GUIDE BOOK
SOCIETY OF ECONOMIC GEOLOGISTS

ARKANSAS—TEXAS
ECONOMIC GEOLOGY FIELD TRIP
February 23 and 24, 1974

PREPARED BY
ARKANSAS GEOLOGICAL COMMISSION
Little Rock, Arkansas
1974

REPRINTED 1975

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THE ARKANSAS GEOLOGICAL COMMISSION expresses appreciation to the following contributors who gave of their time in assisting the agency staff in preparing this Guidebook.

R. L. Schell	Alcoa Bauxite, Arkansas
E. C. Farrell	Baroid Malvern, Arkansas
D. R. Owens	Union Carbide Hot Springs, Arkansas
F. L. Pierson	Weyerhaeuser Co. Nashville, Arkansas
R. J. Bearden	Weyerhaeuser Co. Hot Springs, Arkansas
Dr. William R. Kaiser	Texas Bureau of Economic Geology Austin, Texas

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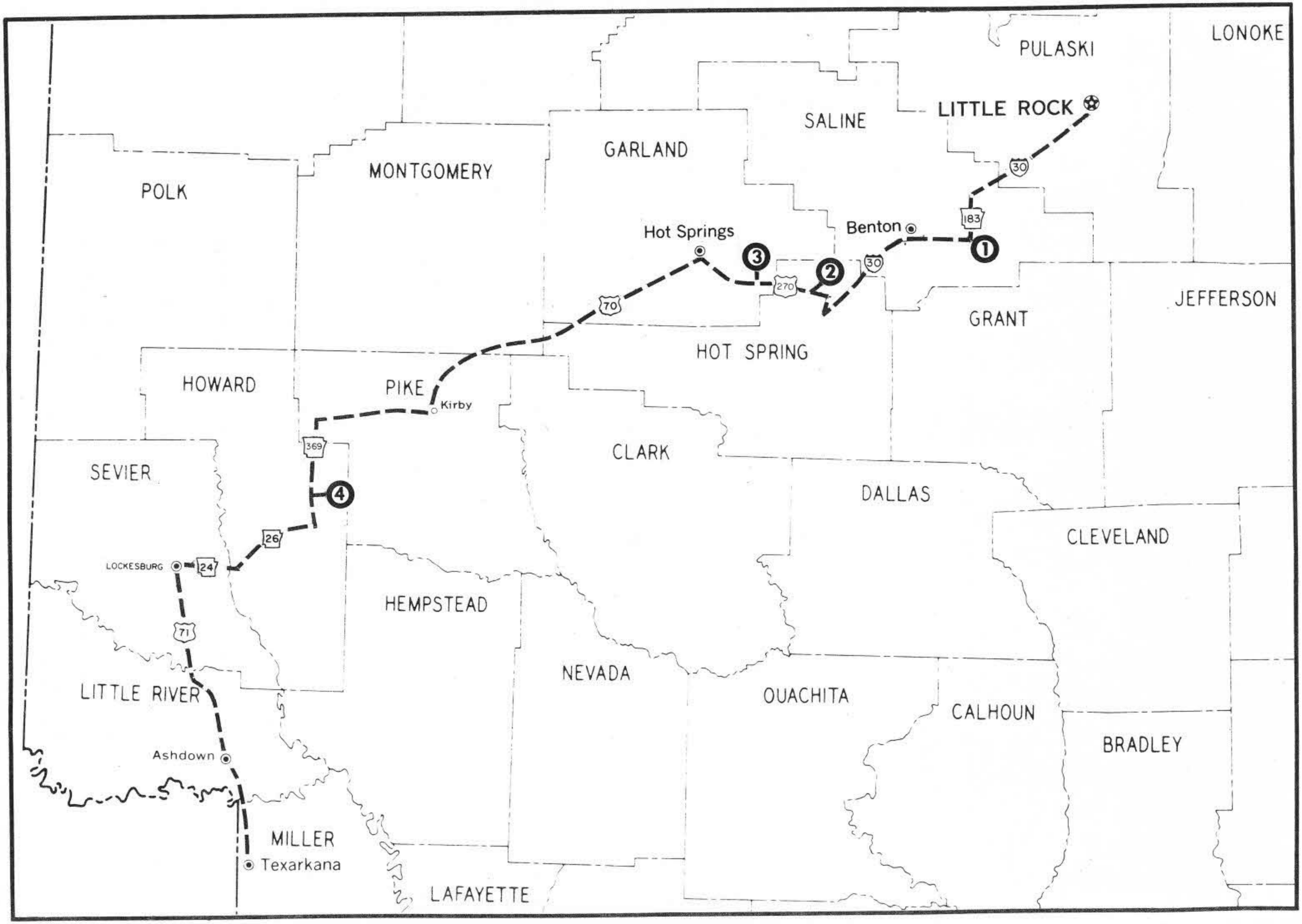


