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CRITICAL MINERALS OF ARKANSAS

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CRITICAL MINERALS OF ARKANSAS

By

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INTRODUCTION

In 2018, as part of a national initiative to reduce reliance on foreign imports of mineral species considered critical to the security and economic prosperity of our country, the U.S. Department of the Interior identified 35 critical minerals of which a significant portion are currently sourced from other countries.

This publication focuses on the 15 critical minerals found within the borders of Arkansas: Aluminum (Al), Antimony (Sb), Barite ($BaSO_4$), Cobalt (Co), Gallium (Ga), Lithium (Li), Manganese (Mn), Niobium (Nb), Rare Earth Elements (REEs), Strontium (Sr), Tantalum (Ta), Thorium (Th), Titanium (Ti), Uranium (U), and Vanadium (V).

Some of these minerals have a history of production in the state while others have been identified via exploration and research. An appendix lists site locations of critical minerals within the state.

REGIONS OF INTEREST

Varying concentrations of these critical minerals are present in each of the physiographic provinces of the state (Figure 1). There are two areas of special interest within the Ouachita Mountains Province, Magnet Cove and Potash Sulphur Spring igneous complexes. Though small in area, their unique geologic setting and diverse mineral assemblages necessitate separate discussion below.

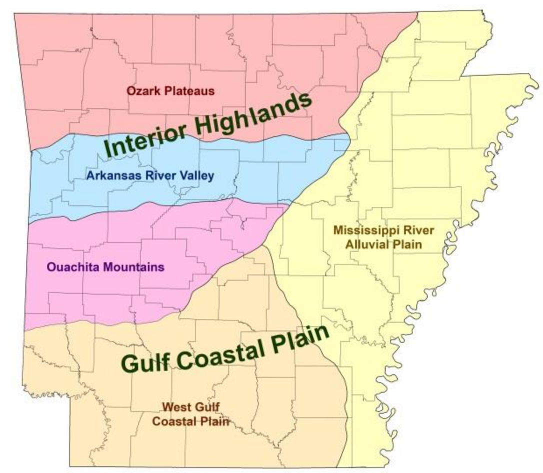

Figure 1 - Physiographic Provinces of Arkansas

Ozark Plateaus

Manganese and accompanying cobalt are of interest in the Ozarks. The historic area of manganese production in and around Batesville was in production for over 100 years before ending in 1959. Cobalt is commonly found in conjunction with manganese deposits in this area. Phosphates present in the Ozarks are also of interest for their potential to include REEs.

Arkansas River Valley

The primary minerals of interest in the Arkansas River Valley region are titanium and lithium. Titanium is present in river sand and has a brief history of production. Lithium is concentrated in quartz veins found on the southern edge of the region within the minerals cookeite, tainiolite, and lithiophorite.

Mississippi River Alluvial Plain

As in the Arkansas River Valley, titanium is present in sand along the White River.

Ouachita Mountains

The mineralization in the Ouachita Mountains Province is prolific and diverse due in part to the unique geologic settings found at the Magnet Cove and Potash Sulphur Springs focus areas, which are described separately below. Additionally, manganese deposits include cobalt potential and barite was mined in this region until the middle 1980s. Antimony is present on the southern boundary of the Ouachitas and bismuth has been identified in conjunction with these deposits. Antimony in the form of stibnite and stibiconite was mined up until 1947. Lithium within the minerals cookeite, tainiolite, and lithiophorite is concentrated in quartz veins in this area.

Magnet Cove

The Magnet Cove ring-dike igneous complex is well known for its mineralogic diversity. More than 100 different minerals have been identified in the approximately 5-square-mile intrusion. Barite and vanadium were mined on the northeastern edge of the intrusion. Several areas of historic titanium mining exist within Magnet Cove. Niobium has been identified in conjunction with the titanium mineralization. Thorium was identified within the igneous rock. Lithium and REEs are also associated with the alkalic igneous rock and surrounding quartz veins.

Potash Sulphur Springs

Smaller but mineralogically similar to Magnet Cove, Potash Sulphur Springs igneous complex contains many of the same critical minerals. There is historic production of vanadium and titanium in the area. Lithium-bearing minerals are found in surrounding quartz veins and niobium is associated with titanium deposits. Studies in the 1950s identified the presence of uranium.

West Gulf Coastal Plain

In the West Gulf Coastal Plain critical minerals of interest include barite, strontium, uranium, and REEs. Strontium in the form of celestite is well known and has a very brief history of mining in this region. Barite has a production history in this region. The presence of uranium in Pike County was discovered in the 1950s. Alkalic syenite intrusions and bauxite deposits weathered from these intrusions contain aluminum, titanium, gallium, niobium, and tantalum. The potential for REEs exists in conjunction with a subsurface alkalic intrusion near Rison.

METALLIC

Aluminum (Al)

Bauxite was mined for aluminum from 1898 – 1990 in Saline and Pulaski Counties (Figure 2). The primary aluminum-bearing minerals are gibbsite and boehmite mined from blanket and sheet deposits (Bramlett, 1936). The highest yearly production was over 6 million tons in 1943 (Malamphy, 1948). See Figure 4 for a graph of production information.

