road-base material and road coverings
- Construction fill
- Snow and ice control
- Filtration purposes
- Railroad ballas

Dredged river sand that is high in feldspar content is recovered as a raw glass additive by one company in Arkansas. Industrial sand and construction sand are recovered as by-products. The feldspathic sand is upgraded by washing, magnetic separation, and leaching processes. This operation's capacity is estimated at 650,000 tons per year of total product.

Deposits of sand and gravel are widely distributed across all of Arkansas. Major deposits are present as sedimentary units, on talus slopes, and as alluvial deposits in the flood plains, beds, and terraces of rivers and streams. Most of these unconsolidated deposits may be mined by open-pit methods. Certain areas of the state are particularly notable for the abundance of these resource materials. The St. Peter Sandstone (Early Ordovician) in Stone County is a pure orthoquartzite and has numerous specialty uses (see **Silica Sand**). Some units of Early Cretaceous age in Pike, Howard, and Sevier Counties contain significant beds of sand and gravel, especially the Pike Gravel and Ultima Thule Gravel Members of the Trinity Formation, which range in thicknesses from 20 to 100 feet and 0 to 40 feet, respectively. Units of Late Cretaceous age which contain abundant sand and gravel are the Woodbine, Tokio, and Nacatoch Formations. Sand and gravel deposits are present in the Woodbine Formation in Howard and Sevier Counties. The Tokio contains recoverable sand and gravel in Clark, Pike, Howard, and Sevier Counties. Sand beds are present in the

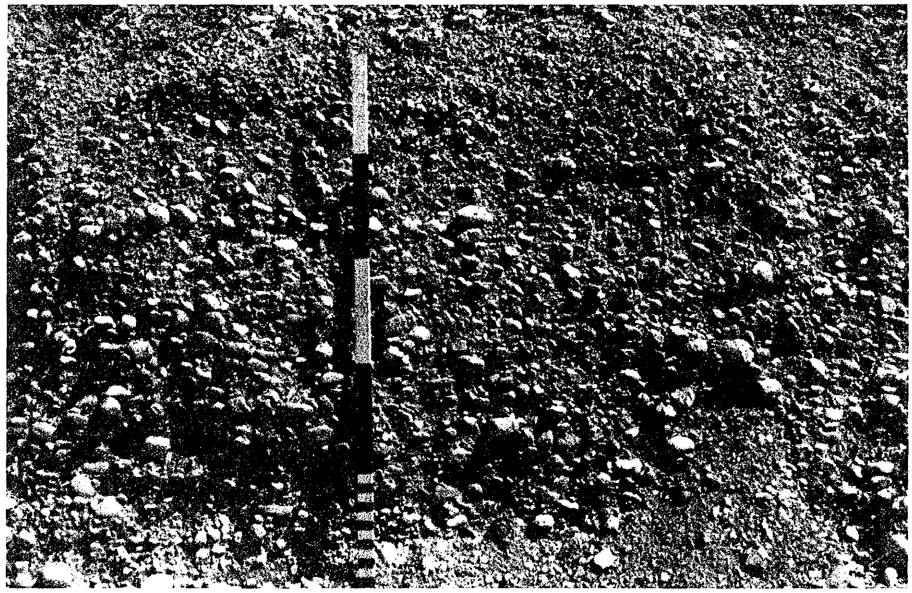
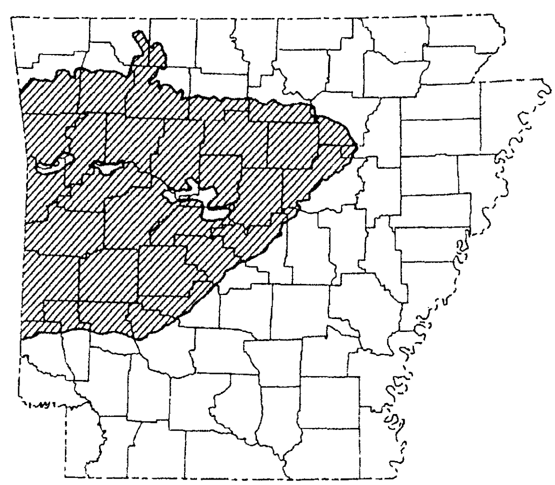


Figure 19. Sand and gravel, Tokio Formation (Cretaceous) near Delight, Pike County. Staff is marked in 1-foot intervals.

Nacatoch Formation in Clark, Hempstead, and Howard Counties. Tertiary gravel deposits are abundant in interstream divides of the Gulf Coastal Plain in southern Arkansas and on Crowley's Ridge in northeast Arkansas. Gravel and sand deposits on Crowley's Ridge are present from St. Francis County northward to the Missouri state line. Extensive Quaternary alluvial deposits of sand and gravel are present in the major river systems in the state. Dredging operations in the rivers, especially the Arkansas River, recover significant amounts of sand and gravel. Also, deposits are present locally within or adjacent to the beds of the smaller rivers and streams in the state. Worldwide, more sand and gravel is mined annually than any other industrial raw material. In 1990, United States industry produced 910,600,000 tons of sand and gravel having a value of $3,249,400,000. Immense quantities of this resource are present within Arkansas, and these materials are currently mined in about 75 percent of the 75 counties. Preliminary estimates of sand and gravel production in Arkansas for 1995 by the U. S. Geological Survey are nearly 11,000,000 short tons at a value of $44,800,000. Nearly 50 percent of this tonnage was used for concrete aggregate and concrete products. Huge tonnages were also used for aggregate in asphalt (and other bituminous mixtures) and for road-base material and road coverings.

Arkansas State Highway and Transportation Department, 1993, Standard specifications for highway construction, edition of 1993: Little Rock, 794 p.

SANDSTONE



Sandstone is a sedimentary rock composed mostly of sand-sized grains cemented by clay, silica, carbonate, or iron oxide as a binder. In Arkansas, as elsewhere, most of the constituent grains are quartz. Sandstone often contains other mineral grains, such as feldspar or mica, and very small fragments of pre-existing rocks. When cemented by silica, sandstone may have great strength, making it suitable for structural uses.

Most of the sandstone quarried in Arkansas is crushed and used for aggregate in concrete and asphalt. Large blocks, termed riprap, are used for fill and in dike and jetty construction. Rough, weathered sandstone blocks and boulders (fieldstone) have been used for years as facing stone on homes and other buildings, and to build other structures such as fireplaces, walls, and walkways. A substantial tonnage of thin flagstone and dimension stone has been produced in the state since the early 1950's. Much flaggy sandstone has been produced from the Hartshorne Sandstone (Pennsylvanian in age) near Midway in Logan County. This type of material is occasionally produced in other counties in west-central Arkansas, specifically Logan, Sebastian, and Franklin. A large quantity of natural or rough fieldstone is obtained for rustic construction from bouldery talus and alluvial deposits throughout the Interior Highlands of Arkansas. It is used for exterior work on buildings and for decorative rock in the con-struction of fireplaces.

There are apparently unlimited quantities of sandstone in the Paleozoic Highland area of Arkansas. An uncalculated, but major proportion of this rock resource is present in the Boston Mountains and, to a lesser extent, in the Springfield and Salem Plateaus. These sandstone units are principally in the lower Atoka Formation, Bloyd Shale, Hale Formation, Batesville Sandstone, St. Peter Sandstone, and Everton Formation. These sandstones range in age from Ordovician to Pennsylvanian. The Arkansas Valley contains vast quantities of sandstone in the Savanna Formation, Hartshorne Sandstone, Atoka Formation, and Hale Formation, all Pennsylvanian age. In the Ouachita Mountain region, sandstone is abundant in the Atoka Formation, Jackfork Sandstone, Stanley Shale, Blaylock Sandstone, Blakely Sandstone, and Crystal Mountain Sandstone. These formations range in age from Ordovician to Pennsylvanian.

Major aggregate quarries produce sandstone-based products near the larger cities and at other strategically located sites throughout most of the Paleozoic Highlands of Arkansas.

Several criteria must be met to determine the best locations for prime aggregate. Quality of available rock, closeness to market, and available transportation facilities (highways, barges, or railroads) are among the criteria. Future demands for sandstone aggregate sources should continue to expand, notably near our larger communities, near and along the Arkansas River, and in the southern Ouachita Mountains. The nearby states of Louisiana, Mississippi, and Texas have been – and apparently will continue to be – areas of major markets for high-quality Arkansas sandstone. Production of sandstone used for aggregate is included in the article on **Crushed Stone**.

Croneis, Carey, 1930, Geology of the Arkansas Paleozoic area with special reference to oil and gas possibilities: Arkansas Geological Survey Bull. 3, 457 p.

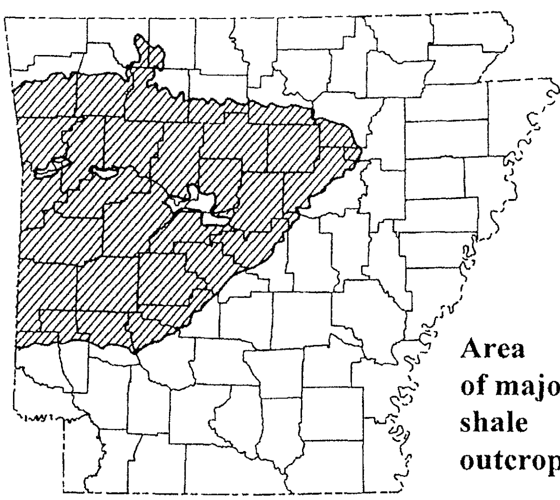
Haley, B. R., Glick. E. E., Caplan, W. M., Holbrook, D. F., and Stone, C. G., 1979, The Mississippian and Pennsylvanian Systems in the United States – Arkansas: U. S. Geological Survey Professional Paper 1110-O, p. 1-14.

Hendricks, T. A., and Parks, Bryan, 1950, Geology of the Fort Smith District, Arkansas: U. S. Geological Survey Professional Paper 221-E, 94 p.

Miser, H. D., 1934, Carboniferous rocks of the Ouachita Mountains: American Association of Petroleum Geologists Bulletin, v. 18, p. 30-43.

Stone, C. G., and McFarland, J. D., III, with the cooperation of B. R. Haley, 1981, Field guide to the Paleozoic rocks of the Ouachita Mountain and Arkansas Valley Provinces, Arkansas: Arkansas Geological Commission Guidebook 81-1, 140 p.

SHALE and SLATY SHALE



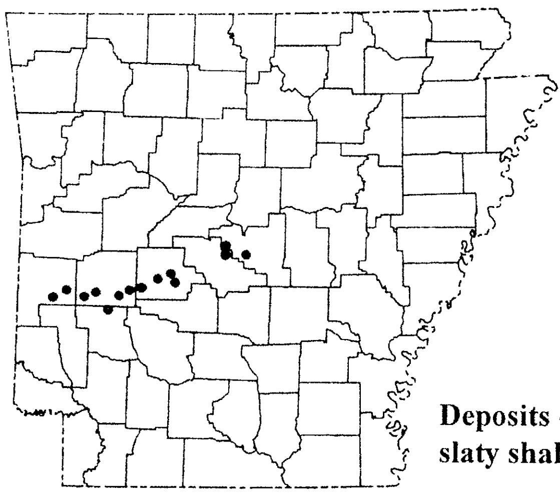
Shale is a sedimentary rock composed predominantly of clay-sized particles. Most of the constituent particles are clay minerals, but other fine-grained clastic materials are normally present. Shale is formed by the lithification of clay or mud, commonly with admixed silt. Shales composed predominantly of clay minerals are fissile, meaning that they easily split into thin flat plates or sheets parallel to bedding. Arkansas shales, when freshly ex-posed, are commonly very dark gray or nearly black, but weather to shades of very light gray to buff. Black and gray shales owe their color to finely divided carbonaceous matter or pyrite. Less commonly, shale may be light gray, greenish, or reddish in color when fresh. Greenish shale probably owes it's color to the presence of ferrous iron and/or chlorite, and reddish shale to the presence of iron oxide. Rock units consisting largely of clay-sized particles of minerals other than clay are termed claystone or mudstone because they lack the fissility of shale.

Throughout most of the Interior Highlands, shale is the dominant type of sedimentary rock. Much of it is contained in very thick sequences of Mississippian and Pennsylvanian rocks in the region. Units consisting almost entirely of shale may be more than 300 feet thick. Shale is more easily eroded than most other sedimentary rocks. Consequently, it underlies valley floors and the lower flanks of mountains where it is less likely to be exposed in outcrop than the more resistant sedimentary rocks occupying higher elevations. It is often exposed in creek beds, along the banks of the major rivers, and in road cuts.

Shale has a number of potential uses. It may be finely ground and used as a filler in paints, plastics, asphalt compounds, roofing cement, and some linoleum. In parts of Arkansas where clay is not locally available, shale is used in place of clay to manufacture brick. Many county roads are based on shale and, if some harder aggregate such as thin-bedded sandstone or limestone is admixed with shale for the road base, a relatively smooth and durable surface results. Shale is often used in paved highway construction as subbase fill material as it is readily available and less expensive to excavate than sandstone or limestone. Some shale units exhibit dramatic swelling when fired and have potential uses as lightweight aggregate. The Chattanooga (Devonian) and younger black shales of the Ozark region of north Arkansas have not been investigated as to their oil shale potential, but may have some potential because corresponding shale units studied in adjoining states yielded up to 15 gallons of oil per ton and averaged around 10 gallons per ton. Recovery was accomplished by distillation, not by solvent extraction.

Shale containing the mineral talc developed from the alteration of shale adjacent to soapstone deposits in Saline County. Ground talcose shale may have potential value as a filler in pottery clay. Baking of shale, as has occurred in the zone of contact metamorphism at the Magnet Cove intrusion in Hot Spring

County, has led to a rock that is usable as a crushed stone product.



Deposits of slaty shale

In parts of the Ouachita Mountains, especially the central core, much of the shale has undergone very low-grade regional metamorphism by increased pressure and temperature. As a result, cleavage has replaced fissility as the dominant planar structure. Cleavage permits the rock to be split easily into relatively thin slabs. The stone industry and many geologists have described such rock in Arkansas as "slate." The degree of regional metamorphism is so low, however, that other geologists, ourselves included, prefer the term "slaty shale." Locally, however, in proximity to some major faults, shaly rocks have been sufficiently recrystallized to be considered low-grade slate. The two types of rock can be used interchangeably for most purposes, but for roofing granules, slaty shale has proven superior. Rough and cut blocks were previously used as shingles, for floors, patios, table tops, and interior and exterior covered walkways. While such rock has proven to be of good quality for interior applications, most appears not to have undergone sufficient recrystallization to stand up to prolonged exterior uses.

The higher quality slaty shale in Arkansas is present in portions of Polk, Montgomery, Garland, Pulaski, and Saline Counties. Deposits are known in the Stanley Shale, Missouri Mountain Shale, Polk Creek Shale, Womble Shale, and Mazarn Shale formations (all of which are Paleozoic in age). Slaty shale in the Stanley apparently have the best physical properties for most uses.

Shale – largely for local construction fill – has been mined throughout much of the Interior Highlands, and slaty shale has been mined throughout the core area of the Ouachita Mountains. Recent "slate" mining has been largely restricted to Montgomery County. Slaty shale in the Stanley Shale north of Glenwood is loaded by power shovel into trucks and hauled from the open pit to a preparation plant where it is crushed and ground into granules for roofing. Slaty shale of the Womble Shale is also mined from an open pit in northern Saline County. Broken rock is transferred by truck to a grinding plant in Bryant. The rock is crushed, dried, ground, and bagged for rail shipment. It is used principally as fillers and additives to paints and plastics.

Shale and slaty shale resources in Arkansas are considered inexhaustible. However, there can be shortages of particular types or colors. Markets for Arkansas slaty shale products are limited by competition from substitute materials and the relatively few industries utilizing slate granules and flour (fines).

Branner, G. C., 1940, Mineral resources of Benton, Carroll, Madison, and Washington Counties: Arkansas Geological Survey County Mineral Report 2, 55 p.

Miser, H. D., and Purdue, A. H., 1929, Geology of the DeQueen and Caddo Gap quadrangles, Arkansas: U. S. Geological Survey Bulletin 808, 195 p.

Nuelle, L. M., and Sumner, S. S., 1981, A preliminary evaluation of shale-oil resources in Missouri: Missouri Department of Natural Resources, Division of Geology and Land Survey, Information Circular 27, 31 p.

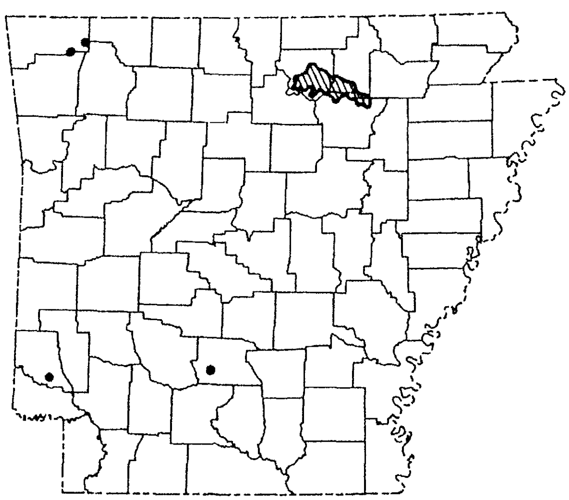
Purdue, A. H., 1909, The slates of Arkansas: Arkansas Geological Survey, 170 p.

Purdue, A. H., and Miser, H. D., 1923, Description of the Hot Springs district: U. S. Geological Survey Atlas, Folio 215, 12 p.

