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ASPHALTITE IN THE OUACHITA MOUNTAINS

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Abstract

The veins and fissure fillings of grahamite and impsonite that occur at 17 localities in southeastern Oklahoma are restricted to an east-trending belt about 25 miles wide in the thrust-faulted northern part of the Ouachita Mountains. They are between the Choctaw fault and the Octavia fault, generally cutting shales and sandstones of the Stanley formation (Mississippian and Pennsylvanian).

For nearly 25 years in the early part of the twentieth century, Oklahoma was the leading state in the production of grahamite, used in the manufacture of roofing and other waterproofing compounds. Most of the production was from the Sardis deposit, the largest known vein of grahamite in the world, and from the Jumbo mine. Impsonite was produced near Page for the high vanadium content of its ash.

Grahamite and impsonite have fixed carbon contents of approximately 50 percent and 75 percent, respectively, and were derived from petroleum by the progressive loss of volatile constituents. The widespread occurrence of these compounds indicates that petroleum may occur at depth, and is partly responsible for increased oil and gas prospecting in the Ouachita Mountain region.

Introduction

Asphaltite is a general name applied to solidified hydrocarbon compounds, derived from petroleum, that occur generally in pure form as veins or as fissure fillings. The various asphaltites originate through the progressive loss of volatile constituents from petroleum, probably in the same general manner as that by which peat is converted to anthracite.

Solidified asphaltic hydrocarbons are well known in the Ouachita Mountains, where they were extensively worked in the period 1903-1924. Two general types are recognized, grahamite and impsonite. Grahamite is a true asphaltite, being fusible, soluble in carbon disulfide, and containing 25-50 percent fixed carbon. It is the most common variety of asphaltite in southeastern Oklahoma and is approximately the petroleum equivalent of bituminous coal. Impsonite is an asphaltic pyrobitumen, insoluble and infusible, and contains 50-85 percent fixed carbon. It represents the most advanced stage in the transformation of petroleum, and is approximately equivalent in the coal series to anthracite.

The grahamite worked in the deepest mine reportedly was becoming softer with depth, thus indicating a downward gradation toward liquid asphalt and possibly to liquid petroleum itself.

Grahamite is known at 16 localities in the northern half of the Ouachita Mountains in Oklahoma, whereas impsonite is known from a single locality in Oklahoma, at Page in southern LeFlore County, and from a deposit barely across the state line in Scott County, Arkansas (Fig. 1). The largest known grahamite vein in the world is in northern Pushmataha County near Sardis, and the second largest vein of this type in Oklahoma is in western Pushmataha County near Jumbo. Mines at these localities yielded most of the 90,000 short tons of grahamite that was produced in the United States in the years 1903-1924. The mines were closed in 1924 and have not been reopened. Principal use of the grahamite was in the preparation of roofing compounds. A small tonnage of impsonite also was produced, not for waterproofing compounds but for the vanadium content of its ash.

The occurrence of asphaltite veins in the Ouachita Mountains of Oklahoma probably is more valuable at this time in demonstrating the petroleum-bearing character of the underlying rocks than in the potential use of the hydrocarbons grahamite and impsonite. The recent increase in mapping, leasing, and drilling for oil in the frontal belt of the Ouachita Mountains and around the Potato Hills is doubtless encouraged by the knowledge that petroleum has been injected during the past into these rocks and may now be present in favorable structures at depth.

Significantly, all the known deposits are in the thrusted northern part of the Ouachita Mountains, nearest the Oklahoma coal basin and the Arbuckle Mountains, in both of which oil and/or gas have been produced. They lie in an east-trending belt about 25 miles wide, bounded on the north by the Choctaw fault and on the south by the Octavia fault (Fig. 1). All the large deposits of grahamite occur as fissure veins cutting shales and sandstones of the Stanley formation (Mississippian - Pennsylvanian) and are restricted to the belt that lies between the Octavia fault and the Windingstair fault. Smaller deposits are in the Bigfork chert (Ordovician), Arkansas novaculite (Devonian and Mississippian), Jackfork sandstone (Pennsylvanian), and possibly in the Atoka formation (Pennsylvanian).