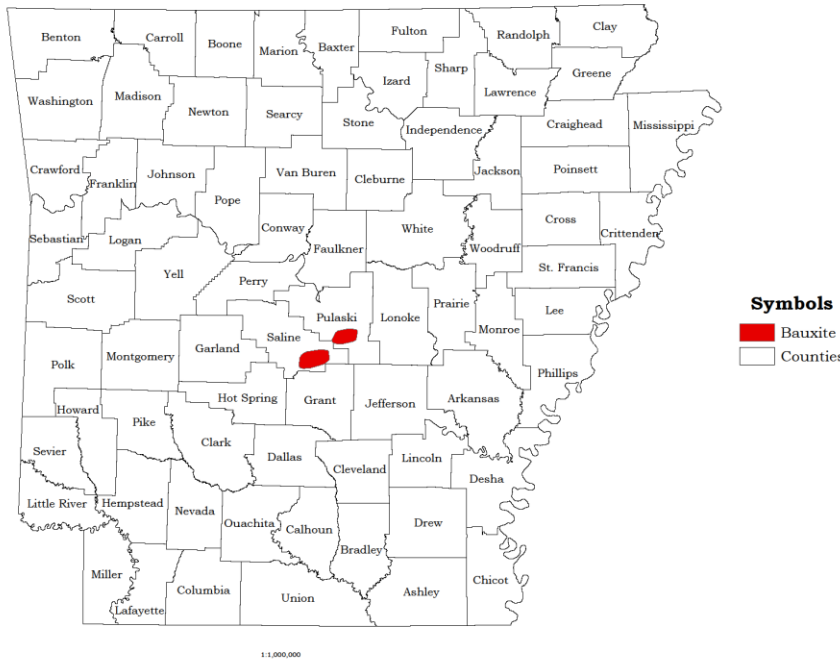

Figure 2 - Map of Aluminum Localities

The majority of mining was done using surface techniques, but during the second World War underground production methods were also employed. By-products include gallium, titanium, and niobium (Goldschmidt, 1937) with gallium being the only one produced, in production from 1947 to 1983. In 1954, the U.S. Bureau of Mines estimated there to be 150 million pounds of niobium metal within mine waste fines and the bauxite deposits (Gordon, 1958).

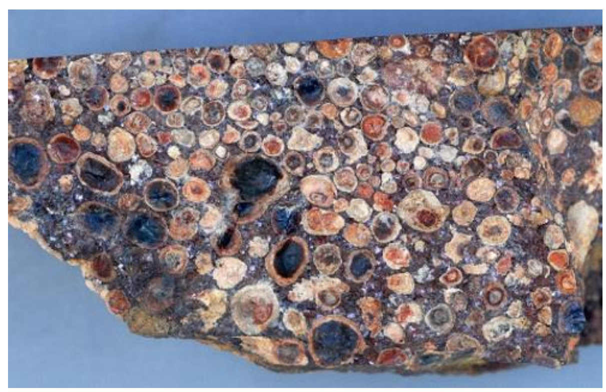

Figure 3 - Image of Bauxite Sample

In Pulaski and Saline counties 33 bauxite mine sites are listed as reclaimed or abandoned. Deposits in Pulaski and Saline counties cover about 275 square miles (Gordon, 1952). Presently, deposits in Saline County are mined intermittently for aluminum oxide used in the proppant industry.

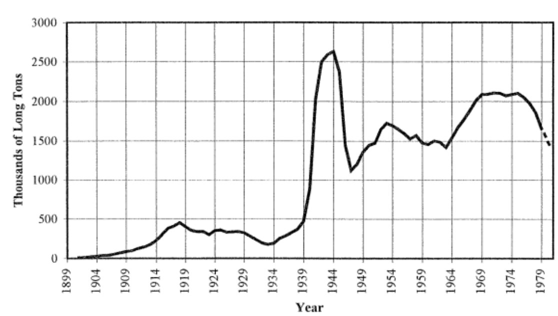

Figure 4 - Bauxite Production in Arkansas 1899 to 1981

Antimony (Sb)

Stibnite and stibiconite (Figure 6) were mined from 1873-1947 in Sevier County (Hall, 1940) (Figure 5). Ore is present in hydrothermal quartz veins (Stearn, 1935) in association with copper, iron, zinc, and bismuth (Pittenger, 1974). Potential resource estimated by the U.S. Bureau of Mines is 5000 tons of concentrates (Hess, 1908).

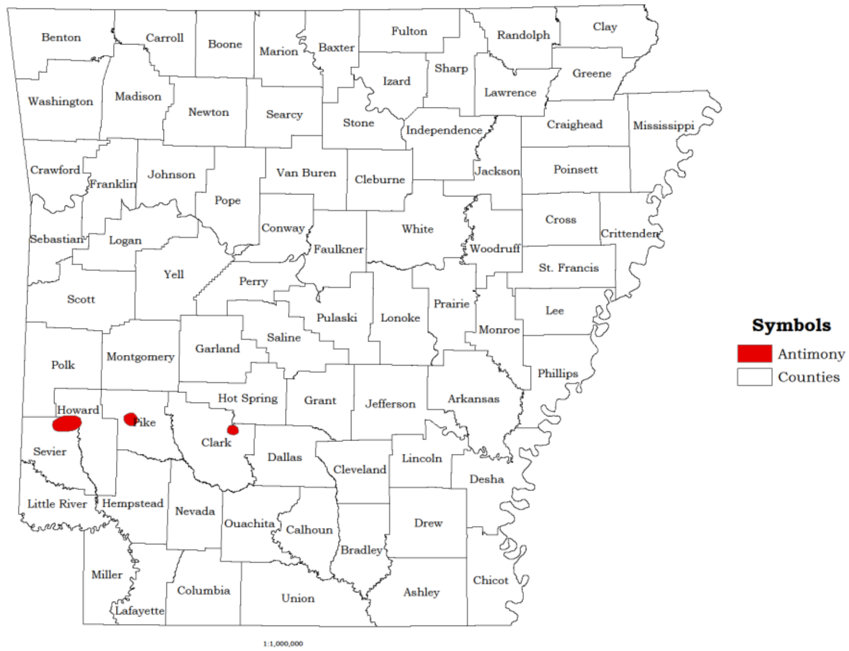

Figure 5 - Map of Antimony Localities

Production through 1947 was 5390 tons of concentrates. There are 27 abandoned mine and prospect sites reported, one of which has a shaft. Antimony is also associated with cinnabar deposits in Howard and Clark counties (Howard, 1979).