INDEX MAP SHOWIN ROUTE OF THE FIELD TRIP IN ARKANSAS

Figure 1

SOCIETY OF ECONOMIC GEOLOGISTS

ARKANSAS-TEXAS FIELD TRIP

ARKANSAS STOPS

SUMMARY

The Arkansas portion of the field trip will consist of visits to the following mines (fig. 1):

STOP 1. Aluminum Company of America's strip mines in Saline County; where Alcoa mines bauxite from the Wilcox Formation of Eocene age to supply their alumina plant at Bauxite.

STOP 2. Baroid Division of National Lead Company's strip and underground mine in Hot Spring County; where Baroid mines barite from the lower portion of the Stanley Formation in the Chamberlain Creek Syncline.

STOP 3. Union Carbide Corporation's Wilson Springs vanadium deposits in Garland County; where the company strip mines vanadium ore for processing to vanadium pentoxide in their plant located near the mines. The ore is derived from mineralized Arkansas Novaculite which occurs adjacent to the igneous intrusions in the area.

STOP 4. Weyerhaeuser Company's strip mines in Howard County; where Weyerhaeuser mines and processes gypsum from the Trinity Formation of Lower Cretaceous age to supply their wallboard plant located near the mines.

DESCRIPTION

STOP 1. (1 hr.) Raw Materials Headquarters of Alcoa.

Bauxite, the major ore of aluminum, was first identified in Arkansas by John C. Branner, State Geologist, in 1887, and has been mined commercially since 1899. Arkansas bauxite production in 1972 was over 2.0 million tons and for many years Arkansas has produced more than 90 percent of the domestic bauxite in the U.S. The primary use of Arkansas bauxite is for making aluminum metal. Other important uses are in chemicals, abrasives, refractories, and alumina cements. Alumina is produced by two plants:

Reynolds' plant at Hurricane Creek and Alcoa's plant at Bauxite. Aluminum metal is produced at two plants by Reynolds; the Jones Mill Reduction plant on Lake Catherine and the Gum Springs plant at Arkadelphia.

In addition to these two major producers of bauxite in Arkansas there are two minor producers. The American Cyanamid Company mines and ships high grade dried bauxite and kaolinite clay to the chemical and abrasive industry; and the Porocel Corporation processes bauxite for the chemical industry.

The Arkansas bauxite area covers approximately 275 square miles and is located in Pulaski and Saline Counties, Central Arkansas. There are two principal mining districts; in Pulaski County south of Little Rock, and the larger and more productive district around Bauxite in Saline County.

The bauxite deposits are centered around intrusives of nepheline syenite. These nepheline syenites, and related igneous rocks of Late Cretaceous age, were intruded into highly folded Paleozoic beds. Subsequent erosion exposed some parts of these intrusives to weathering and subsequent partial burial by sediments of Tertiary age. The bauxite deposits of central Arkansas are the result of lateritic weathering of the nepheline syenite during early Eocene times.