Discovery and History

All the deposits of grahamite and impsonite that have been exploited commercially in the Ouachita Mountains were found before Oklahoma became a state (1907), when that region was part of the Choctaw Nation in Indian Territory. At first believed to be coal, because it had a black color, conchoidal to hackly fracture, and would burn with a hot flame, the material was later shown by geologic investigations to be related to asphalt and thus to have been derived from petroleum.

The first geological reports dealing specifically with asphaltites in southeastern Oklahoma were those of Taff (1899, 1909). A comprehensive report by Eldridge (1901) contains much valuable information about these deposits, but because this information was largely supplied by Taff, it is to him that the credit for field reporting is due. It is a remarkable tribute to Taff that in the period 1897-1909 he published 26 reports and maps on the geology of southern Oklahoma, including 5 folios (Coalgate, Atoka, Tishomingo, Tahlequah, and Muscogee folios), one professional paper on the geology of the Arbuckle and Wichita mountains, and numerous reports on segregated coal and asphalt lands. In the course of this work Taff established the basic geologic concepts for the region, and he also gave to many of the formations the names that are in current use. He was the first to recognize the true nature of the solidified hydrocarbons in the Ouachita Mountains (Taff, 1899).

As reported by Taff (1899, p. 219), asphaltite was first discovered in 1890 and the deposit was explored in 1892 by a shaft sunk into the vein from the outcrop. Located in Impson Valley, in the southern part (sec. 28) of T. 1 S., R. 15 E., the workings in the 25-foot vein at this site later became known as the Jumbo mine, the second largest producer of grahamite in the state. In 1898 the mine was being operated to a depth of 30 feet, and an inspection made by Taff showed the material to be in the form of a vein cutting folded green shale and dipping 70 degrees east. Later the shale was shown to be in the upper part of the Stanley formation. Tests made on the asphaltite showed it to contain 55.97 percent fixed carbon and to have some of the properties of albertite, a solid bitumen from Nova Scotia and New Brunswick, Canada. Two other prospects were noted, one on McGee Creek, sec. 23, T. 1 N., R. 14 E., and the other in Impson Valley, sec. 16, T. 1 S., R. 15 E.

Eldridge (1901, pp. 263-269) gives substantially the same information as above, but at the time of his writing the large deposit in sec. 28, T. 1 S., R. 15 E. was being worked in two levels 20 and 35 feet beneath the surface and extended as much as 120 feet along the vein. The operator was George D. Moulton and the deposit was called the Moulton mine. For the asphaltite from this mine Eldridge (1901, p. 265) proposed the name impsonite, taken from the Impson Valley, believing it to be sufficiently different from albertite to warrant a distinctive name. Application of this name was rejected by Taff, who in 1909 used the name grahamite for all known asphaltite deposits of Impson Valley and McGee Creek, using the name long applied to entirely similar material from Ritchie County, West Virginia. Grahamite is now the accepted name for all Ouachita Mountain asphaltites, including those of Impson Valley, that contain approximately 50 percent fixed carbon and are soluble in carbon disulfide. The name impsonite has come to be used for insoluble, infusible pyrobitumen having a considerably higher percentage of fixed carbon (Abraham, 1945, p. 298). Only one deposit of impsonite has been described in Oklahoma, and it is not in Impson Valley.

In the early 1900's there was considerable demand for waterproofing compounds, which at that time were derived mostly from asphaltites and native asphalt rather than from petroleum refining. Encouraged by the discovery of the apparently large deposit in Impson Valley, search went forward vigorously for new deposits. This search was successful, resulting in the discovery early in 1906 of an even larger deposit in Jackfork Valley, near the present settlement of Sardis, in sec. 9, T. 2 N., R. 18 E. This proved to be the largest known grahamite vein in the world. Also early in 1906, or late in 1905, a deposit on McGee Creek, sec. 30, T. 1 S., R. 14 E., was opened by a shaft 75 feet deep. This later was known as the Pumroy mine.

Both Taff's report of 1909 and Hutchison's report of 1911 contain descriptions of all the deposits that have been commercially exploited. Virtually the entire production of grahamite from Oklahoma has come from the Sardis deposit and from the Jumbo mine in Impson Valley, together with a small tonnage from the Pumroy mine. The remaining localities shown on Fig. 1 are either prospects or occurrences of thin veins. All the large deposits and most of the smaller ones are in the Stanley shale.