Figure 6 - Image of Stibnite Sample

Cobalt (Co)

Cobalt is associated with manganese-bearing sites in Polk and Montgomery counties (see Figure 9). In 1983, analysis of 140 samples by the U.S. Bureau of Mines found that concentrations of cobalt ranged from 0.05 to 1.2% in combination with copper, lithium, and nickel in 40% of the deposit samples. Cobalt is concentrated in lithiophorite. Resource estimates range from 1 million to 6.4 million tons (O'Connor, 1992).

Gallium (Ga)

Gallium is a by-product of bauxite mining (Gordon, 1952). It was produced from 1947 to 1983. The average gallium content of the bauxite is 0.0086% or 2.75 oz/ton (Gordon, 1958).

Lithium (Li)

Lithium is present in two physiographic provinces of Arkansas (Figure 7). It is in the bromine-rich brine from wells in the Upper Jurassic Smackover Formation in the Gulf Coastal Plain of south Arkansas (Collins, 1974). The resource area in south Arkansas includes Union, Columbia, Miller, Lafayette, and Ouachita counties. The second region is in the Ouachita Mountains (Stone, 1976) where lithium is included in alkaline igneous rocks and quartz veins associated with the Magnet Cove igneous complex (Miser, 1938).

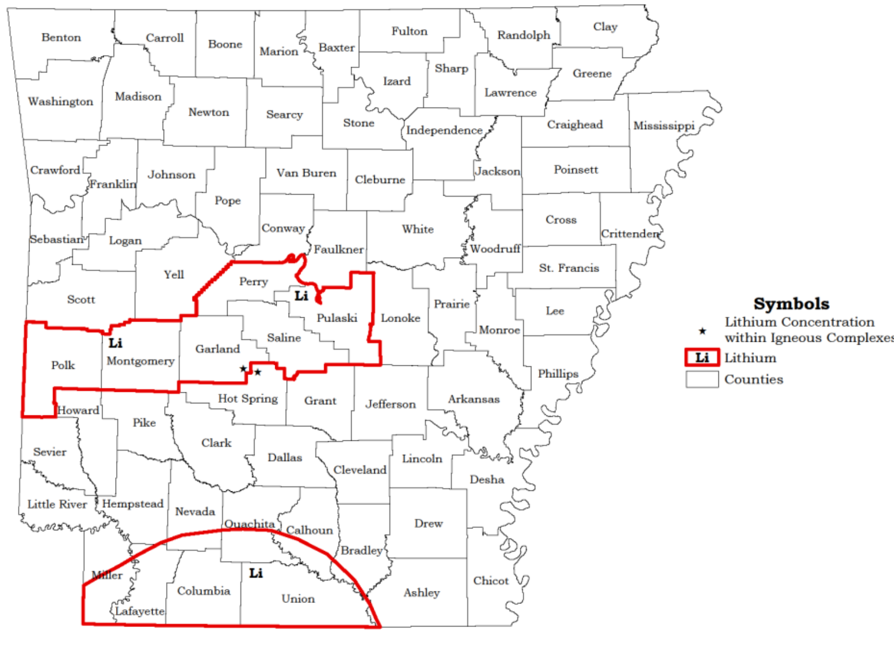

Figure 7 - Map of Lithium Localities

Lithium in quartz veins has been noted in Polk, Montgomery, Garland, Perry, Saline, Hot Spring, and Pulaski counties. The primary lithium-bearing minerals present in the quartz veins are cookeite (Figure 8), tainiolite, and lithiophorite. Very little exploration has taken place for lithium in this province outside the Magnet Cove area.

The resource present in the Gulf Coastal Plain is presently under production. One company's plant has a production rate of 20 tons of lithium carbonate/year and another is building a pilot plant to test extraction techniques. When this unit comes on line, production is expected to double current production values. The brine from the Smackover Formation contains up to 445 parts per million of lithium. The U.S. Geological Survey estimates there is 500 million tons of lithium in the brine of south Arkansas.

Figure 8 - Image of Quartz with Cookeite

Manganese (Mn)

Manganese is present in two physiographic provinces in the state, the Ozark Plateaus and the Ouachita Mountains (Figure 9).

The majority of historic mining was centered in the Ozarks in the Batesville District, an area of about 100 square miles in northern Independence County, southern Izard County, and southeastern Stone County (Stroud, 1981). About 98% of the manganese mined in the state came from this area.