According to Gordon, Tracey, and Ellis (U.S. Geological Survey Prof. Paper 299) the bauxite deposits can be classified into four types:

(1) residual deposits on the upper slopes of partly buried nepheline syenite hills;

(2) colluvial deposits at the base of the Berger Formation (lowermost formation of the Wilcox Group (Eocene);

(3) stratified deposits within the Berger Formation and

(4) conglomeratic deposits at the base of the Saline Formation (formation in the Wilcox Group (Eocene) that overlies the Berger Formation).

Bauxite in the various mines differs considerably in its character and physical properties. Most of the bauxite is pisolitic, and ranges from very hard to soft and earthy. Generally, it is hard at the top of a deposit, firm to mealy in the middle, and clayey though not plastic at the base. In color it ranges from a light gray through tan and brown to red. Color is not necessarily an index of grade nor of the amount of iron present, as some of the brick-red bauxite has very little iron. The principal mineral in the bauxite is gibbsite (aluminum trihydrate). The chief impurities are silica, iron, and titanium. A significant concentration of gallium is present and is recovered as a valuable by-product. Possibly in the future other by-products of alumina production and other alumina sources within the bauxite area may be utilized.

Briefly these possibilities are:

(1) the recovery of titanium, iron, and columbium from the black sands and red muds which are waste products from the alumina plants;

(2) the recovery of both the iron and alumina from the large deposits of high-iron bauxite and

(3) the recovery of alumina from the vast deposits of high-alumina clays associated with the bauxite deposits (estimated to total over 100 million tons).

The A. P. Green Refractories Co. mines kaolinite clay that is found associated with the bauxite deposits for production of high heat duty refractories.

Bauxite reserves in the area in 1950 were estimated at about 70.7 million long tons averaging 50 percent alumina and 9 percent silica, but assuming no cutoff on iron. Of this total about 62.2 million tons occur in Saline County and 8.1 million tons in Pulaski County.

STOP 2. (1 hr.) Office of Baroid Division of National Lead Company, The Chamberlain Creek Barite Deposit.

The two companies operating this deposit produced 161,801 tons of barite in 1972. Exploitation of the deposit began in 1939 when the Magnet Cove Barium Corporation started mining and milling operations, utilizing flotation to concentrate the ore. The Baroid Sales Division of the National Lead Company started mining and milling barite in 1942.

The office of Baroid Division of the National Lead Company is on the southern limb of the syncline and the Magnet Cove Barium Corporation's office is on the northern limb of the syncline. They originally removed the shallow ore along the syncline by stripping, but the depth of their ore has forced them to go exclusively to underground mining.

In the milling operations the ore is ground to 325 mesh and processed by froth flotation. The concentrates produced run about 98 percent $BaSO_4$ with a loss of only about 10 percent of the original values. All of the barite produced from this deposit is used as a weighting agent in oil well drilling muds.

The Chamberlain Creek barite deposit is a stratiform deposit at the base of the Stanley Shale (Mississippian). This zone is essentially conformable with the bedding of the enclosing sediments and averages 60 feet in thickness. Structurally, the deposit lies in an asymmetrical syncline. The syncline plunges southwest toward the Magnet Cove intrusive one mile to the west and is truncated at its eastern end by erosion giving the orebody a spoon-like shape. The maximum length of the orebody is 3200 feet and its maximum width is 1800 feet. Some of the ore is nodular, but most of it has a dark gray, dense appearance resembling limestone. The barite is intimately mixed with minor amounts of fine-grained quartz, pyrite, and shale. A typical analysis of high-grade ore would be 85 percent $BaSO_4$, 11 percent SiO_2, and 3 percent iron oxide and alumina. The average mill feed is about 60 percent $BaSO_4$.

STOP 3. (2 hrs. 30 min.) Arkansas Operations, Mining and Metals Division of Union Carbide.