Stone, C. G., and Bush, W. V., 1984, General geology and mineral resources of the Caddo River watershed: Arkansas Geological Commission Information Circular 29, 32 p.

Swanson, V. E., 1960, Oil yield and uranium content of black shales: U. S. Geological Survey Professional Paper 356-A, 44 p.

SILICA SAND



Silica sand, also called industrial sand, is a high-purity quartz (SiO_2) sand deposited by natural processes. Depending on its chemical and physical characteristics, silica sand is used as glass sand, foundry sand, abrasives, fillers, and hydraulic fracturing sand (also termed "frac" sand by the petroleum industry).

The silica sand used in making glass has the most rigid industry-based specifications. Tiny amounts of impurities, such as iron, manganese, chromium, calcium, or aluminum, can alter the color and/or physical properties of the resultant glass. Foundry sand must be able to withstand the high temperatures of molten metals, hold the shape of the mold when moist (usually with the aid of a bonding agent such as clay), be permeable enough to release gases, have sufficient strength to support the weight of the metal, and be of a fine enough texture to result in a smooth casting. Abrasive sands used in sand blasting, grinding, and polishing usually require the individual sand particles to be very nearly the same size and somewhat angular with sharp edges. Sand used as fillers in paints, plastics, rubber, and ceramics is usually in the form of ground sand or silica flour. Hydraulic fracturing sand is pumped at very high pressures into subsurface rock strata to prop open the fractures created by the high pressures. This process is used to increase the permeability of the rock, thus increasing the rate of flow of oil and gas. "Frac" sand is normally free of impurities, well sorted, and composed of very well rounded grains.

In Arkansas, silica sand in economic quantities is known in two formations: the St. Peter Sandstone and some members of the Everton Formation, both Ordovician in age and present in the Ozark region. The most significant recovery of silica sand comes from underground mines developed in the St. Peter Sandstone at Guion, Izard County. A significant by-product is a sand that has applications as a filter material.

Giles, A. W., 1930, St. Peter and older Ordovician sandstones of northern Arkansas: Arkansas Geological Survey Bulletin 4, 187 p.

SOAPSTONE

Soapstone deposits in Arkansas were first described by the Arkansas Geological Survey in 1888. The massive soapstone typically consists of 50 to 80 percent talc ($Mg_3Si_4O_{10}(OH)_2$) admixed with chlorite, serpentine, pyrite, quartz, calcite, magnesite, and dolomite. The rock is either massive or flaky depending on the talc and chlorite content. It is soft and has a slightly greasy or dry soapy feel when rubbed on the hands. Soapstone and talc, because they are usually associated, are generally grouped together for the purpose of discussion.

One company periodically operates soapstone mines at various open pits along a narrow 4-mile-long belt in northeastern Saline County and processes the rock at a grinding plant at Bryant, Saline County. The soapstone is crushed, dried, ground to a fine powder, passed through a cyclone separator, and bagged. The material is used principally as an inert filler in paints, rubber, and roofing products, resurfacing for tennis courts, coatings for pipes, in brake shoes, and as a carrier for insecticides. Most Arkansas production is used as inert fillers and in brake shoes. Although talc is an extremely versatile mineral in its use, Arkansas soapstone has seen only limited application as fillers in ceramic ware, tailor's chalk, pencils for marking steel, heat and electrical insulators, and slabs for the construction of acid-resistant tanks and for table tops and ornamental carvings.

The soapstone-serpentine deposits are probably Precambrian in age and are present as exotic lenses or masses in shale and chert beds of Ordovician age. They were most likely injected into the younger rocks by tectonic processes. Because the serpentine pinches and swells in breadth and winds sinuously, lenses of soapstone appear as isolated bodies, though in places they may join at depth.

Evidence suggests that the known deposits contain more than 500,000 tons of soapstone. Reserves of soapstone in Arkansas are apparently sufficient to maintain the current rate of mining for many years in the future. Output has been sporadic, but on average, about 1,500 short tons of soapstone are mined annually.

Cox, T. L., 1988, Tectonically emplaced serpentinites of the Benton uplift, Saline County, Arkansas, *in* Colton, G. W., ed., Proceedings of the 22nd Forum on the Geology of Industrial Minerals: Arkansas Geological Commission Miscellaneous Publication 21, p. 49-61.

Sterling, P. J., and Stone, C. G., 1961, Nickel occurrences in soapstone deposits, Saline County, Arkansas: Economic Geology, v. 56, p. 100-110.

Stone, C. G., and Sterling, P. J., 1964, Relationship of igneous activity to mineral deposits in Arkansas: Arkansas Geological Commission Miscellaneous Publication 8, 23 p.

Wicklein, P. C., 1957, Geology of the nickeliferous soapstone deposits of Saline County, Arkansas: Columbia, University of Missouri, M. S. thesis, 68 p.

STONE, CRUSHED AND DIMENSION

Crushed stone is any rock that has been broken by mechanical means into smaller fragments. The output of the crushing process is usually screened to separate the material into different size categories, ranging from dust to boulders (fig. 20). The use of crushed stone in construction depends on the type of stone and its physical characteristics as determined by using standard engineering tests. Although crushed stone is utilized in a wide variety of applications, the construction industry utilizes some 80 percent of mine output. Conditions necessary for a deposit of rock to be developed as a source of crushed stone for construction use include:

- Quality – the rock must meet specifications for strength and durability.
- Quantity – adequate volume of rock necessary for a minimum of 10 years production life, preferably 20 years.
- Market – must have adequate market to sell the new product to.
- Transportation – cost of transport must keep the product competitive with existing materials.
- Environmental – the impacts of the operation must be within acceptable limits.
- Legality – Commonly, the mining, processing, and transport of the stone must be approved and permitted by a state and/or federal agency.

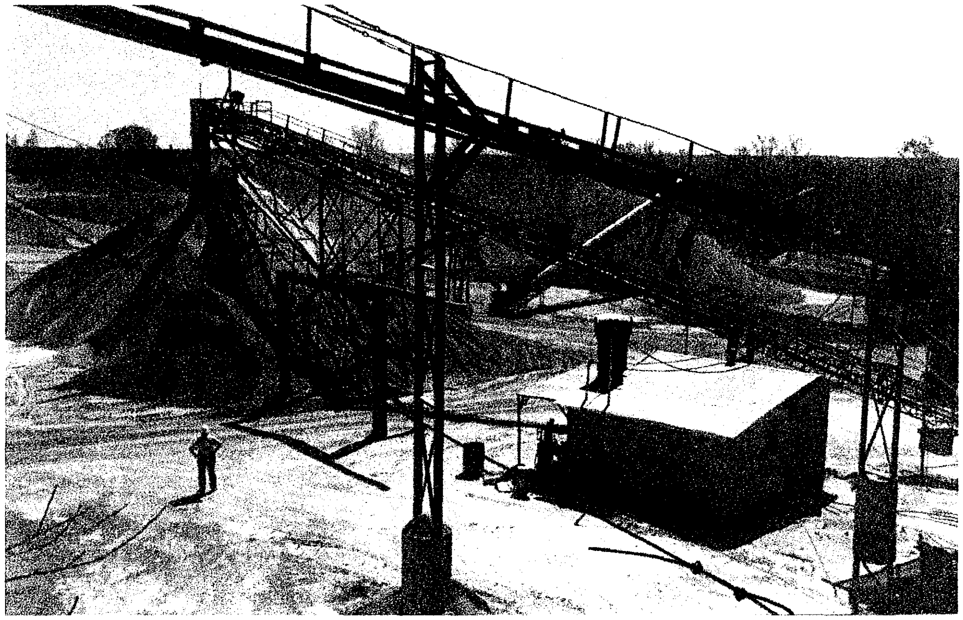


Figure 20. Crushed stone is sorted into stockpiles of various size ranges, each having its own particular application and uses.

Nepheline syenite, limestone, dolostone, sandstone, quartzite, novaculite, slate, and volcanic tuff are the major types of stone quarried and utilized in Arkansas as crushed stone. See each section concerning these specific rock types. Transportation costs to a specific job site are a major economic consideration when determining whether to use rock from any given quarry. At present, all of these rock types are mined from open pits. In 1990, Arkansas ranked 25th in the nation in crushed stone output, producing 16.2 million tons valued at $76, 900,000.

Dimension stone includes rock that has simply been removed from its original site to be used (fieldstone) and rock that has been broken, sawn, dressed and/or ground and polished (processed) for use as building and/or ornamental stone. While most of the high-quality dimension stone produced in Arkansas is used in-state, some is shipped to markets worldwide. Limestone, slate, and sandstone are utilized as dimension stone in Arkansas. Past production of "marble" has been significant. See each section concerning these specific rock types.

Some dimension-stone operations can produce blocks of stone weighing up to about 9 tons. Such large blocks require specialized equipment for extraction and transportation. The manufacture of building stone remains a labor intensive industry. A finished piece of building stone is an expensive product due to extra labor costs. This means that a piece of stone which has been highly worked and/or polished costs more than a partially finished or rough block. Dimension stone may be sold as rough blocks, sawn slabs, or finished products.

The production of crushed stone in Arkansas in 1994 was approximately 23.5 million tons, valued at $114,000,000. This figure includes all types of rock used as crushed stone. There are no data available at this time concerning the production and value of Arkansas dimension stone.

U. S. Geological Survey, 1996, Arkansas 1995 annual estimate: U. S. Geological Survey Mineral Industry Surveys, 5 p.

White, D. H., Jr., and Bush W. V., 1991, The mineral industry of Arkansas, *in* U. S. Bureau of Mines, Minerals Yearbook, v. II, Area reports – Domestic: p. 89-98.

SULFUR

Sulfur (S) is a pale yellow nonmetallic element with a low melting point and low specific gravity (2.07 to 1.95). Sulfur is used in the manufacture of a wide variety of products. Probably the largest modern market is in the manufacture of chemical fertilizer. Much of the importance of this element as a raw material stems from its conversion into sulfuric acid, which has numerous industrial applications.

Sulfur is consumed mainly in the form of acid or other intermediate chemicals used to manufacture a final product that often does not contain much, if any, sulfur. Sulfuric acid represented 86 percent of shipments for domestic use in 1990 in the United States. The largest market as sulfuric acid is in the manufacture of chemical fertilizer, accounting for over 60 percent of domestic use. Other industrial applications include copper-ore leaching, production of other inorganic chemicals, synthetic rubber and plastic materials, industrial organic chemicals, and petroleum and coal refining.

A source of sulfur for early pioneers was the mineral pyrite (FeS_2). Sulfur was important to them because it is an essential ingredient in black powder (gun powder). During the War between the States, a deposit of pyrite at Magnet Cove was investigated by representatives of the Confederacy as a source of sulfur. A pyrite deposit near Berryville in Carroll County was explored as a possible source of sulfur by drilling during 1937 and 1938. The pyrite is in a highly fractured zone of the Cotter Formation (Ordovician). This deposit has been calculated to contain 482,000 long tons of ore ranging in grade from 6.5 to 32.4 percent sulfur, averaging 24.3 percent. A second major, though not used, resource of sulfur is the gypsum deposits of Pike and Howard Counties in southwest Arkansas. Presently, processed sulfur from other sources is so inexpensive as to preclude the development of commercial sulfur from gypsum.

The first experimental plants in the United States for the recovery of sulfur from natural gas were located in Columbia and Lafayette Counties in Arkansas. Analyses of oil field gases were first published in 1940 and were instrumental in bringing attention to this resource in the state. Pilot plants built in 1941 led to the construction of two full-scale production facilities, one in each county, in 1943. The Columbia County plant served the Dorcheat-Macedonia field for some 15 years and was dismantled and moved to Texas in 1958. In the Dorcheat-Macedonia area, the hydrogen sulfide content of natural gas was reported to be as high as 2,400 grains per 100 cubic feet. The Columbia County plant had a production capacity of 10 long tons per day of free sulfur. The plant in Lafayette County was built to serve the McKamie field. The gas from the McKamie field contained as much as 4,500 grains of hydrogen sulfide per 100 cubic feet of natural gas. This "sour" gas was purified to a hydrogen sulfide content of 0.05 grains per 100 cubic feet in the pilot-plant operation. The ensuing commercial plant was producing 65 tons of free sulfur daily by the end of 1943 and was recovering 97 percent of the sulfur in the gas. In 1960, the McKamie facility had a production capacity of 110 long tons per day. The plant is presently in operation.

The start of full-scale operations in the McKamie field marked the initial use of the Claus process for sulfur recovery in the United States, that process being the first devised for recovering sulfur from hydrogen sulfide. The Claus process involves burning one-third of the hydrogen sulfide to form sulfur dioxide, which then reacts with the unburned hydrogen sulfide in the presence of a surface-active catalyst to form sulfur and water vapor. The sulfur is condensed to liquid form and shipped or stored in that manner, or is allowed to solidify for handling as a solid.

Prior to the development of sulfur-extraction units, natural gas containing appreciable amounts of hydrogen sulfide was flared because of its corrosive nature and unpleasant odor. If used as a boiler fuel, gas may contain as much as 360 grains of hydrogen sulfide per 100 cubic feet and still not be too objectionable. However, natural gas used for domestic purposes is not permitted to contain more than 1.5 grains of hydrogen sulfide per 100 cubic feet.

Sulfur has been produced by one petroleum refinery in Union County for many years. The source of the sulfur is gas freed at the refinery during the production of other petroleum products. Production capacity was rated at 10 long tons per day in 1960. In 1984, a company near Magnolia, Columbia County, began recovering sulfur during bromine extraction. To date, the plant continues this practice.

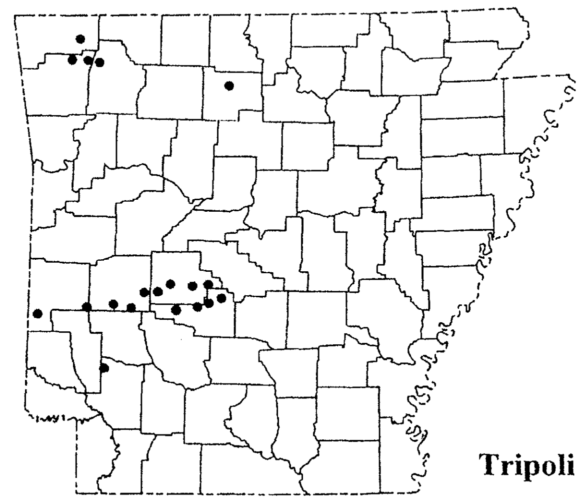
Blade, O. C., and Branner, G. C., 1940, Survey of crude oils of the producing fields of Arkansas: U. S. Bureau of Mines Report of Investigations 3486, 40 p.

Grandone, Peter, and McHarg, R. E., 1952, Oil, gas, and sulfur in the Arkansas and Red River basins, Arkansas: U. S. Inter-agency Committee on Arkansas-White-Red River Basins, Minerals and Geology Workgroup, Preliminary Report, 12 p.

Netzeband, F. F., Early, T. R., Ryan, J. P., and Miller, W. C., 1964, Sulfur resources and production in Texas, Louisiana, Missouri, Oklahoma, Arkansas, Kansas, and Mississippi, and markets for the sulfur: U. S. Bureau of Mines Information Circular 8222, 77 p.

TRIPOLI

Tripoli is a microcrystalline form of quartz (SiO_2) which is derived either by the alteration of chert, chalcedony, or novaculite, or by the leaching of highly siliceous limestones. Tripoli has for many years had numerous applications, principally as an abrasive in polishing, buffing, and burnishing compounds, in scouring soaps and powders, and more recently, as a filler or extender in plastics, rubber and in sealants and epoxy resins, and as a pigment in paints.



Compact blocks may be cut to desired shapes and sizes for use as water filters. Tripoli can also be added to Portland cement to increase washability, water tightness, and strength of the applied product. Some firing tests on tripoli blocks have shown its potential as a high-quality lightweight aggregate.

Tripoli is present in 3 general areas of Arkansas: northwestern Arkansas near Rogers in Benton County, in the Ouachita Mountains near Hot Springs in Garland County, and near Athens in Howard County. Analyses of Arkansas tripoli show the silica content to be greater than 99 percent. All 3 areas have been mined; however, there is only one active mine and processing facility at this time. The Malvern Minerals Company of Hot Springs in Garland County markets their products under registered trade names. A typical analysis of processed tripoli from Arkansas novaculite is as follows: 99.49 % SiO_2, 0.015 % TiO_2, 0.102 % Al_2O_3, 0.039 % Fe_2O_3, 0.021 % MgO, and 0.014 % CaO for a total of 99.68 %.

The deposits of northwestern Arkansas were derived by the weathering of cherty limestones of the Boone Formation (Mississippian), while the Ouachita Mountains deposits were developed by the leaching of a limy phase within the Upper Division of the Arkansas Novaculite (Mississippian). Originally, portions of the Upper Division contained as much as 30 percent carbonate. Tripolitic zones developed in the Bigfork Chert (Ordovician) in western Saline County have been investigated recently for their commercial potential. Other exposures of tripoli are reported in Baxter, Montgomery, Pike, Polk, Pulaski, and Washington Counties.

Tripoli has been mined by both underground (Ozark region) and open-pit (Ouachita region) methods. The mined material is dried, crushed, pulverized, disaggregated, and sized by screening or air-flotation. The range of particle size of individual quartz grains composing tripoli is from 0.5 to 10 microns, the individual grains being essentially equidimensional. A micron is one millionth of a meter, a meter is about 39.37 inches. The gross color of the tripoli varies considerably even within the same deposit. Colors include white, cream, tan, and brown, with white being the least prevalent but most marketable.