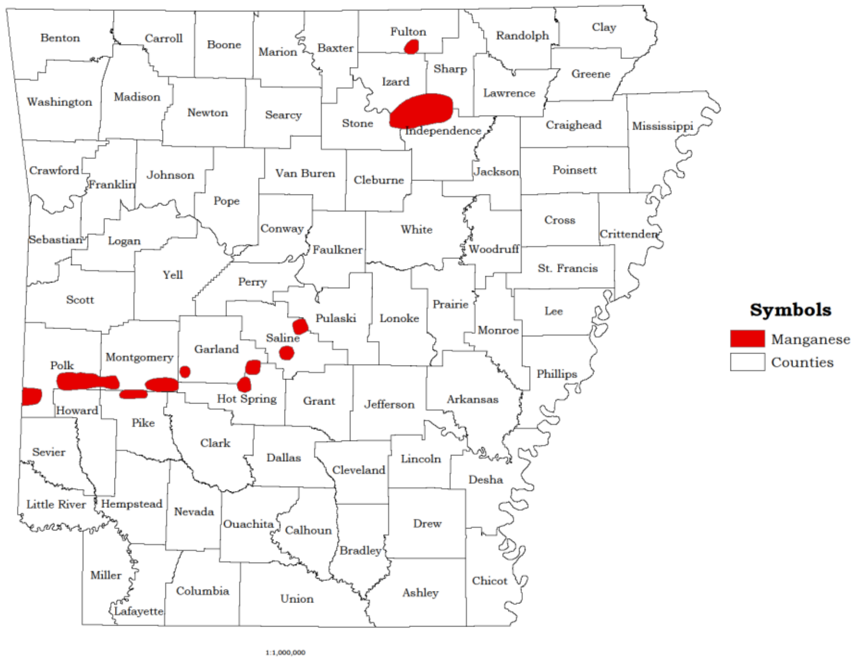

Figure 9 - Map of Manganese Localities

In the Ouachitas this resource has been noted in Pulaski, Saline, Hot Spring, Garland, Pike, Montgomery, and Polk counties, although mining was confined to Polk and Montgomery counties. The Batesville District ore deposits are classified into 4 main types: manganiferous limestone, in situ clay, clay-talus residuum, and placer. They are typically present in the Upper Ordovician Fernvale and Cason Formations. The Batesville District deposits were worked from 1847 to 1959. During 1956 more than 29,000 tons of manganese ore (Figure 10) were extracted. The U.S. Bureau of Mines resource estimates for this district are 200 million tons of ore containing 4 to 9 % manganese in the ground.

In the Ouachita Mountains, the Arkansas Novaculite, of Devonian - Early Mississippian age, and Stanley Formation, of Mississippian age, host manganese-oxides in veins and breccia associated with fracture zones measuring from fractions of an inch to more than 10 feet in width (Miser, 1922). Production was recorded in the early 20th century from surface and subsurface mines in the Ouachitas.

Cobalt may be a byproduct if manganese production were resumed in Polk and Montgomery counties. All mining of manganese stopped when the federal stockpile program ended in 1959.

The Batesville District is included in the Earth Mapping Resources Initiative Phase One mapping program, part of a recent effort by the USGS to learn more about the availability and extent of rare earth elements in the upper Ordovician units.

Figure 10 - Image of Manganese Ore

Niobium (Nb)

Arkansas has three areas of mineralization for niobium: Magnet Cove in Hot Spring County, Potash Sulphur Springs in Garland County (Fryklund, 1954) (see Figure 11), and the bauxite deposits in Saline and Pulaski counties (Gordon, 1952). At Magnet Cove and Potash Sulphur Springs, niobium is associated with the alkaline igneous intrusions and zones of contact metamorphism (Erickson, 1963).

In Pulaski and Saline counties, it is associated with the titanium-bearing minerals in bauxite deposits. In the Magnet Cove area, there are substantial deposits of titanium-bearing minerals such as rutile, brookite, and perovskite. Crystals of the rutile and brookite average 2% niobium with a maximum of 5%. Perovskite may contain up to 9% niobium.

The U.S. Bureau of Mines estimated that 12 million pounds of niobium are contained in the rutile-brookite deposits at Magnet Cove (Neiberlein, 1954). The niobium at Potash Sulphur Springs is present in the mineral pyrochlore. Soil samples from this site contain up to 0.9% niobium. Arkansas' bauxite deposits are reported to contain niobium values from 0.02 to 0.1% and average 0.05%. In 1954 the U.S. Bureau of Mines estimated that the bauxite deposits and waste fines contain up to 150 million pounds of niobium metal. Niobium could also be recovered as a by-product of bauxite processing.

Rare Earth Elements (REEs)

This is a group of elements consisting of scandium, yttrium, and the lanthanum group elements. They are known to be present in

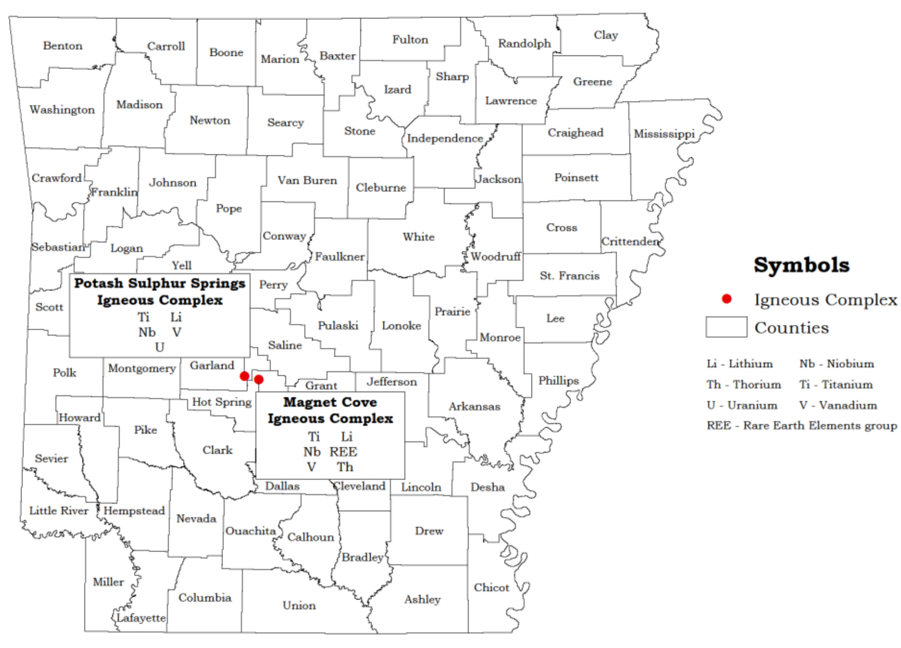

Figure 11 - Location of Magnet Cove and Potash Sulphur Springs Intrusions

three areas of the state and in two different rock types. REEs associated with igneous rocks are present at the Magnet Cove igneous complex in Hot Spring County (Erickson, 1963) and igneous intrusions in Pulaski, Saline, Cleveland and Garland counties (Figure 11). Samples analyzed from auger drilling in the central region of Magnet Cove showed up to 4.3% combined rare earths (Barwood, 1990). Selected samples of bastnaesite collected by the Arkansas Geological Commission contained over 30% combined lanthanides. The mineralization is present in veins up to 4 inches thick in carbonatite.