Mining was started at the Wilson Springs vanadium operation in 1966 and it is the only mine in the United States developed for vanadium as the only product. Union Carbide produced 481,082 tons of vanadium ore in 1972. Although the Wilson Springs area was investigated in the 1950's for uranium and columbium, the economic vanadium potential was not determined until 1960. Two open pit mines are presently being developed.

The ores contain approximately one percent vanadium pentoxide which is recovered in this plant by hydrometallurgical methods. The majority of the vanadium produced is alloyed in steel.

The ore deposits occur in the vicinity of the contact between the Potash Sulfur Springs alkalic igneous complex and the surrounding Paleozoic sedimentary rocks. The intrusive complex, which was probably emplaced in Late Cretaceous time has a crude ring structure similar to Magnet Cove. The outer ring is alkali syenite and fenite, and much of the central part of the complex is nepheline syenite. Jacupirangite, melteigite, ijolite, and carbonatite.

See article in this guidebook for more details of the area.

STOP 4. (1 hr.) Weyerhaeuser Company's gypsum mining operation at Briar, Arkansas.

Two companies presently mine

gypsum in Arkansas and they produced about 425,000 tons in 1972. The Weyerhaeuser Company strip mines gypsum which is consumed in the manufacture of wallboard in their plant at Briar, Arkansas. The Dulin Bauxite Company strip mines gypsum at Highland, Arkansas, and most of it is sold to consumers who use it as a retarder in cement.

The gypsum occurs as beds in a sedimentary sequence of rocks which make up the DeQueen Limestone member of the Trinity Formation of Lower Cretaceous age. The DeQueen Limestone is about 60 feet thick and consists of beds of limestone, clay, gypsum, celestite, and some lignite. The gypsum and celestite are in the lower part of the section. Gypsum has been observed in outcrop from Plaster Bluff, three miles southwest of Murfreesboro in Pike County, to Messer Creek in central Howard County; approximately 20 miles in distance. Beds of gypsum as much as 14 feet thick occur in the eastern end of this outcrop belt. Maximum reported thickness of the celestite is 10 inches.

See article in this guidebook for more details of the area.

NOTES

THE CHAMBERLAIN CREEK BARITE DEPOSIT

Berton J. Scull
Manager, Mineralogy Section
Sun Oil Company R & D Laboratory
Richardson, Texas

The occurrence of barite in the Ouachita Mountains of Arkansas has been known since 1890. With the development of the use of ground barite as a weighting agent in oil well drilling muds, interest was shown in the Arkansas deposits, and in 1939 the Magnet Cove Barium Corporation found that an acceptable drilling mud barite could be obtained from the ore by flotation. The company then began producing barite from the Chamberlain Creek syncline deposit near Magnet Cove in Hot Spring County, and in 1941 the Baroid Division of the National Lead Company started mining and milling operations on a portion of the same deposit. Annual production from this deposit expanded rapidly from 2,500 short tons in 1939 to a peak of 468,000 short tons in 1957. Although production has declined since 1957 because of decrease in drilling activity and competitive sources, Arkansas is second only to Missouri in domestic barite production.

The barite region of Arkansas comprises about 2700 square miles in the southern part of the Ouachita Mountain system and the northernmost part of the West Gulf Coastal Plain of Arkansas. The most important occurrence is the Chamberlain Creek deposit.

The Chamberlain Creek syncline deposit is in the Magnet Cove district in the northeast part of the Malvern quadrangle and lies wholly within Hot Spring County. The Paleozoic rocks exposed in the district range from the Ordovician (Bigfork Chert) to the Mississippian (Stanley Shale). The Mesozoic is represented by the Magnet Cove igneous rocks and the Cenozoic is represented by the lower Tertiary Midway Formation, which overlaps the Paleozoic rocks on the southeast side of the district. Structurally, the district incorporates the eastern end of the Mazarn Basin, part of the Zigzag Mountains, the northernmost part of the Trap Mountains, and the Magnet Cove ring dike complex which truncates the Chamberlain Creek syncline on the southwest. The major barite deposit is located in the Stanley Formation in this syncline, one of the southwestward plunging synclines of the Zigzag Mountains.