The mined output of tripoli typically amounts to about 15,000 short tons per year. In 1995, Arkansas ranked 3rd in the nation in tripoli production. Reserves of higher-grade white tripoli are limited, but reserves of the other color grades are thought to be several million tons.

Griswold, L. S., 1892, Whetstones and the novaculites of Arkansas: Arkansas Geological Commission Survey Annual Report for 1890, v. III, 443 p.

Holbrook, D. F., and Stone C. G., 1978, Arkansas Novaculite – A silica resource, *in* Johnson, K. S. and Russell, J. A., eds, Thirteenth Annual Forum on the Geology of Industrial Minerals: Oklahoma Geological Survey Circular 79, p. 51-58.

Keller, W. D., Stone, C. G., and Hoersch, A. L., 1985, Textures of Paleozoic chert and novaculite in the Ouachita Mountains of Arkansas and Oklahoma and their geological significance: Geological Society of America Bulletin, v. 96, p. 1353-1363.

Steuart, C. T., Holbrook, D. F., and Stone, C. G., 1984, Arkansas Novaculite: Indians, whetstones, plastics, and beyond, *in* McFarland, J. D., III, and Bush, W. V., eds., Contributions to the geology of Arkansas, v. II: Arkansas Geological Commission Miscellaneous Publication 18-B, p. 119-134.

TUFF

Tuff is a pyroclastic rock composed largely of angular fragments of volcanic material deposited from the air on land or in water. If deposited on land while still very hot, the particles may weld themselves together as a welded tuff; otherwise they will be lithified by normal sedimentary processes.

In Arkansas, two major tuff units are present along with several thinner, more discontinous beds of tuff and tuffaceous sandstone. The most important tuff commercially is the Hatton Tuff Lentil of the Stanley Shale (Mississippian), which is exposed in Polk County. Southwest of the community of Hatton, the tuff attains a maximum thickness of 300 to 400 feet, but 90 feet is more typical. The tuff is massive, homogeneous, and often so well jointed as to make the determination of bedding difficult. The unweathered fine-grained rock is dark gray and may appear spotted due to the presence of light-colored feldspar crystals. When examined under the microscope, numerous broken volcanic glass fragments (shards) are seen to compose much of the rock. The unweathered rock is tough and compact and may contain some Late Pennsylvanian milky quartz veins. Several additional thinner tuff beds are present in the Stanley Shale in Polk County. All the tuff units in the western portion of the state merge with normal appearing quartzose sandstone beds to the east. Geologic mapping of the Stanley Shale to the northeast of Malvern, Hot Spring County, resulted in the discovery of tuffaceous sandstone in the lowermost Stanley, which was tentatively identified as the Hatton Tuff Lentil.

The units were noted to be as much as 50 feet thick. Tuff beds are also present in southwest Arkansas in the Woodbine Formation (Cretaceous), but have no known resource potential for aggregate.

Although the Hatton tuff is not used in Arkansas for aggregate, it does readily pass concrete-aggregate specifications as set forth by the Texas Highway Department. It is actively quarried from a site near Hatton and the production is exported to east Texas for use in concrete. The Hatton may warrant research into its potential use as a cementing agent.

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Miser, H. D., and Purdue, A. H., 1929, Geology of the DeQueen and Caddo Gap quadrangles, Arkansas: U. S. Geological Survey Bulletin 808, 195 p.

Williams, J. F., 1891, The igneous rocks of Arkansas: Arkansas Geological Survey Annual Report for 1890, v. II, 457 p.

VERMICULITE

Vermiculite is a mica-like silicate mineral of the general formula $(Mg,Fe^{2+},Al)_3(Si,Al)_4O_{10}(OH)_2 \cdot 4H_2O$ that rapidly expands upon heating, resulting in a low-density material. The expanded material has many uses: as a lightweight aggregate and as insulation in the construction industry, as a carrier for fertilizers and a soil conditioner in agriculture, as a fragrance carrier, and as a filler and texturizer for plastics and rubber.

Vermiculite is known from Magnet Cove, Hot Spring County, where deposits were observed during mining of iron ore in the 1940's and 1950's. Residual flake vermiculite originated from the iron-rich mineral biotite contained in igneous rock, then various processes of alteration and weathering resulted in the formation of vermiculite. These deposits have not been investigated for their commercial potential. Exploration for vermiculite deposits is a straightforward process since they are the products of surface and near surface weathering processes.

Although Arkansas does not mine vermiculite, it is interesting to note that companies in Arkansas expand imported vermiculite, placing Arkansas among the principal expanded-vermiculite-producing states in the United States.

Erickson, R. L., and Blade, L.V., 1963, Geochemistry and petrology of the alkalic igneous complex at Magnet Cove, Arkansas: U. S. Geological Survey Professional Paper 425, 99 p.

Williams, J. F., 1891, The igneous rocks of Arkansas: Arkansas Geological Survey Annual Report for 1890, v. II, 457 p.

WOLLASTONITE

Wollastonite ($CaSiO_3$) is a mineral which may develop in two different ways: in certain types of contact metamorphic deposits and as a primary magmatic mineral (associated with carbonatites). The mineral cleaves into particles of varying needle-like shapes, having great strength. Wollastonite plays an important role as a high-performance mineral filler in paint, plastics, and thermal board; it also serves as a substitute for asbestos and is an additive to ceramics, where it imparts strength and rapid firing, and inhibits shrinkage and warping. The mineral has a number of unique properties which may lead to continued growth in its demand. Wollastonite reduces energy costs when used to replace sand and limestone in glass and glass fiber by lowering the fusion temperature. Surface-modified wollastonite powders in fine and ultrafine grades are having increased usage as plastic filler.

In Arkansas, wollastonite formed along the contact zone of the Potash Sulphur Springs igneous intrusion and its silica-rich sedimentary host rock, the Arkansas Novaculite, where carbonate-rich fluids from the intrusion reacted with novaculite. There has been no mining of wollastonite from Arkansas and the known deposits have not been commercially evaluated. Known resources are limited to one location, but might be recovered as a by-product should the host rock be processed for other mineral values.

Milton, Charles, 1984, Miserite, a review of world occurrences with a note on intergrown wollastonite, *in* McFarland, J. D., III, and Bush, W. V., eds., Contributions to the geology of Arkansas, v. II,: Arkansas Geological Commission Miscellaneous Publication 18-B, p.97-114.

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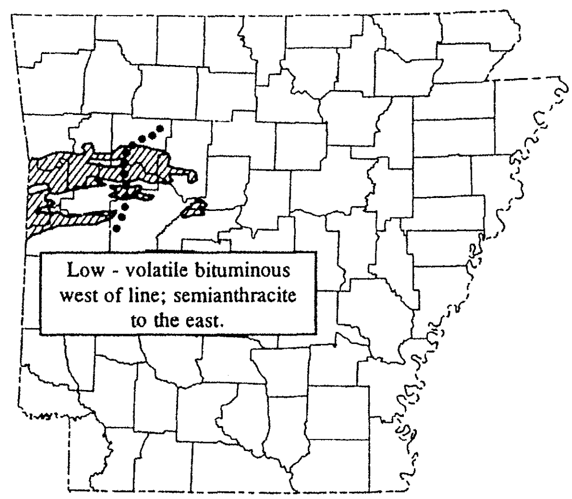
FOSSIL FUELS

Fossil fuels have provided much of the energy that has made the nation's industrial development possible. Fossil fuels are being consumed at an ever increasing rate, and they are not renewable within human life spans. A comparison between the consumption of energy of the average U. S. citizen and each Arkansas citizen is presented below (fig. 21). Hydroelectric power has long been an extensively developed alternative to power based on fossil fuels. However, in recent years, there has been increasing public resistance to developing more hydroelectric power sites. After an early acceptance of nuclear-generated power, it too has fallen into disfavor, and other alternatives, including hydrogen, the sun and wind have not yet gained widespread acceptance for a variety of reasons.

Arkansas' fossil fuels include coal, lignite, natural gas, natural gasoline, and petroleum. We also include here a discussion of asphalt since it is a natural hydrocarbon-based material, although it is not burned as a fuel. Because uranium is used to generate energy, uranium-bearing minerals might be considered in this section. However, they are discussed in the section on metallic minerals because they are present in such small amounts in Arkansas that it is unlikely they will serve as a fuel source.

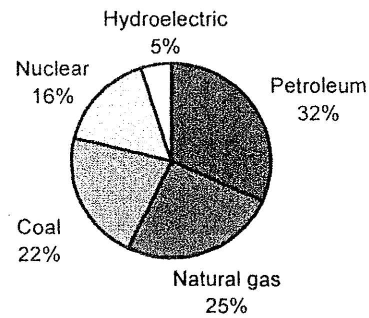
Since modern industry and our everyday lives are so dependent on these fuels as energy sources, conservation programs have been adopted this century to insure their efficient production and wise use.

COAL



Coal is a combustible substance consisting of carbonized vegetable matter formed over a long period of time. Hundreds of millions of years ago swampy conditions existed in the area where coal is now present. The various plants in and near these swamps died, fell into the water, and were covered with sediment before they completely disintegrated. Pressure and heat slowly altered the buried vegetable matter. The complete succession of coals formed over time, beginning with vegetable matter and ending with high-rank coal, is: (1) peat, (2) lignite, (3) high-volatile bituminous coal, (4) medium-volatile bituminous coal, (5) low-volatile bituminous coal, (6) semianthracite, and (7) anthracite. Only lignite, low-volatile

1993 Arkansas energy consumption, by fuel type



1993 USA energy consumption, by fuel type

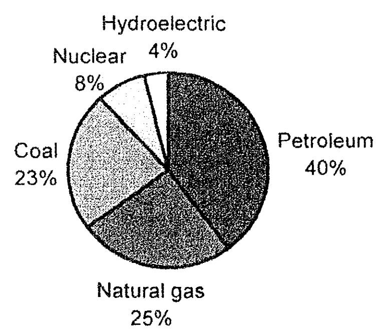


Figure 21. Energy consumption of the average Arkansan compared to the average United States citizen, by fuel type for 1993. Combined alternative energy sources (geothermal, solar, wind, and others) make up less than 0.2 percent in each graph and, therefore, are not shown.

bituminous, and semianthracite are present in significant quantities in Arkansas.

Coal is commonly analyzed by its major components, which are moisture, volatile gases, fixed carbon, ash, and sulfur. Volatile gases and fixed carbon are the fuel elements, and water, ash and sulfur are the impurities. The higher rank (harder) coals are commonly classified according to their fixed carbon content, and the lower rank (softer) coals according to their heat value. Arkansas Valley coals are all of high rank. They range from low-volatile bituminous coal in the western part of the Arkansas field to semianthracite in the eastern part.

Table 1 summarizes analyses of 258 samples of Arkansas coal and shows the average analyses of coal that has been mined from the various coal beds and fields in the state. Heat value is shown in British thermal units (Btu). One of the principal advantages of Arkansas coal is that it gives off little smoke when burned. Another is that its sulfur content is relatively low, compared to many coals mined in the United States and elsewhere.

Table 1. Average analyses of Arkansas coals, in weight percent, as received from the mines

Coal bed	Number of samples	County	Moisture	Volatile matter	Fixed carbon	Ash	Sulfur	Heat of combustion[1]
Charleston	5	Franklin, Sebastian	2.4	18.2	74.0	5.5	2.6	14,363
Paris	43	Franklin, Logan	1.8	17.9	70.6	9.8	2.4	13,765
Atoka	3	Johnson, Pope	1.4	13.8	77.2	7.6	3.4	14,070
Lower Hartshorne	125	Scott, Sebastian	2.9	17.4	72.1	7.7	1.3	13,771
Lower Hartshorne	68	Franklin, Johnson	3.0	13.5	75.9	7.6	1.8	13,854
Lower Hartshorne	14	Logan, Pope	2.8	12.0	75.7	9.6	1.7	13,499

[1]Heat of combustion is the heat evolved when a substance is completely burned in the presence of oxygen. Reported in British thermal units (Btu).

Arkansas coal has been used largely to produce steam to power electric generating plants and steam locomotives, as metallurgical coal in steel mills, to heat homes and other buildings, and as a source of coal tar and other chemicals. The chemical and physical properties of a coal determine the use to which it is best suited. For example, the hard coals, even though they produce less heat, are better adapted to domestic use because they give off less smoke than the soft varieties. Soft coals are usually suitable for the manufacture of coke and the by-products of coke manufacture, such as coal tar, ammonium sulfate, gas, benzol, toluol, naptha, and naphthalene (the principal component of moth balls). Almost all Arkansas hard coals are relatively low in volatile matter and are, therefore, non-coking. However, some coal in the western part of the coal field has been found to result in a satisfactory coke when blended with high-volatile bituminous coal from other areas. A blend containing 10 to 20 percent low-volatile bituminous coal and 80 to 90 percent high-volatile bituminous coal yields a strong coke that is suitable for metallurgical use. Presently, some Arkansas coal goes into the manufacture of so-called "charcoal" briquettes. Franklin and Sebastian Counties have an excellent grade of coal for this purpose.

Arkansas' coal fields are along the valley of the Arkansas River between the western border of the state and Russellville, encompassing an area about 33 miles wide and 60 miles long. The thickness of the coal beds may exceed 9 feet, but they are normally much thinner. Individual coal fields are often of small extent because the coal beds are lenticular and have been folded, faulted, or eroded in many places. Commercial mining of coal in Arkansas has been limited to Johnson, Sebastian, Logan, Frankin, Pope, Scott, and Yell Counties. A small amount of coal, sometimes used locally, is present in central, northern, and northwestern Arkansas.

Arkansas coal was first mentioned in the literature as early as 1818. The first recorded mine output in Arkansas was 220 tons in 1848. At the Old Spadra mine in Johnson County, a steam plant was installed in 1873. Soon after the extension of the Little Rock and Fort Smith Railroad, about 1873, coal from the Coal Hill mines in Johnson County was put on the market. When the St. Louis and San Francisco Railway was extended south to Fort Smith in 1887, numerous mining operations began at Huntington, Hackett, Jenny Lind, Paris, Charleston, Scranton, and other localities in the

Arkansas Valley, eventually resulting in extensive development.

Coal was first mined in Arkansas from open pits (strip mines). However, as production increased, it became increasingly more difficult to mine the remaining near-surface coals with the equipment then available, and underground methods were adopted. For many years, most coal was produced from underground mines. With the gradual introduction of heavier equipment, especially draglines, it became economically feasible to resume mining from open cuts. Since 1957, surface mining output of coal has exceeded that from underground mines, and today, underground mining is minimal.

From 1880 to 1920, coal ranked first in the value of Arkansas' mineral and fuel output, but since 1922 the value of oil has exceeded that of coal. The peak year of coal mining activity in Arkansas was 1909, when annual production reached nearly 2,400,000 short tons (fig. 22). During 1993, 63,798 short tons of coal from 6 mines in Sebastian and Johnson Counties were recovered. The original reserves of coal in Arkansas prior to mining were calculated by the U. S. Geological Survey to be over 2.225 billion short tons. Approximately 106 million short tons of coal had been mined through 1993. The remaining reserves in Arkansas are more than 2 billion short tons. Assuming a 50 percent loss in mining, the recoverable reserves of coal should be approximately 1 billion tons.

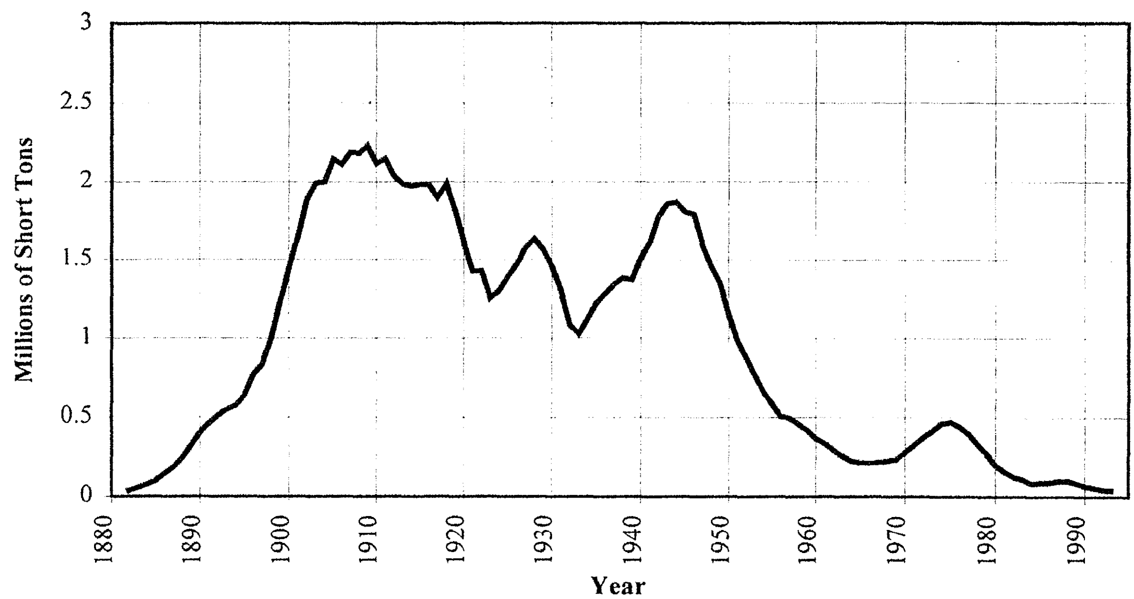


Figure 22. Coal production in Arkansas, 1882-1993. Curve smoothed by using a 5-year moving average.