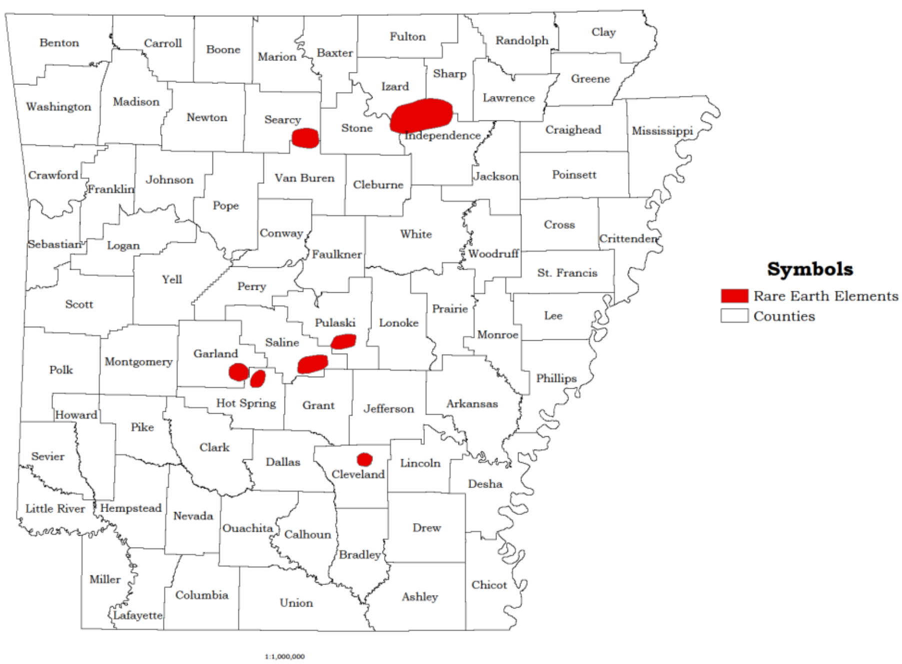

Figure 12 - Map of REE Localities

In the Batesville District (Stone, Izard, and Independence Counties), REEs are present in sedimentary deposits associated with phosphorite enrichment in the Cason Shale, Upper Ordovician (Figure 12). The phosphorite has an average content of 1692.2 parts per million of REEs. Analysis of recently collected samples indicates larger amounts of the light rare earths and lesser heavy rare earths (Grosz, 1995).

In 1962, investigations of a phosphate deposit present in Searcy and Van Buren Counties involved core drilling and analyses for phosphate content (Figure 12). Stratigraphic and gamma ray logs were produced for each drill hole where possible. Mining of phosphate-rich rock took place following these investigations for a short time in 1963. Only a few thousand tons of material was mined at that time.

Strontium (Sr)

Strontium is present in Howard and Pike Counties (Figure 13) (Dane, 1929). The strontium-bearing minerals are celestine (Figure 14), which contains 56.4% strontium oxide, and strontianite, which contains 70.1% strontium oxide. The only mineral with commercial potential in Arkansas is celestine derived from evaporate deposits present in the DeQueen Limestone of the Trinity Group of Early Cretaceous age. Two intervals are present about 25 to 35 feet above the base of the DeQueen. One appears to be lenticular and the other 2 to 6 inches thick in an area of about 3 square miles.