Local Structure. The Chamberlain Creek syncline from where it is truncated on the southwestern end by the Magnet Cove intrusives in the eastern part of Sec. 17, T. 3 S., R. 17 W. extends northeastward with a subsymmetrical outline for about two miles. Structurally the syncline is decidedly asymmetrical, with the southeast limb being steeper and locally overturned (Fig. 2).

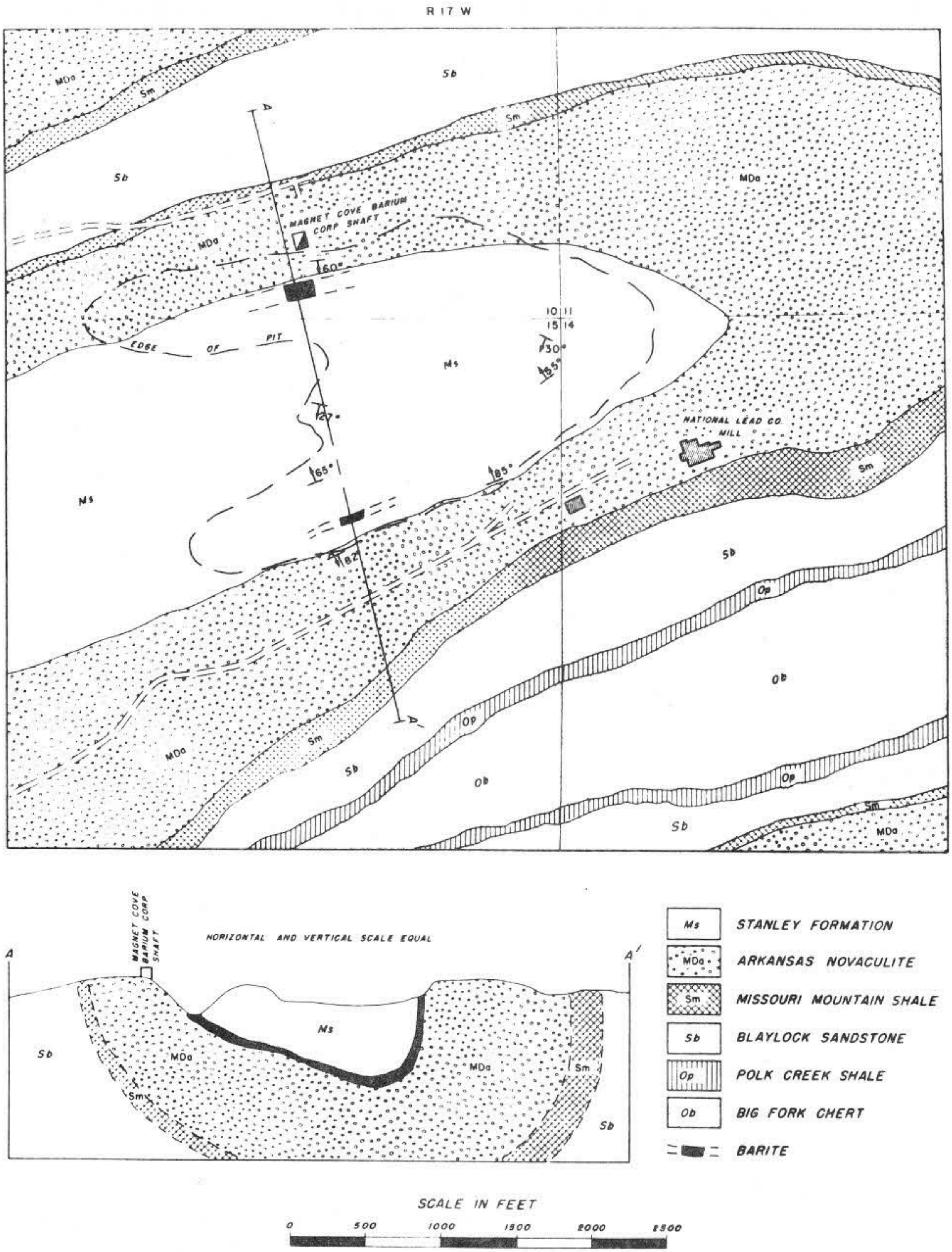
In the rock exposures made available by the underground mining operations, many more local structures can be seen than anywhere in the district. Underground, minor structures in the form of V and chevron folds, rollovers, and normal and reverse faults are common. The displacement along the faults is ordinarily only a few inches. These local structures have no appreciable effect on the concentration of the barite, although there is a slight increase in the grade of the ore along the axes of some of the folds.