While this early developmental work on grahamite was going on, two deposits of superficially similar yet quite different character were found—one on the south slope of Black Fork Mountain near Page, southern LeFlore County, sec. 23, T. 3 N., R. 26 E., and another about 12 miles east on Fourche Mountain in Scott County, Arkansas. Both deposits are in the Jackfork sandstone. Although Taff called the material grahamite, he realized that the fixed carbon was much higher than in the grahamites in the western part of the Ouachita Mountains, in fact " . . . probably so high as to place it in a class of bitumens . . . other than that of grahamite . . . The high percentage of fixed carbon suggests that the material will be found practically insoluble by the media used in testing soluble bitumens." (Taff, 1909, p. 295). According to later usage, which is still current although not formally proposed in the literature, the solid bitumen from Page and Fourche Mountain is called impsonite, and is characterized by high percentage of fixed carbon, infusibility, and insolubility. Because of its insolubility, impsonite could not be used successfully in waterproofing compounds.

Properties, Production, and Use

The properties of grahamite and impsonite are summarized in Table I, taken largely from the comprehensive report of Abraham (1945, pp. 273-277, 298-299). The analysis of grahamite from sec. 4, T. 1 N., R. 15 E. is taken from Beach (1945, p. 60), and the proximate analyses are cited from Taff (1909, p. 296).

PROPERTIES OF GRAHAMITE AND IMPSONITE FROM THE OUACHITA MOUNTAINS

TABLE I

	GRAHAMITE				IMPSONITE	
	Sardis deposit 9-2N-18E	Jumbo mine 28-1S-15E	Pumroy mine 30-1S-14E	4-1N-15E	Page deposit 23-3N-26E	Fourche Mtn., Arkansas 2 miles east of Harris
Fusing point	530 - 604°F	460 - 520°F	473°F	505°F	Infusible	Infusible
Fixed carbon	52.76 - 55.00	48.5 - 53.0	38.42 - 41.0	44.63	75.0 - 81.6	80.0
Solubility in CS_2	>99.5	90.5 - 96.2	83.7 - 95.0	very soluble	4 - 6	Trace
Free mineral matter (ash)	0.21 - 0.70	1.1 - 6.7	0.98 - 7.1	0.34	0.7 - 2.5	0.6
Hardness (Mohs)	2	....	....	2	2 - 3	3
Specific Gravity	1.18 - 1.195	1.175	....	1.14	1.235	1.25
Color	Black	....	....	Black	Black	Black
Streak	Black	....	....	Black	Black	Black
Fracture	Conchoidal-hackly	....	....	Conchoidal	Hackly	Hackly
PROXIMATE ANALYSIS						
Moisture		0.25			0.09	2.51
Volatile bitumen		43.33			23.06	17.78
Fixed carbon		55.97			75.90	79.15
Ash		1.45			.95	.56
Sulphur		1.47			1.69	1.38

The higher state of metamorphism of impsonite results in correspondingly higher specific gravity and percentage of fixed carbon (75-81 percent), rendering the material insoluble and infusible. These are the principal distinctions from grahamite, which is soluble in carbon disulfide and has a fixed carbon percentage that ranges in Oklahoma material between 38.4 and 55.0. The solubility of grahamite is the chief reason why it was extensively used from Oklahoma deposits for roofing compounds.

As grahamite is no longer mined in Oklahoma, statements regarding its use are taken from earlier reports. During the period of maximum development, it was stated by Shannon (1914, p. 100) that the pure asphaltites were used " . . . in the manufacture of candles, ointments, powders, as an adulterant for beeswax, for making paints and varnishes, such as are used for iron work, for lining chemical tanks, roofing pitch, insulating electric wires, as a substitute for rubber in garden hose, and as a binder for pitch in making coal briquets."

At the time when production was dwindling rapidly, the use of grahamite was somewhat more specialized, according to the following statement by Ladoo (1920, p. 8): "The chief use for grahamite has been in the manufacture of prepared roofing due, it is claimed, to the fact that mastic made from it is more resistant to grease and oil than the ordinary type. Since grahamite is fused with difficulty, it is usually softened with a heavy asphaltic flux. When so fluxed it is less susceptible to heat than gilsonite and is more rubbery and elastic. It is also used, either fluxed or mixed with other bitumens, in the manufacture of varnishes, rubber substitutes, as a filler for brick and artificial stone blocks, electrical wire insulation, and in molded insulation."