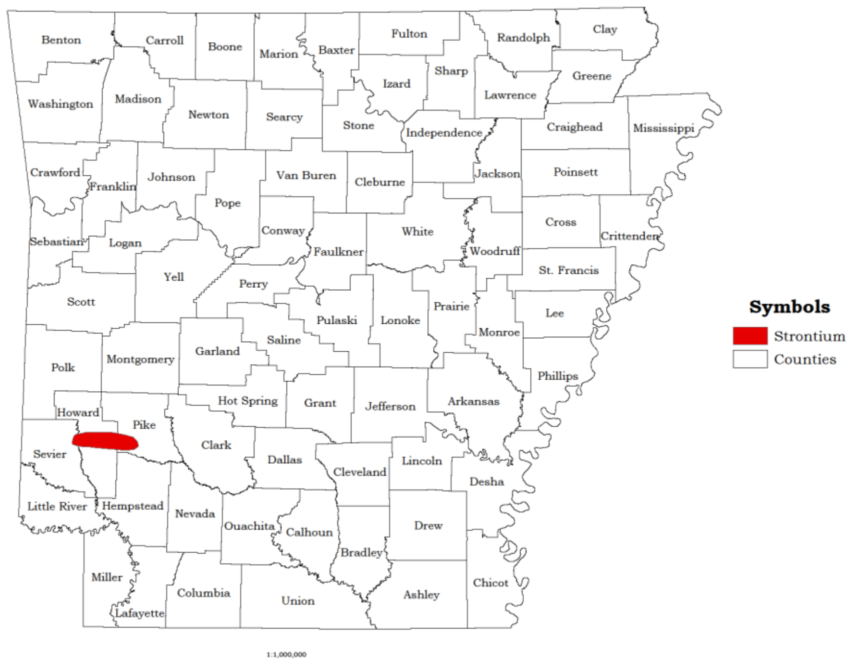

Figure 13 - Map of Strontium Localities

The first report of celestine in the state was by the U.S. Geological Survey in 1929 (Miser, 1929). In 1941, 1500 pounds of celestine was collected by the W.F. Hintze Company. During 1942 and 1943, a prospecting and exploration project was conducted. Test pits and 750 test holes were drilled over a 30 square mile area in Howard County (Hanson, 1999). Afterwards, 90 tons of ore were mined by open-pit methods and sent to Nacagdoches, Texas for processing. Since then, no further mining has taken place in the state. The best exposure of celestine is located at the Certain-Teed gypsum mine in Howard County.

Figure 14 - Image of Yellow Celestine

Tantalum (Ta)

To date, no tantalum has been recovered in the state. However, because tantalum is associated with niobium, resource potential exists in Arkansas. See the niobium and titanium sections for more information.

Thorium (Th)

Thorium minerals are generally radioactive. During the 1950s, exploration for radioactive elements led to the discovery of anomalies in the Magnet Cove area in Hot Spring and Saline counties (see Figure 11). In Saline County, thorium and uranium are present in a quartz-feldspar rock. An analysis of a selected sample indicated concentrations of 0.019% uranium and 1.5% thorium (Erickson, 1963). There has been no mining of thorium or uranium in the state.

Titanium (Ti)

Titanium is present in the minerals anatase, brookite, rutile, ilmenite, perovskite, titanite (Figure 16), and the alteration product leucoxene. The most important ore minerals in Arkansas are rutile, brookite, and ilmenite. They are present in Pulaski, Saline, Hot Spring, Garland, Pike, Howard, Sevier, and Little River Counties. They are also present in alluvial sand on the Arkansas and White Rivers (Figure 15).

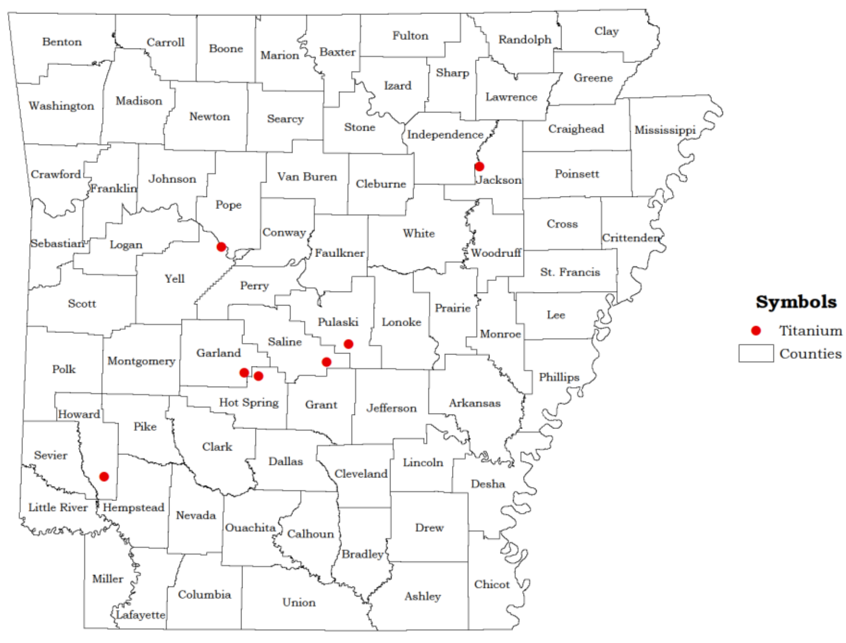

Figure 15 - Map of Titanium Localities

In Pulaski and Saline Counties the titanium-bearing minerals are associated with the nepheline syenite in igneous intrusions and bauxite deposits which weathered from the syenite (Calhoun, 1950). Rutile, brookite, and perovskite are present at Magnet Cove in Hot Spring County in two types of deposits: feldspar-carbonate-rutile veins in intrusive igneous rocks and brookite-quartz veins in an altered contact zone in Arkansas Novaculite adjacent to the intrusion. Perovskite is associated with late-stage, carbonate-rich bodies piercing the interior of the Magnet Cove intrusion. Rutile was mined from open pits in Magnet Cove from 1932–1944. About 5,400 tons of concentrate were recovered (Holbrook, 1947). U.S. Bureau of Mines investigations show 8 million tons of titanium-bearing material containing 4 to 8% titanium-oxide in the Magnet Cove area (Fryklund, 1954). Development of this resource was halted by the presence of niobium. In Garland County titanium values were noted during the mining of vanadium ore at Potash Sulphur Springs but were not recovered (Holbrook, 1948). South of Magnet Cove, high-level terrace placer deposits above the Ouachita River were mined from open-pits during the 1930s. Grain size here ranges from sand to pebble to gravel. In Pike, Howard, Sevier, and Little River Counties, ilmenite is present in the upper parts of the Cretaceous Tokio Formation (Hanson, 1997). Its outcrop belt extends from near Arkadelphia in Clark County westward to the Arkansas state line north of Arkinda, in Little River County. A deposit near Mineral Springs, in Howard County was surface mined and produced only a small amount of ilmenite. Investigations done by the Arkansas Geological Commission in this area demonstrated about 110,000 tons of titanium-bearing minerals within 50 feet of the surface (Fryklund, 1950). During 1939-1940, 12.8 tons of ilmenite was processed from sand along the Arkansas River in Yell County. More recently, an industrial sand operation along the White River in Independence County was able to separate titanium-bearing sand. No production values of the titanium-bearing minerals are available for this site. Presently no titanium-bearing minerals are mined in the state.