Stratigraphic Relations. The barite ore in this deposit lies near the base of the Stanley Formation being separated from the underlying Arkansas Novaculite Formation by a bed of black shale varying in thickness from 2 to 22 feet.

In the area of the mine workings there is a maximum of 600 feet of shale, sandstone, and siltstone of the Stanley Formation overlying the black shale unit. This Formation is probably about 2,000 feet thick near the contact with the Magnet Cove intrusion.

The Ore Bodies. The barite deposit in the Chamberlain Creek syncline is located in the northeastern part of the structure. It has a maximum length of 3,200 feet and apparently is restricted to that portion of the syncline in which the axial trend is nearly eastward. The maximum width of the ore body (1,800 feet) occurs at the west end of the deposit. Because of natural truncation, the width diminishes eastward. The ore body has been completely eroded away at the eastern tip of the structure. The average thickness of the mineralized zone is about 300 feet and the average thickness of commercial concentration is about 60 feet. The maximum thickness of commercial ore occurs just north of the axis of the syncline where it has a thickness of 80 to 100 feet.

The available drill hole information and the exposures in the surface and underground mine workings show that in this thicker portion the mineralized zone is split into two bodies separated



GEOLOGIC MAP OF THE CHAMBERLAIN CREEK BARITE DEPOSIT
HOT SPRING COUNTY ARKANSAS

AFTER B J SCULL 1958

ARKANSAS GEOLOGICAL COMMISSION

Figure 2

by an essentially barren shale lens 5 to 15 feet thick. This is the only place in the commercial ore zone where a persistent barren or non-productive unit occurs.

With respect to texture and structure there are several types of barite ore. The major types in order of decreasing abundance are: finely crystalline in beds and lenses, dense microcrystalline in beds and lenses, nodular, and coarsely granular in lenses. These major types grade into each other laterally, pinch out, grade into low baritic sediments, or grade into non-baritic sediments. The thicker (1 to 3 feet) units ordinarily grade into low grade baritic shales and siltstones or nodule-bearing shales and siltstones. They do not pinch out as true lenses.

The nodular type ore makes up from 3 to 30 percent of the ore body, depending on the section measured. Coarsely crystalline barite is rare in this deposit. Most of the ore is of the gray to dark gray dense variety. Much of it has, superficially, a close resemblance to a dense limestone.

Origin. The origin of the barite in Arkansas has been the subject of two Ph.D. dissertations: B. J. Scull, University of Oklahoma, 1956 (published 1958, Arkansas Geological and Conservation Commission, Information Circular 18) and R. A. Zimmermann, University of Missouri, 1964.

Scull postulated that all of the Arkansas barite deposits were lower Upper Cretaceous in age, derived from the sub-silicic Upper Gulf Coastal Plain igneous suite and, with the sulfide deposits in the Ouachita Mountains, represented a minerogenetic province. Zimmermann concentrated on the deposits in the Stanley Formation (several thousand times greater in volume than the combined other types of deposits) and postulated that they are of sedimentary origin, and thus Mississippian in age.