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Haley, B. R., 1977, Low-volatile bituminous coal and semianthracite in the Arkansas Valley coal field: Arkansas Geological Commission Information Circular 20-K, 26 p.

Hendricks, T. A., and Parks, Bryan, 1937, Geology and mineral resources of the western part of the Arkansas coal field: U. S. Geological Survey Bulletin 847-E, p. 189-224.

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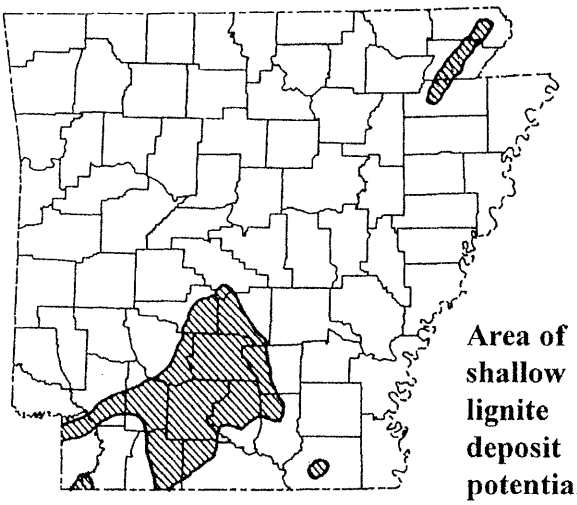
LIGNITE



Area of shallow lignite deposit potential

Lignite is defined as a low rank, consolidated, brownish-black coal that, when burned, produces less than 8,300 British thermal units (Btu) per pound on a moist, mineral-matter-free basis. Lignite has a high content of volatile matter which makes it more readily converted into gas and liquid petroleum products than the higher ranking coals. However, its high moisture content and susceptibility to spontaneous combustion may cause problems in transportation and storage.

Lignite is mined by stripping methods in other states to burn for the generation of electric power. Arkansas has lignite deposits that are suitable for this purpose and have been tested for power generation. In 1988, a 221,799 ton sample of Arkansas lignite mined in Saline County was successfully test-burned in a local power plant as a blend of up to 20 percent lignite with coal from the western United States.

The Arkansas Geological Commission conducted studies over a period of years resulting in an estimated lignite resource of some 9 billion tons at depths of less than 150 feet. Proven reserves announced by private companies are slightly more than 2 billion tons.

Lignite was mined in south Arkansas by underground methods and used before the War between the States. It was first used for steam-boiler fuel and later as fuel for small locomotives near the mines in Ouachita County. In 1907, two small oil-distilling plants were in operation in Ouachita County. The plants produced oils from lignite mined by open pit methods in the Camden field in Ouachita County. In 1913, it was reported that lignite from the Camden area yielded as much as 38 gallons of oil per ton, although the average oil recovery was closer to 25 gallons per ton. In 1938, a plant was constructed in El Dorado, Union County, to extract Vandyke brown dye from lignite, and another plant at Malvern, Hot Spring County, went on line in 1943. The dye was used in staining ammunition boxes their characteristic brown color during World War II. Annual output during the war years was small – on the order of 1,000 tons per year. Another company at Malvern extracted Montan wax from lignite for a few years. Montan wax is used in some polishes, carbon paper, and insulating materials.

During the 1970's, various companies carried out exploration programs and discovered a number of major lignite deposits within the state. The lignite was examined for use as a boiler fuel for electric-power generation, as a source of chemical feedstock, and as a source of petroleum-type products through gasification and liquefaction.

Lignite is present at shallow depths in sedimentary strata of Eocene age in the West Gulf Coastal Plain and along Crowley's Ridge in the Mississippi River Alluvial Plain. These rocks are divided, from oldest to youngest, into the Wilcox, Claiborne, and Jackson Groups. The sediments of the Gulf Coastal Plain are essentially flat-lying.

The Wilcox Group is as much as 850 feet thick. Within the Wilcox, lignite is present in beds up to 10 feet thick; and typically they are lenticular in shape. The larger, more important lignite layers appear to be in the lower and middle parts of the Group, but thinner beds are scattered throughout. The resource potential of lignite in the Wilcox is estimated to be about 4.3 billion tons. The lenticular nature and erratic distribution of the lignite beds is a consequence of the fluvial environment in which the Wilcox was deposited (fig. 23).

The overlying Claiborne Group, as much as 1,200 feet thick in Arkansas, is composed largely of sand, silt, and clay. Lignite beds in the Claiborne are lenticular, generally of limited areal extent, and although their thickness may exceed 10 feet locally, their average is much less. Variations in the areal distribution and the chemistry of the lignite in the Claiborne are the result of changes in the depositional environment, which fluctuated from deltaic to near-shore, shallow marine. The Claiborne Group is estimated to contain 4.7 billion tons of lignite resource, the major deposits being in the middle of the stratigraphic section.

The Jackson is the youngest of the 3 Eocene units in Arkansas and in many places contains sediments deposited in a marine environment. No commercial deposits of lignite are known to exist in the Jackson Group.

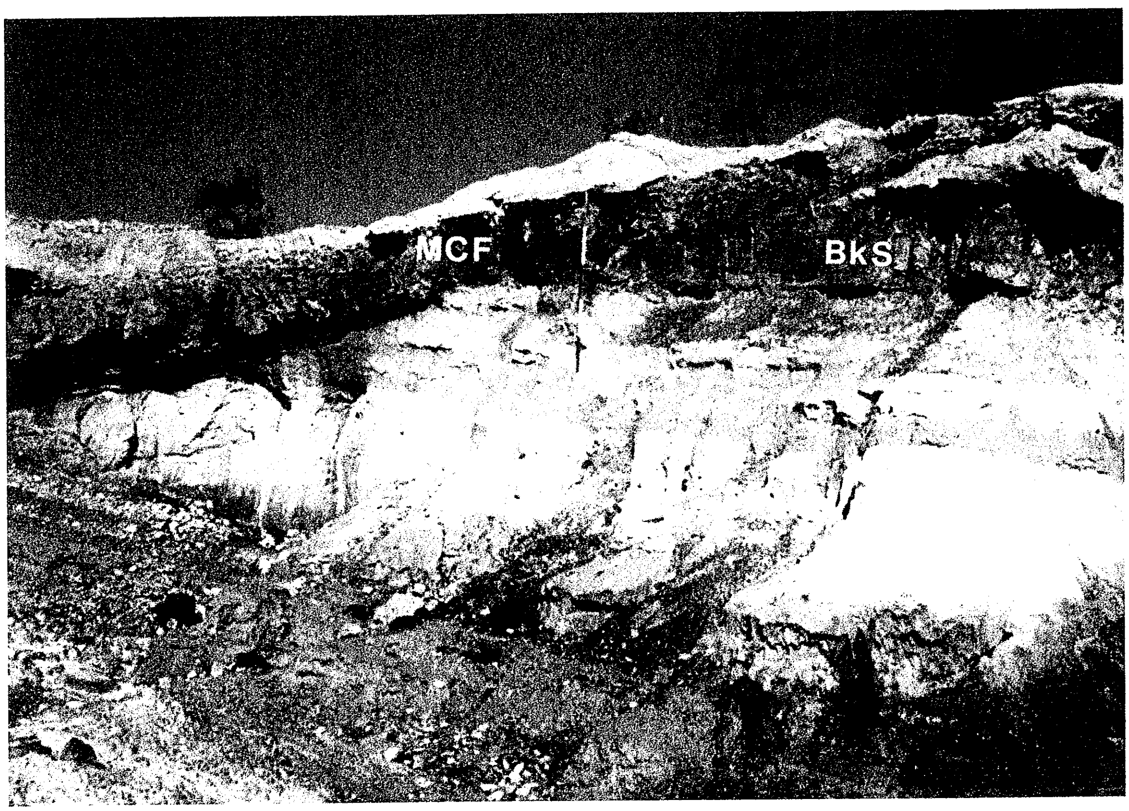


Figure 23. Meander channel-fill (MCF) and back swamp (BkS) lignite deposits of the Wilcox Group, Gulf Coastal Plain region, Hot Spring County. Staff marked in 1-foot intervals.

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Selvig, W. A., Ode, W. H., Parks, B. C., and O'Donnell, H. J., 1950, American lignites: geological occurrence, petrographic composition, and extractable waxes: U. S. Bureau of Mines Bulletin 482, 63 p.

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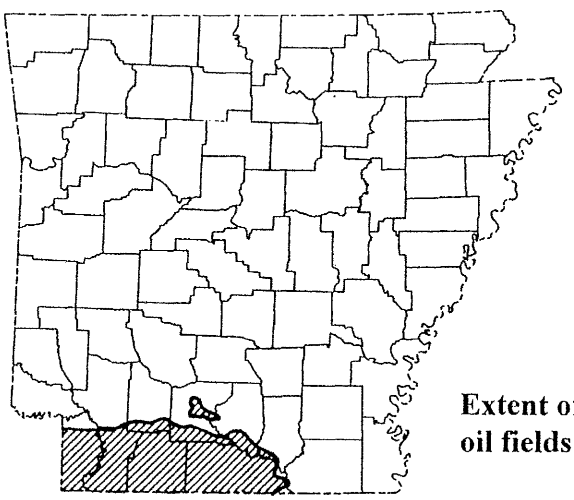
PETROLEUM



Extent of oil fields

Crude petroleum (oil to many and crude or crude oil to others) is a naturally occurring hydrocarbon-based liquid which is sometimes present in porous rocks beneath the surface of the earth. Petroleum is formed by the slow alteration of organic remains through long periods of time. It consists of a mixture of liquid hydrocarbon compounds and varies widely in composition, color, density, and viscosity. This liquid, after distillation, yields a range of combustible fuels, petrochemicals, and lubricants. Petroleum is usually classified according to the predominance of paraffin or asphaltic compounds and, accordingly, is said to have a paraffin base, an intermediate base, or an asphalt base.

Petroleum is used principally as a source of fuel and lubricating oils. Compounds and mixtures of compounds separated from crude petroleum by distillation include gasoline, diesel fuel, kerosene, home-heating oil, some types of alcohol, benzene, heavy naphthas, different grades of lubricating oils, and residuum. South Arkansas has several refineries currently in operation, processing in excess of 30,000 barrels of crude oil daily. Many hydrocarbons extracted from petroleum are used by the petrochemical industry in the manufacture of plastics and synthetic materials.

The southern part of the Gulf Coastal Plain of south Arkansas contains all the oil-producing fields of the state. These are in Ashley, Union, Ouachita, Columbia, Nevada, Hempstead, Bradley, Calhoun, Lafayette, and Miller Counties. For the year 1993, oil recovery from over 200 active fields was in excess of 29,000 barrels of oil and approximately 105 million cubic feet of gas per day. Oil and condensate reserves as of January 1, 1994, were calculated to be in excess of 205 million barrels while the gas reserves associated with the oil and condensate were calculated at over 466 billion cubic feet. Data for 1993 indicate that the petroleum consumption of Arkansas citizens, by products, was predominantly as gasoline (55 percent) and distillate fuel (31 percent), but also included the following other products: asphalt and road oil (3 percent), liquefied petroleum gas – LPG – (4 percent), jet fuel (2 percent), lubricants (1 percent), and other petroleum products (4 percent). See the section on **Natural Gas** for the reserve estimates for northern Arkansas gas fields.

The first oil discovered in Arkansas was in a well near Stephens in Ouachita County in April of 1920. During the same month, gas was discovered in the northern part of the present El Dorado field in Union County by the Constantin Oil and Refining Company. On January 10, 1921, oil was discovered in the S. T. Busey well in the same field. This marked the beginning of commercial oil production in Arkansas.

In south Arkansas, several wells have been drilled to depths exceeding 16,000 feet. An exploratory well in Hempstead County was drilled to 17,349 feet. On the other side of the state, an exploratory well in Ashley County was drilled to a depth of 16,611 feet. As of 1995, the depth record for an exploratory well drilled in Arkansas was held by the Occidental Petroleum #1 U. S. A., located in Yell County, with a total depth of 20,661 feet. There are several oil wells which produce from a depth exceeding 11,000 feet along the southern border of Arkansas in Lafayette County.

Arkansas has two oil-producing fields that are considered to be giant fields. Giant fields are defined as those that have exceeded 100 million barrels of oil recovered. The Smackover field, discovered in 1922, had produced 569,974,000 barrels of crude oil as of January 1, 1995. The Magnolia field, discovered in 1938, had produced 164,656,000 barrels as of January 1, 1995.

During the early development of the Arkansas oil fields, prospecting and locating structures favorable for the accumulation of oil and gas were based almost entirely on information gained by the study of the relationship of rock units in time and space from records of previously drilled wells. In recent years, geophysical methods have largely replaced older methods of locating favorable structures for the accumulation of petroleum and natural gas. The most widely used geophysical instrument in petroleum exploration is the seismograph.

Present-day production methods, based on existing technical knowledge and principles of conservation, have greatly increased the amount of oil and gas that can be recovered from an oil pool. Better equipment makes it possible to pump oil profitably from depths exceeding 11,000 feet. Improved handling and storage facilities at wells have eliminated much of the waste that existed in the early fields, when earthen pits or wooden storage tanks were used. Modern recovery methods are much more efficient than early methods and include the use of natural underground forces of gas and water pressure to obtain the greatest recovery of oil over the longest period of time.

Oil and gas production involves relatively high fixed costs, the largest item in the total investment being the cost of drilling. Drilling cost varies with such factors as depth of the well, physical characteristics of the rocks composing the formation(s) penetrated, diameter of the hole, and materials required. A well may cost from a few dollars a foot to more than a thousand dollars per foot after all expenses are computed. Historically, any decrease in prices permitted by competition, improved skills, and better equipment is usually offset, by increasing the depth of exploratory drilling.

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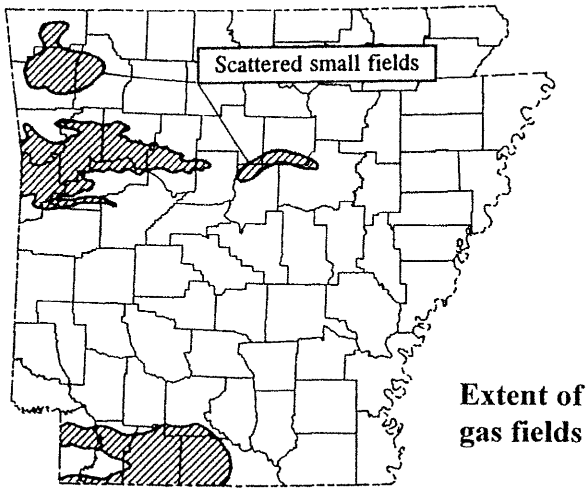
NATURAL GAS



Natural gas consists of combustible hydrocarbons which are gaseous at ordinary temperatures and pressures, and which have essentially the same origin as fluid hydrocarbons. Methane (also called marsh gas) and ethane are commonly the chief constituents. Most natural gases usually contain small and variable quantities of carbon dioxide, carbon monoxide, sulfur dioxide, hydrogen sulfide, nitrogen, hydrogen, and oxygen. In the absence of sulfurous compounds, natural gas is colorless, nearly odorless, and, when mixed in certain proportions with air, is highly explosive. An odorant is added before gas is sold to the public to aid in detection of gas leaks.

Natural gas is commonly discussed as either "wet" or "dry" gas. Wet gas contains some of the heavier fluid hydrocarbons as vapor, is commonly associated with petroleum, and is particularly valuable because of the extractable hydrocarbon liquids it contains. Most gas from oil fields in southern Arkansas is of this type. Dry gas differs from wet gas in that it does not carry appreciable quantities of the heavier hydrocarbons as vapor. The gas of the Arkoma basin in west-central Arkansas is of this type.

The heating value of gas varies from about 700 to 1,200 British thermal units (Btu) per cubic foot. Dry natural gas from the Arkoma basin fields has a heating value of from 986 to 1,016 Btu per cubic foot, and is used principally as fuel. Data concerning the gas consumed in Arkansas in 1993 indicate that 67 percent is used for industrial and commercial purposes, the remainder being divided between residential (20 percent), electric power generation (9 percent) and transportation (4 percent).

Major accumulations of natural gas are present in two areas in Arkansas – the Arkoma basin and the southern Arkansas oil fields in the West Gulf Coastal Plain. The Arkoma basin, a widely used term in the petroleum industry, is an elongate sedimentary basin extending from central Arkansas into east-central Oklahoma. It includes, but is not restricted to, the Arkansas River Valley physiographic region of western Arkansas. There were 82 gas fields in the Arkansas portion of the Arkoma basin as of April, 1995. The fields contain more than 2,800 gas wells, without considering multiple producing zones in each well as separate wells. Production in Arkansas extends from White County westward to the Arkansas-Oklahoma boundary.

Natural gas was first discovered in 1887 at Fort Smith, but commercial development did not begin until 1902 when two gas wells were brought in near Mansfield, Sebastian County. Gas was first discovered in southern Arkansas on April 22, 1920, when the Constantin Oil Company completed a gas well near El Dorado, Union County.

The Atoka Formation of Pennsylvanian age contains the principal gas-producing units in the Arkoma basin. The Atoka is a succession of alternating beds of sandstone and shale with a maximum thickness of about 7,000 feet in this region. Some dry gas has also been produced from the Morrowan Series (Pennsylvanian), which underlies the Atoka Formation. Both formations composing the Morrowan (the Hale Formation below and the Bloyd Shale above) have been productive. Atokan and Morrowan beds have been folded into numerous east-west trending open folds which serve to trap the gas within porous beds. Pre-Pennsylvanian reservoirs down to and including rocks of Ordovician-age have been sporadically tested in the Arkoma basin to determine their potential for natural gas. Their potential merits and justifies additional deep test wells.