Nearly all the production of grahamite from deposits in the United States was in the first quarter of the twentieth century, and practically the entire tonnage came from Oklahoma. Although a breakdown of production data by states is not available from published reports, the figures given in Table II are believed to represent tonnages produced chiefly from the Sardis deposit and from the Jumbo mine.

TABLE II

Production of grahamite in the United States, 1903-1924, in short tons

1903	877	1914	9,669
1904	1,000	1915	10,863
1905	1,635	1916	8,431
1906	1,952	1917	4,618
1907	966	1918	3,803
1908	2,286	1919	5,000
1909	3,894	1920	9,940
1910	4,000	1921	2,004
1911	5,000	1922	41
1912	7,700	1923	—
1913	6,500	1924	60
		Total	90,239

Data for the years 1903-1909, 1911, and 1922 are strictly Oklahoma production, taken from Dale and Beach (1951, p. 12). Data for the other years are taken from Abraham (1945, p. 111), who lists during this period no active deposits in the United States other than those in Oklahoma.

First production of Oklahoma grahamite was from the Jumbo mine about 1892, when it was marketed as coal. From then until 1903 development was sporadic and no figures were reported, although during this time the true nature of grahamite was recognized and it was first used for roofing compounds. Since 1924 there has been no production of grahamite, principally because of (1) competition with petroleum asphalts, production of which in the United States rose from 20,826 tons in 1902 to 3,178,370 tons in 1925 (Abraham, 1945, p. 111), and (2) competition with gilsonite from Utah, which contains 10-20 percent fixed carbon, has a lower fusing point than grahamite, and has a greater solubility in petroleum naphtha, so that it is still extensively used for the manufacture of paints, lacquers, inks, battery boxes, and asphalt tile. The average value of Oklahoma grahamite for the years 1903-1909 was $11.28 per short ton (Dale and Beach, 1951, p. 12).

Production of the insoluble impsonite from Page is included in the data of Table II. This material was first worked about 1900 for coal, and it doubtless burned well in blacksmith forges because the fixed carbon percentage of 75 or more is as high as that of anthracite. By 1911 (Hutchison, 1911, p. 79) the Page deposit had not been developed commercially. About the same time, the discovery was made that the ash from the Page impsonite (then called grahamite) contained vanadium (Richardson, 1910); and a short time later analyses made by the U. S. Bureau of Mines (Moore and Kithil, 1914, p. 55) showed a vanadium content in the ash ranging from 6.77 to 34.5 percent. This material also was investigated by the U.S. Geological Survey, Clarke (1924, p. 723) reporting that ash from the Page impsonite contains 12.2 percent V_2O_5. The writer collected from the underground workings in 1954 a sample that was analyzed in the laboratory of the Oklahoma Geological Survey by T. E. Hamm, who reported 0.76 mineral ash containing 21.46 percent V_2O_5. These results are summarized in Table III.

TABLE III

Vanadium content of ash from impsonite at Page, Oklahoma

	Moore and Kithil (1914)		Clarke (1924)	T. E. Hamm (1954)
	Drift sample	Outcrop	——	Drift sample
Ash	0.83	3.39	0.95*	0.76
V_2O_5 in ash	34.5	6.77	12.2	21.46
V_2O_5 in total sample	0.28	0.22	——	0.17

* Cited by Taff (1909, p. 296); probably same sample used by Clarke.

This discovery of vanadium, valuable as an alloying element in steel, led to the leasing of the Page deposit by a Pittsburgh concern, but the property remained idle through 1913. At some later date, not available from records but probably during World War I when demand for vanadium was high, the deposit was opened and impsonite was mined for the vanadium content of its ash. The impsonite was burned on the property near the tunnel entry, and about 2,000 pounds of ash was shipped from Page on the Kansas City Southern Railroad. As the ash content is slightly less than 1 percent, it is probable that about 100 tons of impsonite was mined. After this shipment the deposit was idle through May, 1954. During World War II no attempt was made to use impsonite for its vanadium content, as richer supplies were available from uranium-vanadium ores of Colorado, Utah, and Arizona, and from ores mined in Peru.