Figure 16 - Image of Titanite Crystal

Uranium (U)

In the 1950s, uranium anomalies were discovered in Marion, Garland, and Pike Counties. Several locations yielded samples containing 0.1% or more uranium oxide. At Potash Sulphur Springs, in Garland County, uranium was discovered to be associated with the igneous intrusion (Stroud, 1951). The uranium mineralization is at the contact of the Cretaceous syenite complex and folded Paleozoic novaculite and shale units. The U.S. Geological Survey identified the primary uranium-bearing mineral to be pyrochlore. Soil samples assayed up to 0.4% uranium from this site by the Atomic Energy Commission. The Rankin Prospect in Pike County produced radioactive carbonized wood fragments in the lower Cretaceous Trinity Group. The highest assay obtained was 0.24% uranium oxide. The Bear Hill Prospect in Marion County has the highest assayed uranium oxide content in the state of up to 2% in Paleozoic black shale (Swanson, 1962). No economically viable deposits have been discovered and there has been no mining in the state for radioactive ore.

Vanadium (V)

While searching for radioactive minerals in the 1950s, vanadium was discovered in economic quantities at the Potash Sulphur Springs igneous complex in Garland County (Hollingsworth, 1974) and the Magnet Cove igneous complex in Hot Spring County (Erickson, 1963) (see Figure 11). In 1962, Union Carbide delineated several ore-grade deposits in highly altered Paleozoic rocks in the contact metamorphic zone around the Magnet Cove complex (Flohr, 1994). The Christy Deposit also has ore-grade material present in recrystallized and altered Arkansas Novaculite (Evans, 1984). The principal ore minerals are vanadiferous goethite (Figure 17) with lesser amounts of vanadium-bearing brookite (Taylor, 1969). Since mining for vanadium started, approximately 4.8 million tons of material containing 1.2% vanadium-oxide has been processed from Arkansas ore. Mining was done by open-pit methods. The last time vanadium was produced in the state was in 1990. The T Deposit and the Spaulding Deposit at Potash Sulphur Springs contain ore grade rock that has not been mined to date (Howard, 1995). Additionally, a sample from one drill hole in Montgomery County indicated the presence of vanadium. Reclamation work is nearly complete at Potash Sulphur Springs and the nearby processing facility is recovering vanadium from waste material imported from Venezuelan oil fields.

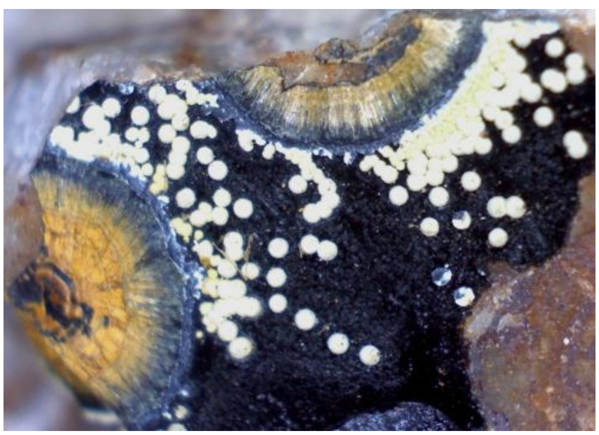

Figure 17 - Image of Kidwellite Spheres on Vanadiferous Geothite

NONMETALLIC

Barite ($BaSO_4$)

Barite is present in the Ouachita Mountains province (Figure 19), specifically in Hot Spring, Montgomery, and Polk Counties (Jones, 1948). It is also present near Dierks in Howard County in the Gulf Coastal Plain province (Scull, 1958). Barite was first discovered in Montgomery County in 1888 and near Magnet Cove in Hot Spring County in 1900 (Hanor, 1977). It was mined beginning in 1939. During 1944-1966, the Chamberlain Creek Deposit at Magnet Cove was the nation's leading producer of barite. In the 1970s-1980s, barite was mined from the Fancy Hill District in Montgomery County. Other mines active at this time were near Pigeon Roost Mountain, northeast of Glenwood, and east of Dierks, Howard County (Mitchell, 1984).

Figure 18 - Image of Barite

Most of the deposits are present in the Mississippian aged Stanley Formation, with lesser deposits in the Arkansas Novaculite. In the Dierks District of the West Gulf Coastal Plain, barite is found to be the cementing material in sand and gravel of the lower Cretaceous Trinity Group (Zimmerman, 1965). At Chamberlain Creek, mining was performed by surface and subsurface