During the past 45 years, at least a dozen scattered small gas fields have been discovered in Washington, Madison, and Benton Counties in northwestern Arkansas. Production has been from 5 formations ranging in age from Late Mississippian to Middle Ordovician.

Natural gas has been recovered, commonly with oil, in the southern Arkansas oil and gas fields in Ashley, Bradley, Calhoun, Columbia, Hempstead, Lafayette, Miller, Nevada, Ouachita, and Union Counties. Drilling methods for natural gas are very similar to those for oil. Most drilling conducted for natural gas in the Arkoma basin is presently done by rigs which utilize air to remove cuttings from the bottom of the hole, whereas standard rotary rigs utilizing mud as a medium to remove cuttings are used in southern Arkansas.

The annual production of natural gas in Arkansas for 1993 was more than 205.4 billion cubic feet. North Arkansas fields accounted for approximately 83 percent and south Arkansas for the remainder. Reserves of natural gas in south Arkansas and the Arkansas Valley, as of January 1, 1994, are calculated to be some 466 billion cubic feet and 1,247 billion cubic feet, respectively. Arkansas is considered to have less than 1 percent of the calculated proved recoverable reserves of natural gas in the United States, and was ranked 14th out of 33 gas-producing states in 1993.

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NATURAL GASOLINE

Many wet natural gases contain, in vapor form, considerable amounts of natural gasoline. The wet gas, also known as casinghead gas, is chiefly a mixture of methane, ethane, and the volatile hydrocarbons propane, butane, pentane, hexane, and heptane. The latter 5 form the constituents of natural gasoline, which is recovered in refineries in liquid form mainly by absorption or compression processes. Pentane, hexane, and heptane are liquids under normal atmospheric conditions and are the chief components of ordinary refinery gasoline. Propane and butane are also used, under the names bottled gas, LPG, or LP-gas, for domestic heating, and more recently as fuel for some tractors, cars, and buses. Bottled gas is also a popular and readily transportable source of fuel for recreation vehicles, campers, and outdoor cooking grills.

Wet gas, recovered from the oil and gas fields of south Arkansas, has a natural gasoline content ranging between about 1.6 and 5.5 gallons per thousand cubic feet of gas (MCF). As of November, 1994, Arkansas has 6 natural gasoline plants located in Columbia, Lafayette, Union, and Miller Counties. These include noncycling, cycling, and vacuum plants. Noncycling plants, after the recovery of liquids, sell most of the resulting dry, or residue, gas for fuel use. The liquids and gases extracted by gasoline plants are used as feedstock by the petrochemical industry. Butane is used in aviation fuel and in the manufacture of synthetic rubber; natural gasoline is the raw feedstock for aviation gas, nylon, many plastics, explosives, and cosmetics; ethane-methane mixtures are used for fuel, carbon black, ink, rubber, antifreeze, other plastics, drugs, and dyes; ethane-propane mixtures are used for rubber, yet different plastics, and commercial chemicals. The heavier hydrocarbons are used to make jet fuel, diesel fuel, and kerosene.

The reserves of natural gasoline in southern Arkansas are dependent upon the amount of the wet-gas reserves. Using a calculated wet-gas reserve of 466,400,000 MCF as of January 1, 1994, and an average recovery of 2.8 gallons per thousand cubic feet, the reserves of natural gasoline are approximately 1.3 billion gallons. Since the beginnings of recovery of natural gasoline in the state, yearly production has fluctuated depending on a number of factors. The nation's overall economy, critical energy shortages, peace time versus war time, and price of foreign-supplied fuels are a few such factors.

OIL AND GAS CONSERVATION

Arkansas is recognized as one of the first states among oil and gas producers to enact into law comprehensive conservation programs concerning these irreplaceable resources. Today, Arkansas is a member state of a voluntary organization of producing states called the Interstate Oil and Gas Compact Commission (IOGCC), which is dedicated to preventing the wastage of these resources. The sole purpose of the IOGCC is to encourage oil and gas conservation through established state agencies. The Arkansas Oil and Gas Commission is the state agency charged with the prevention of waste, fostering and encouraging conservation of crude oil, gas, and bromine brine, protecting the rights of the owners of these commodities, and preventing contamination of streams and aquifers by hydrocarbons. To accomplish these goals, the Commission prescribes rules, regulations, and orders for appropriate spacing of wells, determines the most effective rate at which fluids can be removed (withdrawn), and takes other measures to ensure the most effective recovery of these nonrenewable resources.

During the time of discovery and development of the old and settled pools in Arkansas (a 16-year period), lack of knowledge about efficient production methods resulted in the recovery of only about 20 percent of the oil in the reservoirs. Science, as applied by the petroleum production engineer, the geologist, the geophysicist, and the chemist, as well as lessons learned from experience, has transformed production methods for newly discovered pools, and in some old ones, to a point where more than 70 percent of existing oil and as much as 90 percent of the natural gas (N. F. Williams, personal communication) in the reservoirs can be recovered.

Additional information concerning the basic principles involved with the conservation of oil and gas resources is contained in **Appendix A.**

ASPHALT

Asphalt is a brown to black high viscosity liquid or bitumen, having a low melting temperature, that consists almost entirely of carbon and hydrogen. Natural asphalts form in oil-bearing rocks by evaporation of the volatiles. Asphalt has a low specific gravity and burns with a bright, hot flame. Asphalt is used for road surfacing, as a filler for joints in concrete, as a dust preventive, for roofing and waterproofing, in the rubber industry, in asphalt-based paints, and in the manufacture of asphalt flooring tile.

Asphaltic sands and gravels are present in the Trinity Group (Cretaceous) in Pike and Howard Counties. Most deposits are very small, but may range up to 12 feet in thickness. Between 1900 and 1906, asphaltic sands were mined from open pits about 2.5 miles south of Pike in Pike County. Some 4,815 tons of asphaltic sand, valued at $22,368, was mined and shipped to Little Rock for use in street paving.

Essentially all asphalt now used in Arkansas consists of crude oil residues left over from the production of other petroleum products at refineries. None of the asphalt deposits in the state are presently being mined.

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WATER

GENERAL CHARACTERISTICS

Water (H_2O) is composed of the two elements, hydrogen and oxygen. Near and at the earth's surface, water exists in the liquid, gaseous, and solid states, all of which are odorless and colorless. Water vapor, the gaseous form, is a tremendously important component of the earth's atmosphere. The amount of water vapor in the air is measured as humidity. At temperatures between 32° and 212° F, water vapor can condense into tiny liquid droplets (20,000 in a cubic inch!) which, in turn, can accumulate in sufficient numbers to form clouds and fog. With further condensation, larger droplets form which fall to earth as rain. At atmospheric temperatures less than about 32° F, water, either in vapor or liquid form, solidifies (freezes) and may fall to the earth as snow, sleet, or hail. Rain and snow are the immediate source of most of the water presently in the world's streams, lakes, and oceans and in the uppermost part of it's crust. The original source for the water now present on our planet's surface is thought to have been derived early in the planet's evolution by a volcanic venting process called degassing, a process still active today wherever volcanoes erupt.

Because water exists in 3 physical states, it forms a continuous circulation pattern called the hydrologic or water cycle (fig. 24). The cycle is a conceptual model to explain the movement of water within and between 3 worldwide reservoirs – the atmosphere, the surface of the earth, and the earth's crust. Due to the geographic position of the state, Arkansas has abundant water resources. Arkansas' average precipitation is 49 inches per year, which is approximately 124 billion gallons per day (bgd). Rivers and streams flowing into the state add an additional 37 bgd as surface water. Of this amount, about 50 percent returns as vapor to the atmosphere, nearly 48 percent becomes surface runoff, much of it ending up in the Mississippi River, and about 2 percent is consumed in human activities. A very small amount actually soaks into the ground to become a part of the state's ground-water resources.

The quality, quantity, and use of water in Arkansas has been, and continues to be, studied by various state and federal agencies. Statistical and numerical information utilized in this discussion is derived primarily from articles by, and dialogues with, employees of the U. S. Geological Survey Water Resources Division.

WATER – ITS QUALITY AND ITS USE

Water is an integral component of all living matter, that is, all known forms of life are water-based. Our health, food sources, and economy – even our very civilization – depend on an abundance of **clean** water. The principal factor

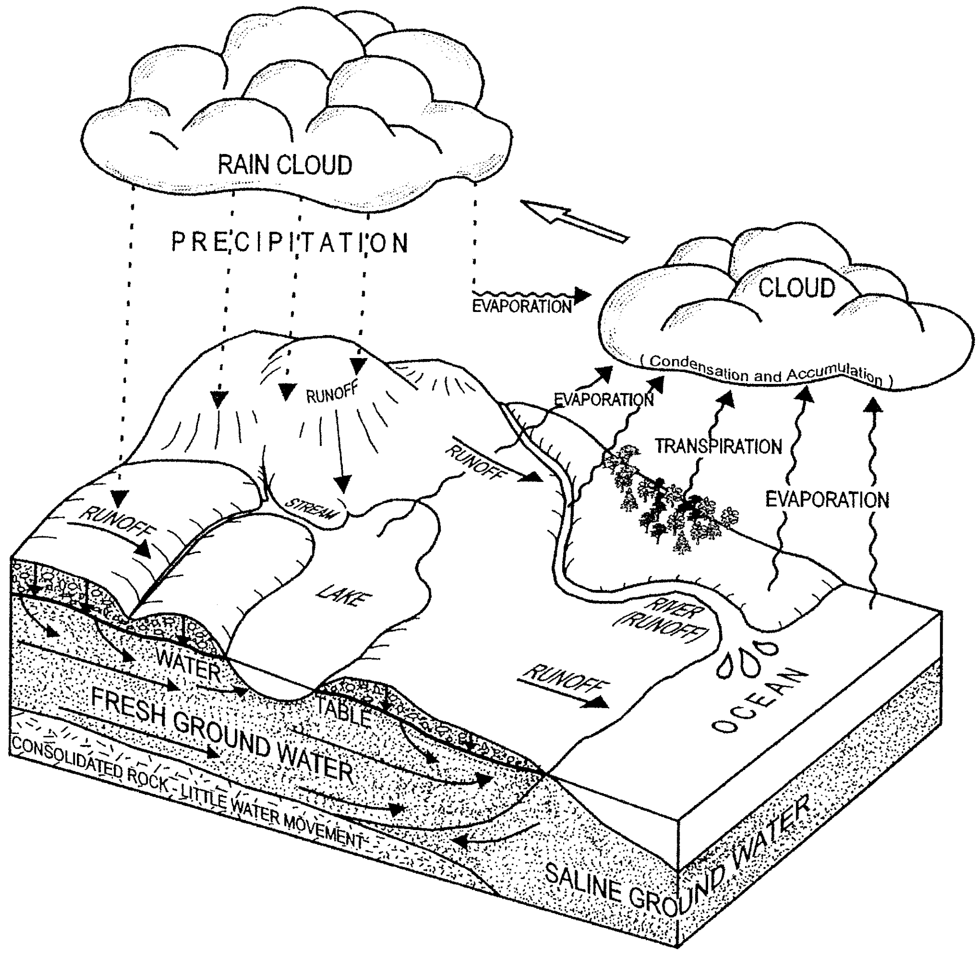


Figure 24. The water cycle. A schematic portrayal of the continual movement of water in the atmosphere, on the earth's surface, and beneath its surface.

that determines how we use water is its purity. Water suitable for industrial and agricultural purposes may be unusable for drinking and cooking because of impurities. Among the more common impurities are health-threatening bacteria, poisonous chemicals, and undesirable components such as iron, hydrogen sulfide, and salt (sodium chloride).

Water has been described as a "universal solvent". During the passage of rain through the earth's atmosphere, it picks up various solid particles (pollen, dust, and bacteria are examples). Atmospheric gases, especially oxygen, carbon dioxide, sulfur dioxide, and the oxides of nitrogen, are also soluble in water. Therefore, rainwater is naturally acidic. Once on the ground, water is capable of further dissolving a variety of organic and inorganic substances. Most of the elements of the chemist's Periodic Table are present in the earth's water. Even minute amounts of gold are detectable. Water also contains many dissolved gases and other fluids. The ability of water to dissolve so many substances makes it reasonable to consider it a universal solvent as suggested above. Pure (distilled) water is usually available to the public only by commercial processing of natural waters. No natural waters are truly pure from a chemical point of view, since they contain dissolved substances and solid particles.

Water used for domestic purposes is recognized by the average home dweller as a necessity and is noted as an example of the use of a nonrenewable resource on page 2 of this publication. However, few people have considered the many indirect ways in which water is used to satisfy our needs. Water is utilized to produce all of the construction materials composing your home and all of its contents. This includes everything made of metal, plastics, glass, synthetic and natural fibers, leather, ceramics, concrete, and even paper and much wood. The water may have been used in the extraction and processing of the raw materials or in their fabrication into the final products. Because the construction and manufacturing industries are major consumers of water, you as their customer are an indirect user of the same water.

The agricultural industry is also a major consumer of water. In Arkansas, vast amounts of water are used to irrigate crops and for watering livestock and raising poultry and fish. The food-processing industry also requires large volumes of water to prepare "raw food materials" for the market, and subsequently your consumption. Therefore, as a consumer of agricultural products, you are also an indirect user of that water.

Another consideration is the electricity we use and often take for granted. In Arkansas, much electric power is provided by thermoelectric plants (mostly coal-fired or nuclear-powered), which use water in the generation process (fig. 21). As a consumer of electric energy, you are again an indirect user of water. All of the applications of water listed above are considered as consumptive – at least in part – because the water used can not be returned to the environment in its original condition without treatment.

The remainder of the state's electric power is generated by hydroelectric plants along several major rivers. In a hydroelectric plant, water turns turbines which convert the energy of moving water into mechanical energy. Turbines turn generators, converting mechanical energy into electrical energy (electricity). The greatest single application of water in the state is for hydroelectric power generation – some 62 billion gallons per day. This is a non-consumptive application because the water that turns the turbines almost immediately reenters the river in its original condition. The estimated use of water in Arkansas for 1990*, excluding hydroelectric power generation, is presented in the following listing.

Use	percent
Irrigation	67
Thermoelectric power generation	21
Public supply	3.9
Commercial	2.8
Livestock (including fish)	2.4
Industrial (self-supplied)	2.3
Domestic	0.6
Mining	0.03

*adapted from Holland, 1993

We take advantage of water in two other important ways. Arkansas' larger rivers are used to transport bulk materials by barge and many of our rivers and lakes are used for various recreational activities. The attraction of Arkansas' surface waters to tourists provides a significant source of income to the state.

SURFACE WATER

Surface water is present as rivers, streams, swamps, wetlands, and natural and man-made lakes and impoundments. There are 5 major drainage basins within the state. The principal rivers in these drainage basins are the Mississippi – St. Francis, the White – Cache, the Arkansas, the Ouachita, and the Red. Some half million acres of Arkansas are covered by natural and man-made surface lakes (fig. 25).

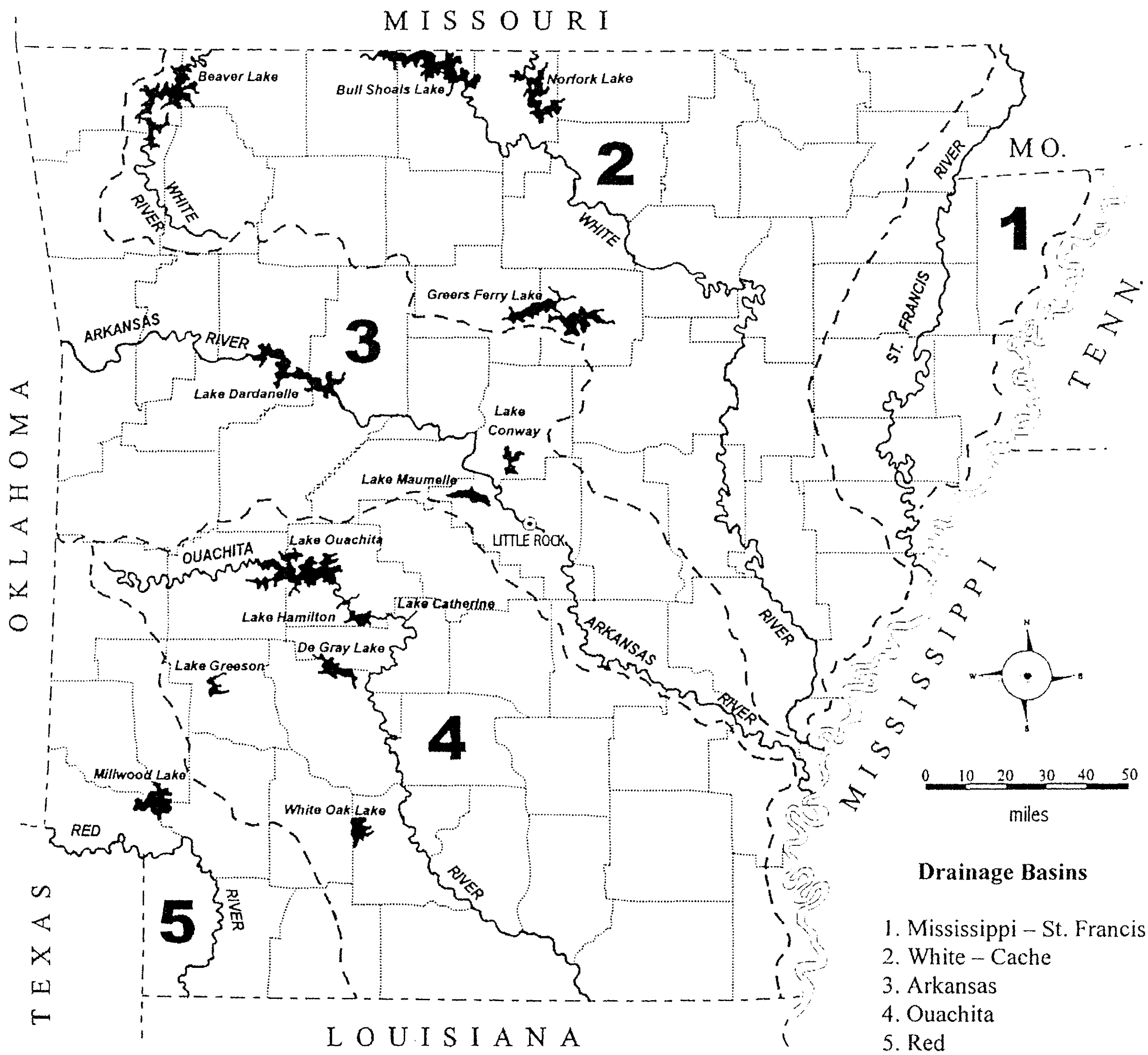


Figure 25. Arkansas' major rivers, larger publicly-owned lakes, and major drainage basins.