Description of Principal Deposits

Sardis Deposit. Also known as the Jackfork Creek deposit and Tuskahoma deposit, this occurrence of grahamite in the NE¼ sec. 9, T. 2 N., R. 18 E., near the settlement of Sardis in north-central Pushmataha County, was the largest discovery made in Oklahoma and later was shown to be the largest known vein of grahamite in the world. It is a mile long and as much as 25 feet wide. The best description of the deposit and workings is by Hutchison (1911, pp. 81-82), who is quoted as follows: "The country rock consists of sandstones and shales near the center of the Standley (Stanley) formation, of Carboniferous age. The rocks here dip south at an angle of 37 degrees at the outcrop, and the vein which is reported to average four feet at the surface, lies parallel to the bedding plane of sandy shales below, and a slightly shaley sandstone above, to a depth of more than 125 feet, where the dip of the deposit changes to about 47 degrees and so continues to the bottom of the mine, but the dip of the formation does not change. The opening occupied by the asphaltite seems to have been formed by a bedding fault probably overthrust from the south. Slickensided surfaces in the wall rock are comparatively few, and none were noted in the vein material, thus indicating that there was very little movement along the fault plane prior to filling and none at all after the bituminous matter had solidified. The mine was opened at the point where the asphaltite was the thickest, about 19 feet. Development has shown a maximum thickness of about 25 feet. Drifts east and west from the main opening have shown that large pieces of the hanging wall fell into the deposit before it had become solid."

"There are two distinct types of the material throughout nearly the entire occurrence as exploited. The lower zone, which ranges from a few inches to more than nine feet, consists of irregular pentagonal prisms, black in color, of bright luster and distinctly subconchoidal to conchoidal fracture. The upper zone is of irregular structure, hackly fracture and dull luster, except on small facets."

Jumbo deposit. Workings at this deposit were variously known as the Jumbo mine, Choctaw mine, or Old Slope mine. This occurrence of grahamite is the first to be developed in what is now Oklahoma, and it proved to be the second largest mine in the state. Material from this deposit was collected by Taff and used as a basis for his 1899 report, in which he recognized for the first time the asphaltic rather than the coaly nature of the deposit.

The deposit is in the NW¼ sec. 28, T. 1 S., R. 15 E., near the present settlement of Jumbo, in western Pushmataha County. It is on Tenmile Creek, along that part known as Impson Valley. The grahamite occurs as a vein, about one-half mile long at the outcrop, that strikes N. 15 degrees E. and dips steeply east, cutting green clay shales in the upper part of the Stanley formation, probably along a fault. The vein is parallel to the general trend of the enclosing rocks, nearly parallel to but generally dipping at a greater angle than the rock strata.

From mine plans and cross-sections published by Hutchison (1911, figures facing p. 80), furnished by the superintendent of the mine while it was in operation, the form of the grahamite vein is well known. The workings extended for 600 feet along the vein, at levels of 50, 70, 90, 110, 125, 135, 155, 180, 200, 220, and 260 feet. As shown by these workings, the vein is characterized as an elongate north-trending lens, tapering generally from 1-2 feet thick at the surface to an average thickness of about 25 feet and a maximum thickness of 40 feet between the 50-foot and 220-foot levels. The base of the lens in the southern part of the workings was found at 180, 260, and 220 feet, below which the vein has a thickness of 1 foot or less. At one locality in this part of the mine the lens was split into two pods, separated by a constriction of the vein to a thickness of about 1 foot.

In the northern part of the workings the base of the lens was not encountered at the 220-foot level, as the lens here plunges northward and reaches its greatest worked thickness of 40 feet between the 200-foot and 220-foot levels.

An explosion killed several miners in 1910, but operations were resumed through 1916, when the mine closed (Beach, 1945, p. 58).

Pumroy mine. The largest of known deposits in McGee Valley, this vein of grahamite was worked by three openings. The location is given by different writers as the NW¼ sec. 30, T. 1 S., R. 14 E., and as the NE¼ sec. 25, T. 1 S., R. 13 E., but there is no doubt that these locations refer to the same deposit. Even before 1906 one shaft had been sunk to a depth of 75 feet and several carloads of grahamite had been produced; and by 1911 three shafts were dug and 100 cars or 5,000 tons were shipped from Stringtown. Hence this is the third largest grahamite mine in Oklahoma.