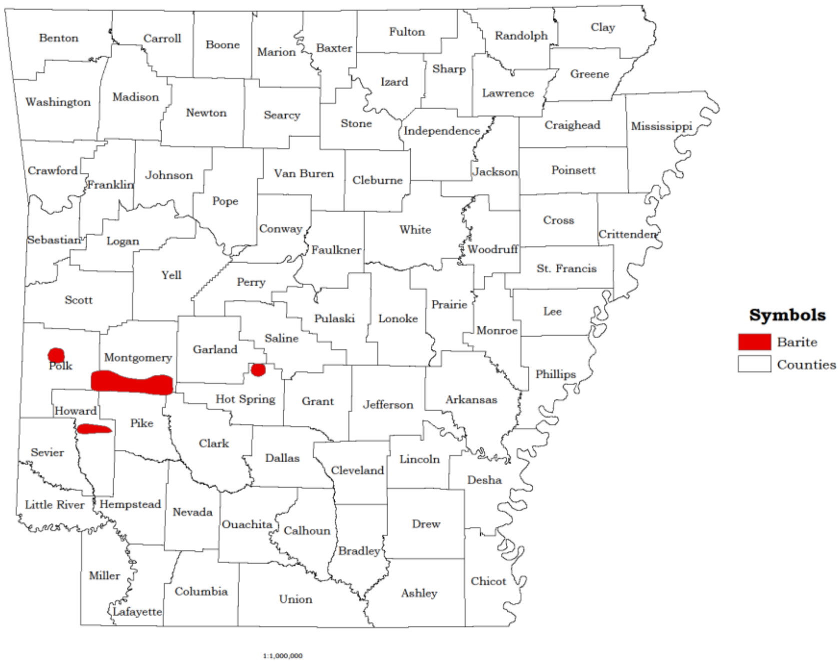

Figure 19 - Map of Barite Localities

techniques while the remaining mines were all open-pit. Total production of barite from Arkansas was 9 million tons (1939-1983) with 8 million tons coming from the Chamberlain Creek Deposit. Reserves are estimated to be in the millions of tons. The Arkansas Geological Survey has all the information Milchem Corporation amassed on the Fancy Hill Deposit in Montgomery County, including over 165 maps and figures detailing mine plans with core analysis.

REFERENCES

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

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

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

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

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

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

Evans. H.T., Jr., Nord, G., Marinenko, J., and Milton, C., 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.

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 Resource and Development Commission, Division of Geology Bulletin 16, 173 p.

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

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

Grosz, A.E., Meier, A.L., and Clardy, B.F., *edited by* Howard, J.M., 1995, Rare Earth Elements in the Cason Shale of northern Arkansas: A Geochemical Reconnaissance, 13p.

Hall, R.B., 1940, Stibnite deposits of Sevier County, Arkansas: Evanston, Ill. Northwestern University, MS thesis, 102p.

Hanor, J.S., and Baria, L.R., 1977, Controls on the distribution of barite deposits in Arkansas, *in* Stone, C.G., ed., Symposium on the geology of the Ouachita Mountains, v. 2: Arkansas Geological Commission Miscellaneous Publication 14, p. 42-47.

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

Hanson, W.D., and McElwaine, R.B., 1999, Celestine (Celestite) in southwest Arkansas, *in* Proceedings of the 34th Forum on the Geology of Industrial Minerals, 1998, *edited by* Johnson, K.S., Oklahoma Geological Survey Circular 102, p. 105-110.

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

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

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

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., 1979, Antimony District of Southwest Arkansas, Arkansas Geological Commission Information Circular 24, 29 p.

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

Howard, J.M., Colton, G.W., and Prior, W.L., 1997, Mineral, Fossil Fuel, and Water Resources of Arkansas: Arkansas Geological Commission Bulletin 24, 115 p.

Jones, T.A., 1948, Barite deposits in the Ouachita Mountains, Montgomery, Polk, and Pike Counties, Arkansas: U.S. Bureau of Mines Report of Investigations 4348, 15p.

Malamphy, M.C., Dale, G.K., Romslo T.M., Reed, Jr, A.H., Ollar, A., and Tracey, Jr, J.I., 1948 Investigation of Arkansas Bauxite, Volume I. U.S. Bureau of Mines Rept. of Inv. 4251, 63 p.

Miser, H.D., 1922, Manganese deposits of the Caddo Gap and DeQueen Quadrangles, Arkansas: U.S. Geological Survey Bulletin 660-C, p. 59-122.

Miser, H.D., and Purdue, A.H., 1929, Geology of the De Queen and Caddo Gap quadrangles, Arkansas: US Geological Survey Bulletin 808, 195p.

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

Mitchell, A.W., 1984, Barite in the western Ouachita Mountains, Arkansas, *in* Stone, C.G. and Haley, B.R., *eds.*, Guidebook to the geology of the central and southern Ouachita Mountains Arkansas: Arkansas Geological Commission Guidebook 84-2, p. 124-131.

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, 23p.

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.

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* Hager, J.P., *ed.*, Process Mineralogy, EPD Congress, The Minerals, Metals & Materials Society, p 379-396.

Phase I: Core-drilling project – Peyton Creek Phosphate Area, Searcy-Van Buren Counties, Arkansas, 1964, by Arkansas Geological Commission, Miscellaneous Publication 9, 39p., 1 fig., 25 logs.

Phase II: Core-drilling project – Peyton Creek Phosphate Area, Searcy-Van Buren Counties, Arkansas, 1965, by Arkansas Geological Commission, Miscellaneous Publication 10, 34p., 2 figs., 22 logs.

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

Scull, B.J., 1958, Origin and occurrence of barite in Arkansas: Arkansas Geological and Conservation Commission Information Circular 18, 101p.

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

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.

Stroud, R.B., 1951, The Areal distribution of radioactivity in the Potash Sulfur Springs complex: Fayetteville, University of Arkansas, MS thesis, 42p.

Stroud, R.B., Arndt, R.H., Fulkerson, F.B., and Diamond, W.G., 1969, Mineral resources and industries of Arkansas, Washington, U.S. Department of Interior, Bureau of Mines Bulletin 645, 418p.

Stroud, R.B., 1981, Manganese resources of the Batesville District, Arkansas: Arkansas Geological Commission Information Circular 27, 146p.

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, 16p.

Taylor, I.R., 1969, Union Carbide's twin-pit vanadium venture at Wilson Springs: Mining engineering, v. 21, p. 82-85.

Zimmerman, R.A., 1965, The Origin of the Arkansas bedded barite deposits with special reference to the genetic value of sedimentary features in the ore: University of Missouri, Rolla, Ph.D. dissertation, 367p.