The Mississippi River, which has the greatest flow of any river in the United States, forms the eastern boundary of Arkansas with both Tennessee and Mississippi. As a waterway for barge traffic, it is a vital part of the nation's transportation system, but its water is seldom used for human consumption. Billions of dollars have been spent by the Federal government maintaining the river's navigation channels and attempting to control its waters during flooding.

The Arkansas River has the largest average daily flow of any river within the state (26.8 billion gallons per day). The quality of the Arkansas River's water as it enters the state near Fort Smith is relatively poor due to its high content of dissolved solids, primarily sodium chloride. During the river's passage through the state, the dissolved solids are diluted by the contributions of its tributaries. Although used in the past as a public water supply, the Arkansas River is presently not used as a municipal water source because better-quality water is now available from man-made reservoirs and lakes. The McClellan-Kerr Navigation System, a series of locks and dams on the Arkansas River, is essential to barge traffic and also provides some degree of flood control. Water from the Arkansas River is used as a coolant at the nuclear-powered thermoelectric plants near Russellville in Pope County and as a supplementary supply for heat-exchange ponds at the coal-fired electric-generation plant at Redfield in Jefferson County.

The White River drains the central Ozark Plateaus region, an area of some 27,765 square miles in northern Arkansas and southern Missouri. Dissolved solids in the water of the White River Basin are due largely to the presence of limestone and dolostone units that are exposed in much of that drainage basin. Acidic rainwater reacts with limestone and dolostone, the dissolved components being carried away by the drainage system. Major dams along the White River and its tributaries provide over 16 million acre-feet of storage capacity. An acre-foot is the volume of water that would cover an absolutely flat 1-acre area to a depth of 1 foot. The controlled release of this water is used to generate electricity. The water in the White River and its lakes is generally of excellent to superior quality in the Ozark region. Southward from Independence County, where the White River traverses the Mississippi River Alluvial Plain, its waters become more muddy, and communities resort to subsurface water supplies.

The Ouachita River, which originates in the Ouachita Mountain province, has generally good to superior water quality. Three man-made lakes on the Ouachita River in Garland and Hot Spring Counties have over 4.5 million acre-feet of storage capacity. The controlled release of this water is used to generate electricity. Where it traverses the Coastal Plain province, its quality, and that of some of its tributaries, is generally less suitable for human consumption. Near Smackover, north of El Dorado, oilfield brines from commercial oil-well operations of the 1920's and 1930's drained into the Ouachita River, causing the content of dissolved solids (primarily sodium chloride) to increase drastically. Corrective actions have largely resolved this problem in recent decades.

The Red River, which forms part of the southwestern boundary of Arkansas with Texas, carries a relatively high content of chloride leached from sedimentary rocks in its upstream reaches in Oklahoma. As in the Arkansas River, the dissolved solids are from natural sources.

Excluding the surface water used – but not consumed – for hydroelectric power generation, recreation, and transportation, Arkansans withdraw some 3.1 billion gallons per day from rivers and lakes. The larger population centers in the Arkansas Valley and the Ouachita Mountains account for a significant percentage. In these areas, shallow ground water is often too poor in quality for household use. The ridge- and valley-type topography of the region is well suited for constructing dams to provide reliable supplies of potable water for local communities.

The Gulf Coastal Plain is underlain by "soft" or unconsolidated Mesozoic, Cenozoic, and some Cretaceous sedimentary deposits. Being nonresistant, they are easily eroded, causing streams and rivers crossing the area to be cloudy owing to suspended particles of sediment and organic matter. In general, the surface waters of the Gulf Coastal Plain are of poorer quality than surface waters of the Interior Highlands. The relatively low relief of the region makes it impractical to construct large reservoirs. Fortunately, the area is underlain by several highly productive aquifers, and people living in this region of Arkansas are heavily dependent on ground-water resources. The major streams in eastern and southern Arkansas are an important source of water for wetlands used for wildlife conservation.

GROUND WATER

Water that fills the voids or open spaces between rock and mineral particles in soil or bedrock is called ground water (fig. 26). The boundary between the saturated zone below (where all the voids are filled with water) and the unsaturated zone above (where all voids are not water-filled) is called the water table. If ground water is present in a rock or sediment, its accessibility for human use is determined by two factors – porosity and permeability. Porosity is a measure of the volume of voids (pore space) in the body, and permeability is a measure of how easily water moves from pore to pore through the body. The first is dependent on the size and number of voids and the second on the degree to which the voids are interconnected. These two characteristics determine how much water is present and how rapidly it will move through the rock or sediment. Aquifers are those bodies of saturated rock or sediment that are sufficiently porous and permeable to yield significant quantities of ground water to wells and springs. The greater the porosity and permeability, the larger the volume of water which may pass into a well or flow from a spring. Well yield is measured in gallons per minute (GPM) during sustained periods of pumping. In earlier times, wells were dug by hand. As a consequence, the well was wider than a human body and only as deep as the first water-saturated zone encountered, because the well digger could go no farther. In the last half of the 19th century, various types of machine-driven drilling rigs were developed, allowing the construction of deeper wells capable of producing better-quality ground water and, frequently, having greater yields than shallow hand-dug types.

The highest-yielding, best-quality aquifers typically consist of highly porous and permeable sandstones, unconsolidated layers of sand and gravel, and beds or zones of highly fractured rock of any type. Impermeable rock units, called aquicludes or confining units, yield little or no water, and restrict the movement of water between aquifers. Such impermeable units are most commonly layers of shale or clay.

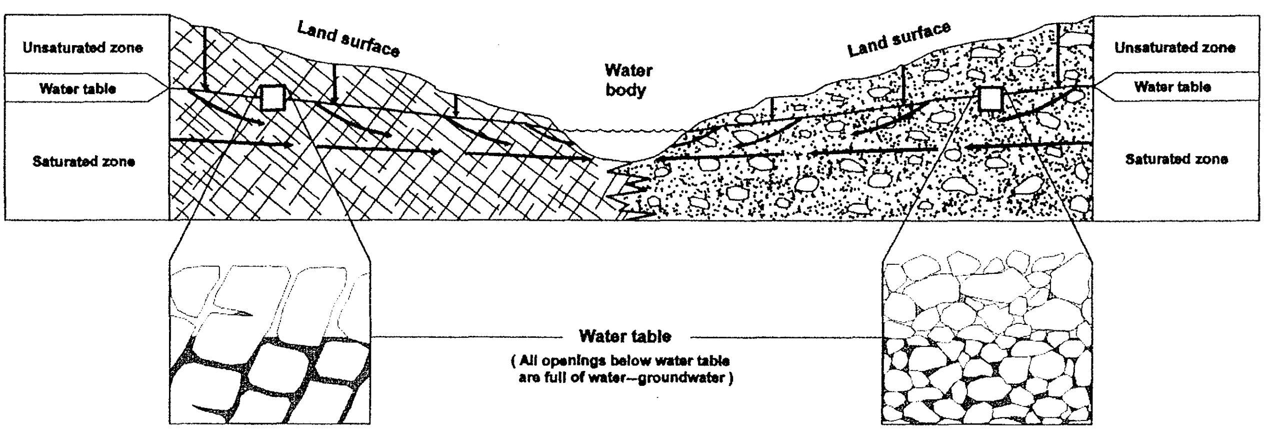


Figure 26. How groundwater occurs in rocks and sediments.

Most of the ground water consumed in Arkansas is for agricultural purposes in the Coastal Plain and along the wider parts of the Arkansas River Valley. Each year 3,000 to 4,000 new wells for domestic use, community supplies, crop irrigation, and commercial purposes are drilled in the state. Over the course of a year, an average of some 4.7 billion gallons of ground water is withdrawn from wells each day in Arkansas. Most of this, some 4.3 billion gallons on average, is used for irrigation. Withdrawals during the growing season, especially during a hot, dry period are much higher.

MAJOR AQUIFERS

A major portion of ground water used in Arkansas comes from Quaternary deposits of sand and gravel in the Mississippi River Embayment. Irrigation wells from 100 to 200 feet deep commonly yield as much as 1,000 to 2,000 gallons per minute (GPM). Although usable for irrigation and some domestic uses, the high iron content of Quaternary aquifers makes the water generally unsuitable for human consumption in many areas. The deeper Tertiary and Cretaceous aquifers which underlie the most of the Gulf Coastal Plain supply most domestic and municipal needs in this part of the state. Within each physiographic region, Arkansas' major aquifers (and their dominant uses) are:

GULF COASTAL PLAIN

Mississippi River Alluvial Plain
Alluvium (Quaternary)...................................... *irrigation*
Claiborne Group (Eocene),
Sparta/Memphis Sand....................................... *municipal*
Wilcox Group (Eocene).................................... *municipal*
Nacatoch Sand (Cretaceous).............................. *municipal*

(Continued next column)

West Gulf Coastal Plain
Claiborne Group (Eocene),
Cockfield.. *domestic*
Sparta*municipal*
Wilcox Group (Eocene) .... *domestic, municipal*
Nacatoch Sand (Cretaceous) .... *municipal*

INTERIOR HIGHLANDS

Ozark Plateaus
Boone (Mississippian), "Springfield aquifer" ..... *domestic*
Roubidoux (Ordovician), "Ozark aquifer" .... *municipal*
Gunter (Ordovician), "Ozark aquifer".............. *municipal*

Arkansas River Valley
Alluvium (Quaternary),
especially along the Arkansas River............... *irrigation*

Ouachita Mountains
Local quartz veins (late Paleozoic) .... *domestic*
Hot Springs Sandstone of the Stanley Shale
(Mississippian).. *domestic*
Arkansas Novaculite (Mississippian-Devonian) . *domestic*
Bigfork Chert (Ordovician)................................ *domestic*

The Cockfield Formation of Eocene age crops out in southeastern Arkansas. Southward from its outcrop belt in Chicot and Desha Counties, the Cockfield is the only source of serviceable ground water for communities in this part of the state. Locally, the formation ranges from 300 to 400 feet in depth and well yields range from 10 to 300 GPM.

Below the Cockfield are the very extensive sands of the Sparta/Memphis aquifer in the middle part of the Claiborne Group (Eocene). The name Sparta is used in southern Arkansas and Memphis in northeastern Arkansas. The top of this major aquifer typically occurs at depths of 200-500 feet, but in some wells water is obtained at depths in excess of 1,000 feet. Individual wells may yield as much as 1,200 GPM. Most communities in southern and eastern Arkansas use it as their principal water supply. Other deeper units that are also used for public supplies include the Wilcox (Eocene) and the Nacatoch (Late Cretaceous). However, because the Wilcox and Nacatoch aquifers are deeper, their waters may be too saline, limiting their usefulness in some areas.

In the Interior Highlands, ground-water supplies are more limited than in the Coastal Plain. Much of the Ozark Plateaus region is underlain by carbonate rocks, which are quite soluble in the presence of acidic water. Solution by ground water has caused many large openings through which water passes so quickly that contaminants from the surface can not be filtered out. Signs of these openings are caves, sink holes, springs, and lost stream segments. As a consequence, the water in shallow wells and many springs in this area of the state is generally considered unfit for human consumption without treatment. However, there are two important aquifers at greater depth – the Roubidoux Formation and the Gunter Member of the Gasconade Formation. Both are permeable sandstones of Ordovician age. These aquifers serve as the principal source of high-quality water for many communities in northern Arkansas.

Because of the predominance of shale in the surface and subsurface rocks of the Arkansas Valley and Ouachita Mountains regions, and the low porosity of many of the interbedded sandstones, few rock units qualify as aquifers. Because most wells yield less than 10 GPM, most communities must rely on surface-water supplies. Among the more favorable units in the Ouachita Mountains are the Hot Springs Sandstone Member of the Stanley Shale (Mississippian), the Arkansas Novaculite (Mississippian-Devonian), and the Bigfork Chert (Ordovician). Lacking appreciable intra-granular porosity, most of the available water in these units is confined to fractures, many of which are related to the geologic processes which formed the Ouachita Mountains. The fractures, which may be quartz-bearing, provide channelways for the movement of ground water, thereby providing a source for wells and springs in the region.

Springs

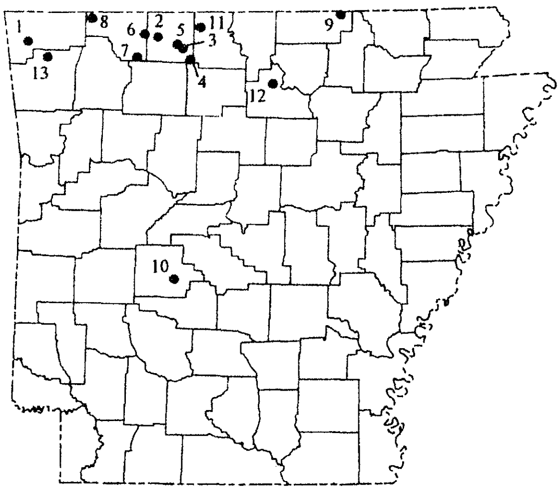
A spring is a place where ground water flows naturally from rock, sediment, or soil onto the land surface. Its presence depends on the nature and relationship of permeable and impermeable units, on the position of the water table, and on the topography. Springs are present throughout Arkansas and consist of two general types: perennial and seasonal. Perennial springs flow year-round whereas seasonal or "wet-weather" springs dry up periodically, especially during droughts or long periods of minimal rainfall. In Arkansas, these conditions often occur during late summer and early fall.

Most of the perennial springs in Arkansas with the largest flows are located in the Ozark Plateaus region. With an average flow of about 150,000 GPM, Mammoth Spring in Fulton County has the largest yield of any spring in the state. In the Ozarks, springs have historically been important community water sources. Most north Arkansas communities have now begun to abandon natural springs as water supplies because shallow springs are susceptible to surface contaminants.

Perennial springs in Arkansas are most common in the Ozark Plateaus and Ouachita Mountains physiographic provinces of the Interior Highlands (table 2). Most of the springs in the Ouachita Mountains are cold, reflecting shallow ground-water circulation. By convention, cold-water springs have a temperature less than about 80° F. However, there are areas of hot-water springs, such as those of Hot Springs National Park, where water temperatures average 143° F. The warm waters typically contain 175 to 200 ppm dissolved solids, primarily silica and calcium.

WATER CHALLENGES

Because of water's significance, any change or trend showing a decline in either the quantity or quality of the state's water resources is of major importance. The increasing demand for ground water in eastern and southern Arkansas is a matter of concern to many. Due to ever increasing rates of withdrawal, largely for irrigation, water levels in the Quaternary aquifer have been falling. The decline in water levels does not yet indicate an immediate shortage of water, but is the reason that wells must now be drilled deeper than before, therefore leading to greater drilling costs and increased pumping expense. Quaternary aquifer water levels are falling most rapidly in the Grand Prairie region, which includes parts of Prairie, Lonoke, Arkansas, and Jefferson Counties. Significant lowering of the water table has also taken place west of Crowley's Ridge in several counties farther north.



The location of the 13 major springs in Arkansas, listed in table 2.

Table 2. Major Springs in Arkansas, arranged alphabetically by county
[Data from U. S. Geological Survey. Rate of flow in gallons per minute (GPM)]

Spring Name	County	Rate of flow
1. Springtown	Benton	4,410
2. Bear Creek	Boone	1,400 - 2,500[1]
3. Unnamed[2]	Boone	1,778
4. Spring No. 20	Boone	1,212
5. Norvell	Boone	1,122
6. Reeves	Carroll	3,000
7. Verna Dodson	Carroll	1,200
8. Blue	Carroll	934 - 5,790[1]
9. Mammoth	Fulton	150,000
10. Hot Springs[3]	Garland	520 - 660[1]
11. Blackmon	Marion	1,000
12. Blanchard	Stone	1,000-103,000[1]
13. Zoo	Washington	1,818

[1]Range of measured flow rates. [2]Sec. 33, T.19N., R.19W. [3]Combined flow from a system of 47 hot springs.

The Sparta aquifer in southeastern Arkansas has undergone major declines in its water table owing to heavy municipal, industrial, and agricultural withdrawals. Most severely affected are Arkansas, Jefferson, Union, and Columbia Counties, especially near the larger cities in these counties. Locally, as in the vicinity of El Dorado in Union County, the decline in water level has exceeded 300 feet. As a result of the water-table declines, salt water has encroached in some areas where municipal wells are located, degrading the quality of the well water.