The grahamite vein cuts at a right angle across interstratified sandstones and shales in the upper part of the Stanley formation, along a dip fault that probably has small displacement. At the outcrop the vein has typical lens form, tapering along a horizontal distance of 90 feet from a maximum width of 10 feet in the central part to 1 or 2 feet at the tips of the lens (Hutchison, 1911, figure facing p. 80). At a depth of 110 feet the vein is reported to be 4 feet wide.

Other thin veins of grahamite in McGee Valley, not sufficiently prospected to reveal their magnitude, are reported from the SE¼ sec. 28, T. 1 N., R. 14 E. and from the SW¼ sec. 23 of the same township. Both veins cut rocks of the Stanley formation.

Page deposit. The best known occurrence of impsonite in Oklahoma is in the NE¼ SE¼ sec. 23, T. 3 N., R. 26 E., about 1 mile east of Page in southern LeFlore County. The deposit is on the south slope of Black Fork Mountain, about 1,000 feet above the level of Big Creek, where the impsonite occurs as veins cutting massive sandstone of the Jackfork formation. Black Fork Mountain is a hogback supported by Jackfork sandstone that dips homoclinally southward 35 to 60 degrees; and at the impsonite mine the dip is 60 degrees.

At the time of the writer's visit in 1953 the workings consisted mainly of a horizontal entry tunnel about 120 feet long, driven northward into the hillside; a shaft sunk about half way along the tunnel; and a main underground room. The country rock is mostly sandstone, partly soft and bituminous and partly quartzitic and barren. Two separate veins of impsonite were encountered, the smaller one being parallel to bedding and 6 inches to 43 inches thick, thinning downdip, but branching westward into a pipelike fissure cutting downward diagonally across the beds. This fissure was worked in a now-filled shaft about 4 feet square, on the west wall of which the impsonite has a vertical contact with sandstone.

The larger vein and principal working is a bedding seam 2 feet wide that passes into a fissure vein 10.5 feet wide at the tunnel level and wedges out upward in a vertical distance of 15 feet. The contact of impsonite against sandstone on the west wall is sharply defined and dips 77 degrees W.

This deposit was worked for fuel on a small scale before 1911, but the main workings were developed apparently during World War I, when the impsonite was burned and the ashes shipped for their high content of vanadium.

Other deposits. Miscellaneous occurrences of asphaltite have been reported in some of the early publications and in the paper by Beach (1945), which is based partly on information contained in the files of the Oklahoma Geological Survey. With the addition of these localities to those already described above, it will be seen that grahamite and impsonite occur in a broad belt trending eastward across the northern part of the Ouachita Mountains (Fig. 1).

NW¼ sec. 4, T. 1 N., R. 15 E. Grahamite in the Stanley shale, reported as a 7-foot vein encountered at a depth of 50 feet. Analysis by Oklahoma Geological Survey cited in Table I.

SE¼ sec. 13, T. 2 S., R. 13 E. Small showings of asphaltic materials around old pit, in rocks of Jackfork or Atoka formations.

NE¼ sec. 31, T. 2 S., R. 13 E. Small seam of asphaltic material.

SW¼ sec. 29, T. 1 S., R. 12 E. Grahamite prospect in Bigfork chert.

NE¼ sec. 34, T. 2 N., R. 25 E. Outcrop reported 14 inches thick for distance of about 5 feet. In Jackfork sandstone. Possibly is impsonite rather than grahamite.

NW¼ sec. 21, T. 3 N., R. 25 E. Vein reported as 12 feet thick on side of steep hill of Jackfork sandstone. Possibly impsonite of same type as that at Page.

Sec. 9, T. 2 N., R. 15 E. Grahamite, identified from material sent to the Oklahoma Geological Survey by the public.

NE¼ sec. 31, T. 1 N., R. 22 E. Vein of asphaltite, probably grahamite, reported about 4 feet thick in a well dug for water at a depth of almost 20 feet. Probably in Stanley shale.

SE¼ sec. 1 and NE¼ sec. 2, T. 2 N., R. 19 E. In Potato Hills. Grahamite along bedding planes and joints in Bigfork chert and Arkansas novaculite.