When ground water moves at a slow rate through sediments or rocks, most contaminants harmful or objectionable to humans are normally filtered out. This natural filtering process is not effective at the surface; consequently, surface waters are especially vulnerable to contamination. Elements and chemical compounds present in nature, man-made chemicals, human and animal wastes, disease-causing bacteria, and sediments due to erosion are among the most common sources of contamination affecting water quality. When water quality declines, so does its usefulness. Management and regulation practices, guided by common sense and supported by scientific data, wise land-use policies, and conservation efforts help preserve all our water resources.

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APPENDIX A

OIL AND GAS CONSERVATION PRACTICES IN ARKANSAS

Some of the world's most intensively engineered water-flood projects have been underway for many years in the oil fields of south Arkansas. It is anticipated that the current phase of this secondary recovery program will yield millions of additional barrels of oil.

Since 1917, the state has had rules and regulations concerning the drilling, casing, and plugging of wells to prevent the surface escape of oil, gas, or brines (formation water enriched in salt) into streams. However, little or no attention was paid to recovery practices prior to 1938. The present law not only takes into consideration proper production practices and the prevention of stream pollution, but provides that the oil pools of the state must be developed and exploited to obtain the maximum effective economic recovery of oil.

Conservation practices are controlled by several factors. Generally, an oil pool may be discovered in any subsurface rock formation capable of containing oil, gas, or some other fluid. In addition to having porosity, the formation(s) must also be so disposed structurally that the accumulation of oil and gas in volume is made possible. An overlying impervious layer of rock must also be present to prevent the escape of hydrocarbons.

Most of the hydrocarbon production in Arkansas is from limestone or sandstone reservoirs. The porosity of sandstone can be imagined as analogous to the open spaces between oranges when they are symmetrically grouped, and that of limestone as similar to the numerous openings in a sponge. Porosity is expressed as the percentage of void space in a rock. A porosity of 25 percent, for example, means that one fourth of the bulk volume occupied by the reservoir rock is open or void space.

Permeability is a measure of the ease in which fluids move or flow through a porous media. Since the resistance to flow is less through larger openings, a rock composed of large grains normally has greater permeability. The contents of an oil pool are always found to exist under pressure – usually the greater the depth, the greater the pressure. This pool or reservoir pressure is usually a result of the hydrostatic head of water in contact with the oil or gas.

Gas and water are often present in association with oil. When present, gas may be either dissolved in the oil or it may occur as free gas above the oil. As the amount of gas dissolved in the oil is proportionate to the pressure and temperature, deep pools have oil that is fully saturated with gas and, with any reduction of reservoir pressure, the gas comes out of solution and either occupies space above the oil in the reservoir or is produced with the oil. Gas in solution has desirable effects; the two most important of these are the lowering of the viscosity of the oil, rendering it more fluid or mobile, and the second is the reduction of the surface tension which makes the oil more slick or less sticky. Both of these effects prevent unnecessary retention of oil in the reservoir rock. Therefore, an oil pool should be operated to maintain the maximum amount of gas in solution.

The Arkansas Oil and Gas Commission recognizes that the source of energy by which oil is procured is of vital importance to every reservoir in the state. Many oil pools are abandoned, not because the oil has been exhausted, but because the gas necessary to move the oil has been exhausted, leaving behind "dead" oil with insufficient energy left to bring it into the well bore.

Oil movement through a rock formation to a bore-hole is caused by the pressure on the fluids (liquids and gases) in the oil-bearing formation. The pressure differential between the various parts of the reservoir and the well bore is a result of one of the following forces or a combination of them:

- Gravity (that force which tends to attract objects to the center of the earth) causes oil to trickle out of a saturated formation into the well bore to the bottom of the hole. From a practical standpoint, this force is negligible so far as moving an appreciable quantity of oil from a formation into the bore of a well.
- Water contained in the same strata or zone which is adjacent to an oil or gas deposit is called edge water. It exerts a pressure known as water drive, which varies with each individual pool from as little as a few pounds to more than 4,200 pounds per square inch. Where withdrawals of oil from a reservoir are greater than the encroachment of the edge water, the pressure of the reservoir decreases proportionally. Unless the edge-water pressure or water drive is substantially controlled by uniform spacing of wells and uniform withdrawals from a common reservoir, water-channeling and water-coning result in the trapping of oil and gas deposits which may never be recovered, thereby causing waste.
- The force of expanding gas, either in solution or in contact with oil, is one of the principal causes of oil movement through the formation. Laws require the Arkansas Oil and Gas Commission to establish an efficient gas-oil ratio for every oil

field of the state. These laws define waste as being, among other things, "the operation of any oil well, or wells, with an inefficient gas-oil ratio," the gas-oil ratio being the volume of gas, expressed in cubic feet, produced with each barrel of oil.

- In the absence of an active water drive, when the gas pressure in a formation has decreased to near atmospheric pressure, little differential pressure exists between the formation and the well bore. Recovery ceases, even though 50 to 80 percent of the oil may remain in the reservoir. So, where gas is permitted to escape without doing useful work, oil will be left unrecovered in the reservoir. An efficient gas-oil ratio tends to conserve this source of energy for bringing the oil to the well bore, so that greater amounts of oil are recovered.
- The correct spacing of oil and gas wells in a given pool is important in controlling the operating efficiency of the entire pool. With the advent of restricted withdrawals and the resultant curtailment of production, industry realized that the close spacing of wells as practiced in the past is unnecessary. In fact, many petroleum engineers are now convinced that by proper control of production, even with widely spaced wells, it is possible to recover a larger percentage of oil from the reservoir than in the past.
- In dry gas fields, as in the Arkoma basin, the spacing allocation is usually 640 acres (one section) to each well. Additional wells can be drilled to a different producing horizon in a given section, but only one well can produce from any one horizon in that section.

GLOSSARY

Three references were utilized as authoritative sources for the definitions in this glossary. All have been modified to suit the purposes of this publication.

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A

abrasive(s) a natural or artificial substance (or substances) suitable for grinding, cutting, scouring, or even polishing. Natural abrasives from Arkansas include diamond, novaculite, quartz sand, and tripoli.

aggregate As used here, any of several hard, inert, construction materials (such as sand, gravel, crushed stone, or other mineral material), or combinations thereof, used as variously sized filler material combined with binding materials (such as cement or asphalt) to form masses of man-made rock (concrete, "blacktop", or plaster). May also be used alone in certain applications, like railroad bed ballast and driveway filler.

alloy Said of a material composed of two or more metals, or of a metal and a nonmetal, combined so that they are dissolved in each other. Brass is an alloy of copper and zinc.

alluvial Pertaining to alluvium; that is, unconsolidated sediments such as clay, silt, sand, and gravel that have been deposited by running water.

anomaly A deviation from the accepted normal value or range; usually used to identify high and low values in geophysical data. When used with geochemical data or values due to radioactive decay, typically refers to unusually high values.

anticline A fold in layered rocks in which the older beds are in the center. The opposite of a syncline. If not grossly modified by erosion, anticlines arch upward, whereas synclines form the troughs between anticlines. Compare syncline.

B

bauxite A sedimentary rock composed of a mixture of aluminum-rich minerals. In Arkansas, the minerals are gibbsite and boehmite. It is the principal commercial source of aluminum and alumina (Al_2O_3).

bed A layer of rock or sediment whose properties make it distinct from the layers immediately above or below, and which is separated from them by more or less distinct boundaries. Beds typically range in thickness from less than 0.5 inch to several feet. See strata.

bedding The condition of occurring in beds or layers. It is visible to varying degrees in all sedimentary rocks and sediments in Arkansas. Remnant bedding may sometimes be seen in contact metamorphosed rocks in Arkansas.

binder Any material that holds particles together; a cementing agent.

bitumen A general term for natural, flammable, solid and semi-solid materials composed of hydrocarbons. Asphalts, asphaltites, and mineral waxes are examples.

breccia A coarse-grained clastic rock composed of angular and broken rock fragments 0.125 inch or more in diameter that are held together in a finer-grained matrix and that can be of any composition, origin, or mode of accumulation.

brine Seawater, including ancient seawater with an unusually high content of dissolved salts. Some of the brines in the oil and gas fields of southern Arkansas are a major source of the world's bromine supply.

British thermal unit (Btu) A measure of heat value; the amount of heat required to raise the temperature of 1 pound of water at its maximum density by 1 degree Fahrenheit.

C

cabochon A lapidary term for a highly polished unfaceted gem cut in a convex manner.

calcine To heat to a high temperature without fusing (melting) in order to drive off volatile matter. For example, calcite in limestone is calcined to drive off carbon dioxide (CO_2) leaving lime (CaO), the main ingredient in cement.

carbonate rocks A general term most commonly used to denote the sedimentary rocks, limestone and dolostone.

catalyst A substance that speeds up a chemical reaction which itself is not changed by the reaction. Catalysts are used in the recovery of many metals from their ores and for the manufacture of gasoline from oil or petroleum.

cave formation Any secondary mineral deposit that is formed in a cave by the action of water; synonymous with speleothem.

cement (geology) The chemically precipitated mineral material that binds grains of sediment together to form most sedimentary rock. See binder. (construction industry) A man-made material made variously with limestone, chalk, or marl together with shale or clay and the mineral gypsum. When sand and water are added, the mixture is termed mortar; when sand, gravel, or crushed stone, and water are added, the mixture is termed concrete.

chalk A soft pure variety of limestone, usually white, commonly composed of the shells of calcium-carbonate-secreting organisms.

chemical rock As used here, the term includes sedimentary rocks composed of shell fragments, evaporite deposits, and other rocks precipitated from solution, such as chert.

chert A weather-resistant chemical rock composed primarily of submicroscopic fibrous silica (the grain size is so small individual fibers cannot be seen with an optical microscope). In northern Arkansas, chert typically occurs in thin beds, lenses, or as smaller bodies in limestone and dolostone units. In the Ouachita Mountains, chert is present as thick sequences of thinly bedded units.

clastic Used here to describe a sediment or rock composed principally of grains or fragments that are derived from pre-existing rocks or minerals, providing those materials have been transported some distance from their place of origin as individual particles.

clay As used here, a sediment composed largely of extremely small (less than 0.0025 inch in diameter) particles of clay minerals. Many, but not all clays, exhibit plasticity when wet.

cleavage Said of the tendency of some rocks, whether sedimentary, igneous, or metamorphic, to split along closely spaced fractures or other planer surfaces caused by metamorphism or by intense structural deformation.

coke A combustible material consisting of the fused ash and fixed carbon of bituminous coal, produced by driving off the coal's volatile matter by heat; as a fuel it is practically smokeless.

combustible Said of substances and materials which can burn, giving off heat and light. Common examples are matches, wood, coal, natural gas, and gasoline.

concentrates The product of mining and ore processing which is retained for further processing after eliminating useless material. Typically, this may be a metal (or metal-bearing minerals) which have been separated from the enclosing rock after mining and before smelting.

concretion A collective term applied to various mineral segregations of diverse origins, usually having an internal structure. Often specifically applied to secondary spheroidal accumulations deposited by water passing through a sediment or rock. Compare to nodule.

condensate The liquid hydrocarbon that emanates from a gas well or from the gas cap of an oil well.

contact metamorphism Metamorphism adjacent to an igneous body. In contrast to regional metamorphism, contact metamorphism does not require significant depth of burial of the rocks that are being altered.

corrosion The eating away or destruction of the surfaces of metal objects by chemical processes. The rusting (or oxidation) of iron and many types of steel and the action of seawater on many metals are examples.

cryptocrystalline Said of the texture of a rock consisting of or having crystals too small to be recognized and separately distinguished using an ordinary optical microscope.

D

deltaic (environment) The conditions that exist in an area where a river empties into a body of water and deposits much of its sediment load. Such areas are typically flat, complexly channeled, and partly submerged. Deltas are formed due to the loss of the transporting energy of moving river water as it enters any standing body of water (ponds, lakes, oceans).

dendritic drainage A drainage form in which the streams diverge irregularly in all directions and at almost any angle, presenting a branching pattern. Contrast with trellis drainage.

density The average mass per unit volume.

dike As used here, a tabular or sheet-like body of once-molten rock that cuts across the bedding or other layering of the encasing rocks.

dip As used in structural geology, the inclination from the horizontal of any planer surface in or on a rock body measured perpendicular to a horizontal line drawn on the surface being measured. Normally measured in a downward direction. Only truly horizontal surfaces have no dip.

dolostone A sedimentary chemical rock consisting chiefly of the mineral dolomite. In northern Arkansas, where dolostone is abundant, it resembles limestone and is associated with limestone. Both these rocks are usually of marine origin.

ductile As used here in reference to metals, capable of being drawn out into wire or threads.

E

erosion Most simply, the wearing away and consequent lowering of the earth's surface by natural processes. More specifically, the mechanical destruction of the land and the removal of soil and rock material by running water (including rainfall), waves and currents, wind, or moving ice. Under some conditions erosion can occur on the sea floor.

erratic A relatively large rock fragment which has been transported, often over some considerable distance, from its place of origin.

evaporation The process by which a substance passes from the liquid to the vapor state; also, called vaporization. A key process in the earth's water cycle.

evaporite A generic term for a non-clastic (or chemical) rock composed of minerals deposited by the evaporation of a body of saline (salty) water. Rock salt and gypsum are examples.

extrusion A term used herein to indicate water-saturated masses of sand which were ejected onto the surface of the ground due to the shaking of the ground by earthquakes. The source of the sand was poorly packed water-saturated shallow sand beds. The fluid mass of sand moved upwards through fractures as sand dikes until, upon reaching the surface, they were deposited.

F

faceted A lapidary term describing the result of cutting small flat polished surfaces on gemstones to make them reflect more light and appear more brilliant. Compare with cabochon.

fault A fracture or break in a rock unit (or units) along which there has been discernible movement.

feedstock The rock, mineral, or fuel introduced into any equipment used during various stages in the processing of mineral resources. Lasca, which is a selected type of milky quartz used to grow synthetic quartz crystals, is an example.

fixed carbon The solid combustible material left after the moisture, volatile matter, and ash have been removed from coal and bituminous materials. It is expressed as a percentage of the weight of the original sample.

flood plain The flat nearly level land bordering a river channel. It is covered with river-borne sediments (alluvium) and is subject to flooding during high water.

fluvial environment (geology) The geologic and hydrologic conditions that exist along the channel and floodplains of streams and rivers, extending outward to the visible limits of erosion and deposition by flowing water. Compare with deltaic and marine environments.

fold mountains Elongate chains of mountains (mountain ranges) formed by compression within the earth's crust. They consist largely of rocks that accumulated as sediments on the sea floor. When subjected to compression, these sedimentary rocks were contorted by folding, disrupted by faulting, and forced upward to form mountains. The Ouachita Mountains are a notable example.

formation The basic unit in geology for mapping, describing, and interpreting the geology of an area. It is a body of rock that is distinguishable on the basis of its physical properties from other rocks in the area. To be mappable, it must be of suitable thickness and extent.

G

geophysical (methods) Those remote sensing methods used to measure the physical properties of rock materials in the earth's crust and interior in a quantitative manner. Among the properties are specific gravity, electrical conductivity, magnetic susceptibility, radioactivity, temperature and heat flow, and the propagation of earthquake waves.

glacial outwash Sedimentary debris removed or "washed out" from a glacier or ice sheet by meltwater and deposited downstream from the ice body.

gravel An accumulation of uncemented rounded rock fragments, most of which (by volume) are more than 0.083 inch in diameter. It includes granules, pebbles, cobbles, and boulders. Gravels most commonly accumulate along rivers and shorelines.

H

hydrocarbon An organic compound consisting of the elements hydrogen and carbon in many structural forms. Natural gases and crude oil, a complex mixture of hydrocarbons, are the most common examples.

hydrostatic head The height of a vertical column of water, the weight of which is equal to the hydrostatic pressure at any point.

hydrothermal Pertaining to heated water, to the action of heated water, or to the products of the action of heated water. Many minerals, including quartz, are formed by the action of hot aqueous solutions.

I

igneous Describing a rock or mineral that solidified from molten rock material (magma). Also, the processes related to the formation of such rocks and minerals.

in situ A Latin word, hence used in italics, meaning "in its natural or original position." Used here to describe mineral deposits that are seen where they were originally formed and have undergone little or no alteration since their formation.

interglacial Those intervals of time during the "Glacial Age", or the Pleistocene, when the world's ice sheets had retreated to approximately their present positions and the world's climate was approximately as warm as it is today.

intrusion The process by which molten rock material (magma) is emplaced into a pre-existing rock. Also the igneous body so formed.

L

lamproite A dark-colored igneous rock derived from below the earth's lithosphere. Present in Arkansas as both pipes and dikes. One of only two primary rock types known to contain diamonds, the other being kimberlite.

lapidary A person who cuts, grinds, engraves, and/or polishes stones and gemstones. Also the art of cutting or polishing stones.

lentil A minor rock-stratigraphic unit of limited geographic extent, being a subdivision of a formation.

limestone A general term for a sedimentary rock consisting largely of the mineral calcite. Limestones range widely in color, texture, and origin. In north Arkansas, limestones are of marine origin and are grouped with sedimentary rocks.

lithify To consolidate from a loose sediment to a solid rock. This term is most often used in the past tense (lithified).

loess A homogenous light- to dark-brown windblown sediment composed chiefly of silt-sized particles. Loess in Arkansas consists of fine-grained material winnowed from glacial outwash deposits by wind action and redeposited downwind in Pleistocene time.

long ton 2,240 pounds. By convention, many mineral commodities are measured in long tons. Compare to short ton.

lubricant Any substance with the ability to reduce friction between two surfaces. In geology, water is a common lubricant that facilitates the movement of rocks and sediments.

luster The quality and intensity of light reflected from the surface of a solid substance. With modifiers, it serves as a descriptive term used when describing the light reflected by a mineral. Luster can be described as metallic or nonmetallic.

M

magma Molten (melted) rock, including any contained mineral grains and dissolved gases, that forms when melting occurs below the earth's surface. Upon cooling and solidifying, it becomes igneous rock.

malleable Said of a mineral or metal that can be hammered or rolled into a thin sheet without fracturing or powdering. Gold, silver, and copper, either as native elements or refined metals, exhibit this property.

magmatic Pertaining to, or derived from magma.

mantle The thick shell of dense rock between the earth's crust and its core.

marine Pertaining to any aspect of the seas and oceans.

marl Used in many ways, but is most commonly applied to a sedimentary earthy matter consisting largely of intermixed calcium carbonate and clayey materials.

metal Any of various opaque, fusible, ductile, and typically high-luster substances that are good conductors of electricity and heat. A metal may consist of a single element (as pure silver or copper), two metals (as the alloy bronze), or more than two elements (as some steel alloys).

metallic Made of or containing a metal, or having some of the properties of metals.

metallurgical Pertaining to the science and technology of metals. Also, used when referring to specific types and grades of coal used in the manufacture and processing of steel.

metamorphic Broadly, relating to change or alteration. Specifically, applied to rocks whose former condition (composition or texture) has been altered as a result of changes in heat, pressure, or in the presence of chemically active fluids. Also applies to the processes involved in metamorphism.

metamorphism All changes in mineral assemblage or rock texture, or both, that take place in rocks in the solid state within the earth's crust as a result in any combination of changes in temperature, pressure, and chemically active fluids.

mineral A natural substance having a definable chemistry (usually given by a chemical formula) and an orderly arrangement of the atoms and/or molecules (crystallographic structure) that compose it. **ore mineral** (mining) Any inorganic substance that may be extracted from the earth for profit.

mineral deposit A concentration of naturally occurring mineral material, without regard to mode of origin, which may or may not have economic value.

mineralization Used loosely to describe the enrichment of one or more minerals in a rock; also the process or processes by which the minerals are introduced into a rock.

N

nodule (sedimentary) A small, hard, rounded body of mineral having a contrasting composition from and a greater hardness than the enclosing sediment or rock matrix. In sedimentary rocks, nodules are primarily the result of replacement after deposition of the host rock and are commonly oriented parallel to bedding.

novaculite A hard, brittle, fine-grained sedimentary rock composed almost entirely of microcrystalline quartz. Except for its texture under a microscope, it strongly resembles cryptocrystalline chert. Its composition and texture make it eminently suitable for the manufacture of whetstones.

O

octahedral (mineralogy) Refers to a regular geometric crystal form that has the appearance of two pyramids attached base to base. Magnetite, fluorite, and diamond commonly have this crystal form.

ore A natural material having mineral content of sufficient value as to quality and quantity for it to be mined profitably.

P

physiographic Relating to assemblages of land forms that make one area of the earth's surface distinct from surrounding areas.

pigment (geology) A substance that imparts color to rocks, minerals, sediments, and even ground water. (industry) Any substance that is used to impart color to a material or manufactured item.

pipe In geology, a vertical conduit through the Earth's crust below a volcano, through which magmatic materials have passed. It is usually filled with volcanic breccia and fragments of older rocks.

placer A body of sediment enriched in particles of valuable minerals. River gravel containing particles of gold or beach sand containing particles of ilmenite are examples.

plateau A broad, relatively high, but not necessarily level, area of land that stands above the surrounding country.

primary (mineral or rock) Used here to indicate a mineral or rock that formed by igneous or hydrothermal processes, or from gaseous emissions from igneous activity, and which retains its original composition and form. Compare with secondary.

propants (petroleum geology) Small particles or pellets of a hard material used to prop open artificially induced cracks in oil- or gas-bearing rocks. Their purpose is to increase the rate of flow of oil or gas into the bore hole.

province A large area or region, all parts of which are characterized by similar features or geologic history, making it distinct from surrounding areas.

R

radioactive (chemistry) A property of elements whose atoms spontaneously emit alpha, beta, or gamma rays as their nuclei disintegrate.

rank A term used to indicate the degree to which plant matter has been converted to coal. The lowest rank coal is lignite, intermediate rank coal is bituminous (coal), and the highest rank is anthracite.

red beds Sedimentary units deposited in a continental (nonmarine) environment that are predominantly red in color due to the presence of iron oxide, usually as a coating on mineral grains. At least 60 percent of the layered rock unit must be red before the term is appropriate.

refractory Said of a material that has a very high melting temperature. In industry, a heat-resistant material commonly made from bauxite, novaculite, or certain clays high in alumina and silica. In the form of bricks, these materials are used to line furnaces, tanks, and ovens where very high temperatures are required.

relief Differences in elevation. Contrast with topography.

reserves A calculated estimate within specified accuracy limits of the valuable metal or mineral content of known deposits that could be produced under current economic conditions and with present technology. Compare to resource.

reservoir rock In petroleum geology, any body of rock in the subsurface with sufficient porosity and permeability to permit the accumulation of crude oil or natural gas where a suitable trap is present. Sandstones and limestones are common reservoir rocks.

residual The material left in place by weathering of a rock body after other components of the original rock have been removed by erosion. Much of Arkansas' bauxite is residual.

resistant A relative term that is applied to rocks that withstand weathering and erosion in their present environment better than other rocks nearby.

resource As applied to any given rock or mineral, and to fossil fuels or ground water, it is the total amount of any one of these commodities known or inferred to be present in the earth's crust. A resource may be measured on a local, regional, or global basis. Compare to reserve.

riprap Large, broken rock fragments used to prevent erosion by covering or lining channelways, slopes, or other surfaces. Commonly used along river banks, irrigation channels, dam spillways, road embankments, and in seawalls.

rock A naturally formed stony material composed of one or more minerals.

S

sand dike A sedimentary dike consisting of sand that has been squeezed or injected upward into a fissure. Sand dikes often originate due to the compaction of water-saturated loosely packed sandy sediments during earthquakes. When the mobile sand masses reach the surface of the ground, they become sand extrusions.

sandstone A sedimentary rock composed mainly of sand-sized particles that have been cemented together to form a rock. To most geologists, sand grains range from 0.0025 to 0.083 inch in diameter.

secondary (mineralogy) A mineral formed later than the rock enclosing it and usually at the expense of an earlier-formed primary mineral, as the result of weathering or metamorphism. Smithsonite and malachite are secondary minerals formed by the weathering of the primary minerals – sphalerite and chalcopyrite, respectively.

sediment Particles of fragmental materials (inorganic and organic) that originated by weathering of rocks or by the death and decomposition of organisms, and which have been transported and deposited by water, wind, or ice. Also applies to materials, such as gypsum, that have accumulated by chemical precipitation from solution.

sedimentary Pertaining to sediments, that is, particles of rock material transported by or deposited by water, wind, or ice. Applies to unconsolidated and consolidated (cemented) materials; for examples, sand and sandstones and clay or mud and shales. The term also pertains to the processes involved.

shaft A vertical or steeply inclined man-made passage from the surface to underground mine workings used to haul equipment and the material being mined – or for ventilation. Also a vertical or nearly vertical natural passage in a cave.

shale A finely layered (laminated) sedimentary rock formed from clay, mud, and silt which tends to split into very thin plates or chips upon weathering.

short ton 2,000 pounds. Compare to long ton.

sill A tabular igneous intrusion that parallels the layering or bedding of the enclosing rocks. Contrast with dike.

siltstone A sedimentary rock composed mainly of silt-sized particles that have been cemented together to form a rock. Silt grains are smaller than the smallest sand grains, that is less than 0.0025 inch in diameter, and larger than typical clay particles.

specific gravity A number stating the ratio of the weight of a substance to the weight of an equal volume of pure water. On earth, this ratio value is equal to the substance's density when measured in grams per cubic centimeter.

strata The plural form of stratum. Layers of sediment or sedimentary rock that are distinct and visually separable from other layers above and below. Strata and beds are essentially synonymous. See bed, bedding.

strike (structural geology) The trend or direction of the intersection of a structural element, such as a bedding plane or fault trace, with a horizontal surface. Given in a compass direction, such as north 30 ^{0} east.

strip mine (open-pit mine) A shallow surface mine where the topsoil and other material is removed to expose the rock or coal to be mined. After the mineral or rock is mined, operators are now required to place the unused material back into the excavation, grade it, replace the original topsoil, and establish a cover of vegetation, all according to previously agreed upon specifications.

stripping An informal term for the process of removing overburden in an open-cut mine.

subsurface As most commonly used, it applies to any material or condition below the ground's surface.

surface tension A property of liquids, such as water, which causes their outer surface to contract to the smallest surface area possible. It is why a needle will float on water, even though steel is denser than that liquid. Surface tension is the property that causes soap bubbles to become spherical when they are floating in air.

syenite A crystalline igneous rock which looks much like granite texturally, but which lacks quartz.

syncline In structural geology, a fold in which the younger beds or strata are in the center and are concave upward, except when the fold has been overturned by extreme deformation. Compare with anticline.

synthetic Any substance or material artificially produced by humans. The material nylon, made largely from a derivative of coal or petroleum, is a synthetic as are all of our so called "plastics", many of which are made partly or entirely from petroleum. Many synthetic gemstones, such as ruby, emerald, and alexanderite are now manufactured. Synthetic quartz is used for electronic applications. Large quantities of synthetic diamond are made in this country for abrasives.

T

talus The angular rock fragments that accumulate at the base of a cliff or very steep rocky slope. Also the entire outward-sloping mass or apron of such material, when considered as a unit.

topography The 3-dimensional shape or configuration of any part of the earth's surface. This is shown most frequently by topographic maps, which depict by means of contour lines the elevation above sea level of all points in the map area.

translucent A property of some matter which allows light to pass through, but which diffuses the light so that objects on the other side of the material can not be seen clearly, if at all. Compare with transparent.

transparent A property of some matter which allows light to pass through with so little diffusion that objects on the other side of the material can be seen clearly; common window glass is a prime example.

transpiration A process by which water in vapor form is given off to the atmosphere by plants.

trellis drainage Describes a drainage pattern characterized by parallel main streams or rivers intersected at nearly right angles by their tributaries, which in turn are intersected by smaller branches trending parallel to the main streams. Common in mountains formed by folding, like the Ouachita Mountains. Contrast with dendritic drainage.

tuff A compacted clastic rock composed of ash and dust materials fragmented by volcanic explosion. Any rock consisting of more than 50 percent (by volume) of clastic material derived in such a manner. The rock is described as tuffaceous if it contains significant amounts, but less than 50 percent, of tuff.

U

unconsolidated Used here to describe loose particles of rock material that are not cemented together by natural processes. In this sense, unconsolidated rock material is synonymous with sediment.

V

vapor (chemistry) The name given to gaseous moleculesof a substance at a temperature and pressure that would normally lead us to think of the substance as a liquid or solid. Usually these molecules are diffused into other gases, such as air. Clouds, steam, and fog consist of water vapor.

vein A thin, sheet-like body deposited, usually by mineralized water, into a host rock of any type. Hydrothermal quartz veins filling fractures in sedimentary rocks are common in the Ouachita Mountains.

viscosity The property of a substance, usually a liquid, to offer internal resistance to flow. At room temperature, honey has a higher viscosity than water.

volatile Refers to a substance that evaporates readily at a relatively low temperature.

W

weathering The destructive processes which causes rocks and minerals to disintegrate physically and decompose chemically when exposed to atmospheric and biologic agents at or near the earth's surface. The result is an *in situ* accumulation of rock debris, which, when transported by natural processes, becomes sediment.

THE DIVISIONS OF GEOLOGIC TIME USED IN THIS REPORT

Drawn to scale except for the Quaternary Period, which is too short an interval of time to be shown at this scale. Ages of boundaries from Palmer (1983)

ERA	PERIOD		EPOCH	ESTIMATED AGES OF BOUNDARIES IN MILLIONS OF YEARS BEFORE THE PRESENT
CENOZOIC	Quaternary		Holocene	.01
			Pleistocene	1.6
	Tertiary	Neogene Subperiod	Pliocene	5.3
			Miocene	23.7
		Paleogene Subperiod	Oligocene	36.6
			Eocene	57.8
			Paleocene	66.4
MESOZOIC	Cretaceous		Late	97.5
			Early	144
	Triassic		Late	163
			Middle	187
			Early	208
	Jurassic		Late	230
			Middle	240
			Early	245
PALEOZOIC	Permian		Late	258
			Early	286
	Carboniferous	Pennsylvanian	Late	?
			Middle	?
			Early	320
		Mississippian	Late	?
			Early	360
	Devonian		Late	374
			Middle	387
			Early	408
	Silurian		Late	421
			Early	438
	Ordovician		Late	458
			Middle	478
			Early	505
	Cambrian		Late	523
			Middle	540
			Early	570
Precambrian, undivided (Names of subdivisions rarely used in Arkansas)				
Formation of Planet Earth				4,600

MAJOR EVENTS IN LIFE ON EARTH
<u>*as recorded in the geologic record*</u>

Quaternary	First humans
Tertiary	First horses
Cretaceous	First flowering plants; at the end, extinction of dinosaurs and many other life forms
Jurassic	First birds, first mammals, and first dinosaurs
Permian	At the end, 95% of marine life becomes extinct
Pennsylvanian	First reptiles
Devonian	First amphibians
Silurian	First spiders
Ordovician	First land plants
Cambrian	First fish and trilobites
Precambrian	First multicellular organisms Oldest known fossils

------Formation of Planet Earth-----

ABOUT ARKANSAS, DID YOU KNOW....?

GEOGRAPHY

- Area – 53,182 square miles, making Arkansas larger than half of the world's 189 countries
- Highest area – 2,753 feet above sea level (Magazine Mountain)
- Lowest elevation – 54 feet above sea level (Ouachita River at Arkansas/Louisiana state line)
- Owing to an abundance of ***water***, 18 percent of the state (by area) is irrigated land.
- Navigable length of major rivers: *Arkansas River – 308 miles, Ouachita River – 128 miles, Mississippi River – 321 miles,* and *White River – 255 miles*

GENERAL GEOLOGY

- Oldest known mapped geologic formation (Collier Shale) about 520,000,000 years
- Oldest known surface rock (an altered igneous body, Saline County) about 1,025,000,000 years
- Six most abundant sediments – ***sand, clay, silt, gravel, marl,*** and ***chalk***
- Most abundant sedimentary rocks – ***shale***, ***sandstone***, ***dolostone***, ***limestone***, and ***chert***
- Most abundant igneous rock– ***syenite*** (resembles granite, but rarely contains quartz)
- In recent years, an average of 44 earthquakes a year, occurred in Arkansas. However, from Jan. 12, 1982 to Jan. 12, 1983, a swarm of nearly 20,000 small earthquakes occurred in Faulkner county.
- Fourteen meteorites are known from around Arkansas.

MINERALS & FOSSIL FUELS

- Arkansas: had the 1st ***diamond mine*** in the United States, is the only place where you can find (and keep) a diamond, and led the nation in the recovery of diamonds for over 50 years.
- The two largest ***diamonds*** discovered in North America came from Arkansas.
- There are no known commercial deposits of ***gold*** in Arkansas.
- Arkansas led the nation in the production of ***barite*** for over 30 years.
- Arkansas' annual value of mineral and fossil-fuel production is more than $1,000,000,000.
- Arkansas' 5 most valuable non-fuel mineral resources, based on annual production, are: ***bromine***, ***crushed stone***, ***sand/gravel***, ***clays***, and ***limestone***.
- Three fossil fuels – ***natural gas***, ***oil***, and ***coal*** – are produced in Arkansas today.
- Huge reserves of another fossil fuel – ***lignite*** – are essentially untouched.
- As of 1993, there were about 223 oil and 100 gas fields producing in Arkansas.
- In 1993, about 10,600,000 barrels of ***oil*** were produced in Arkansas – about 29,000 barrels per day.
- Deepest well ever drilled in Arkansas – 20,661 feet (a test well for ***gas/oil*** in Yell County)
- Rocks and minerals currently produced/recovered in Arkansas:

Bauxite	***Dolostone***	***Gypsum***	***Quartz***	***Soapstone***	***Tripoli***
Cement rock	***Gemstones***	***Limestone***	***Sandstone***	***Sulfur***	***Tuff***
Clays	***Glass/industrial sand***	***Novaculite***	***Slate***	***Syenite***	

- Annually, 39 percent of the world's ***bromine*** is produced in Arkansas.
- More ***bauxite*** has been mined in Arkansas than in all other states combined.
- More ***vanadium*** ore has been mined in Arkansas than in all other states combined.
- Among the 50 states, Arkansas currently ranks (as of 1996):

  1st in the production of ***bromine brine***
  1st in the production of ***quartz crystal*** and ***lasca***
  1st in the production of ***novaculite*** and ***silica stone***
  2nd in the recovery of ***diamonds***
  3rd in the production of ***tripoli***
  4th in the production of ***kaolin*** and ***fire clays***
  9th in the production of ***gypsum***
  9th in the production of ***common clays***

Arkansas Geological Commission, 1997