NW¼ sec. 23, T. 2 N., R. 20 E. Vein reported to be 2-3 inches wide at surface and 6-8 inches wide at a depth of about 80 feet. Probably in Stanley formation.

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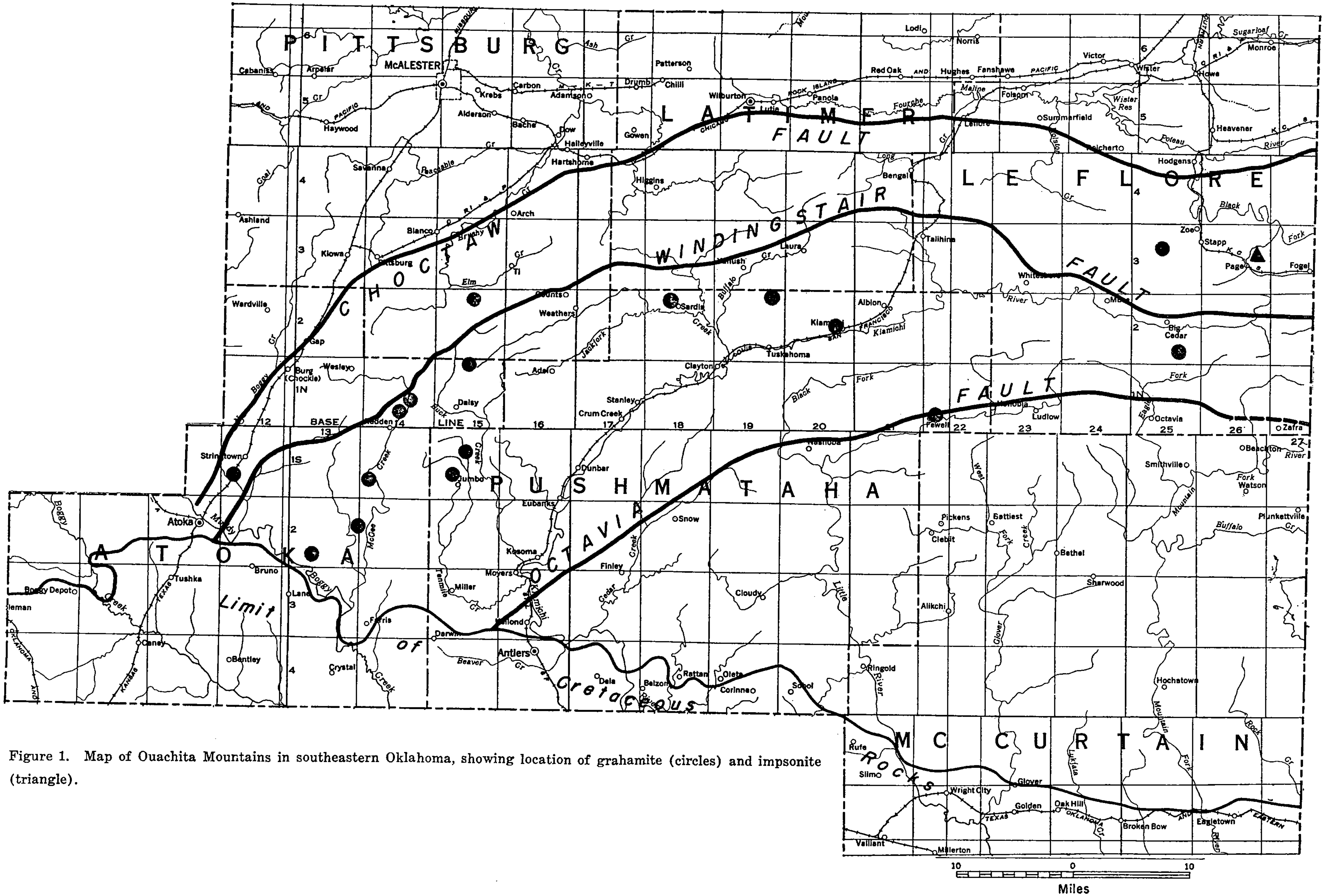

Figure 1. Map of Ouachita Mountains in southeastern Oklahoma, showing location of grahamite (circles) and impsonite (triangle).