GEOLOGY OF THE WILSON SPRINGS VANADIUM DEPOSITS

Garland County, Arkansas

J. S. Hollingsworth
Union Carbide Corporation
Mining and Metals Division
Arkansas Operations

INTRODUCTION

The vanadium deposits currently mined by Union Carbide Corporation at Wilson Springs, Garland County, Arkansas, are the only deposits mined specifically for vanadium in the United States. The geologic setting of these deposits is described in this report.

The Wilson Springs operation takes its name from Wilson Mineral Springs (formerly known as Potash Sulfur Springs), which is located near the edge of the small circular alkalic intrusive also named after these springs. J. F. Williams described the igneous rocks of the area in 1890 and noted that a large hotel existed near the springs. The building was first abandoned and later destroyed by a fire in the early 1930's.

Interest in the economic potential of the Wilson Springs area was primarily initiated in 1950 by the discovery of anomalous radioactivity and one boulder containing small amounts of uranian pyrochlore (Erickson and Blade, p. 83). Several investigations were conducted by the U. S. Geological Survey, the Atomic Energy Commission, the Arkansas Geological Commission, and private mineral interests. Only trace amounts of uranium were indicated by drilling and trenching adjacent to the "discovery boulder." Geochemical determinations by the U. S. Geological Survey and others indicated significant concentrations of niobium and vanadium in the vicinity of the uranium prospect (Beroni, 1955).

Union Carbide geologists first investigated the Wilson Springs area for vanadium in 1960. After obtaining mineral leases, a preliminary core drilling program during 1961-1962 disclosed vanadium ores. Development drilling was resumed in 1964; and by September, 1965, sufficient reserves were indicated to justify the construction of the Wilson Springs Vanadium Plant.

GEOLOGY

The location and general geologic setting of the Wilson Springs vanadium deposits are shown in Figures 3 and 4. The dominant feature of the area is the Potash Sulfur Springs[1] igneous complex, which intruded folded and faulted Paleozoic rocks. The distribution and description of the various rock types are generalized, with modifications, from D. W. Pollock (1966) who performed field and petrographic investigations of the intrusive. The highly variable contact rocks have been studied in detail by V. J. Hoffmann and D. M. Hausen of Union Carbide Corporaiton.

Igneous Rocks

The Potash Sulfur Springs intrusive is a circular alkalic igneous complex exposed for somewhat less than a mile in diameter, that probably was emplaced in early Late Cretaceous time (Zartman and Marvin determined the Magnet Cove intrusive to be 95 ± 5 million years). The complex has a crude ring structure similar to the Magnet Cove intrusive exposed about 6 miles to the east. The outer ring of the complex is alkali syenite and fenite. Much of the central part of the complex is nepheline syenite. Disconnected exposures of jacupirangite, melteigite, and ijolite are present throughout the area. Near the center of the complex a calcite-cemented breccia crops out and carbonatite has been encountered in a few drill holes. Carbonatite is also present as dikes and as irregular masses in the subsurface near the margins of the intrusive. Several igneous and sedimentary rock breccias, commonly with feldsphathic matrix, are present within and near the margins of the intrusive.

Saprolite, highly weathered rock averaging about 40 feet in thickness, is developed over much of the igneous area, but the outer portion of the nepheline syenite ring supports a low ridge.

The basic rocks of the Potash Sulfur Springs complex include jacupirangite, pyroxenite, and members of the melteigite-ijolite series. Nepheline content varies from traces in jacupirangite to a maximum of 60 percent in ijolite. Biotite jacupirangite contains small amounts of magnetite and titanite with biotite as the only major constituent. The pyroxenite contains aegirine-diopside, ferroaugite, and biotite. Locally these rocks have been intensely chloritized. The melteigites have aegirine-

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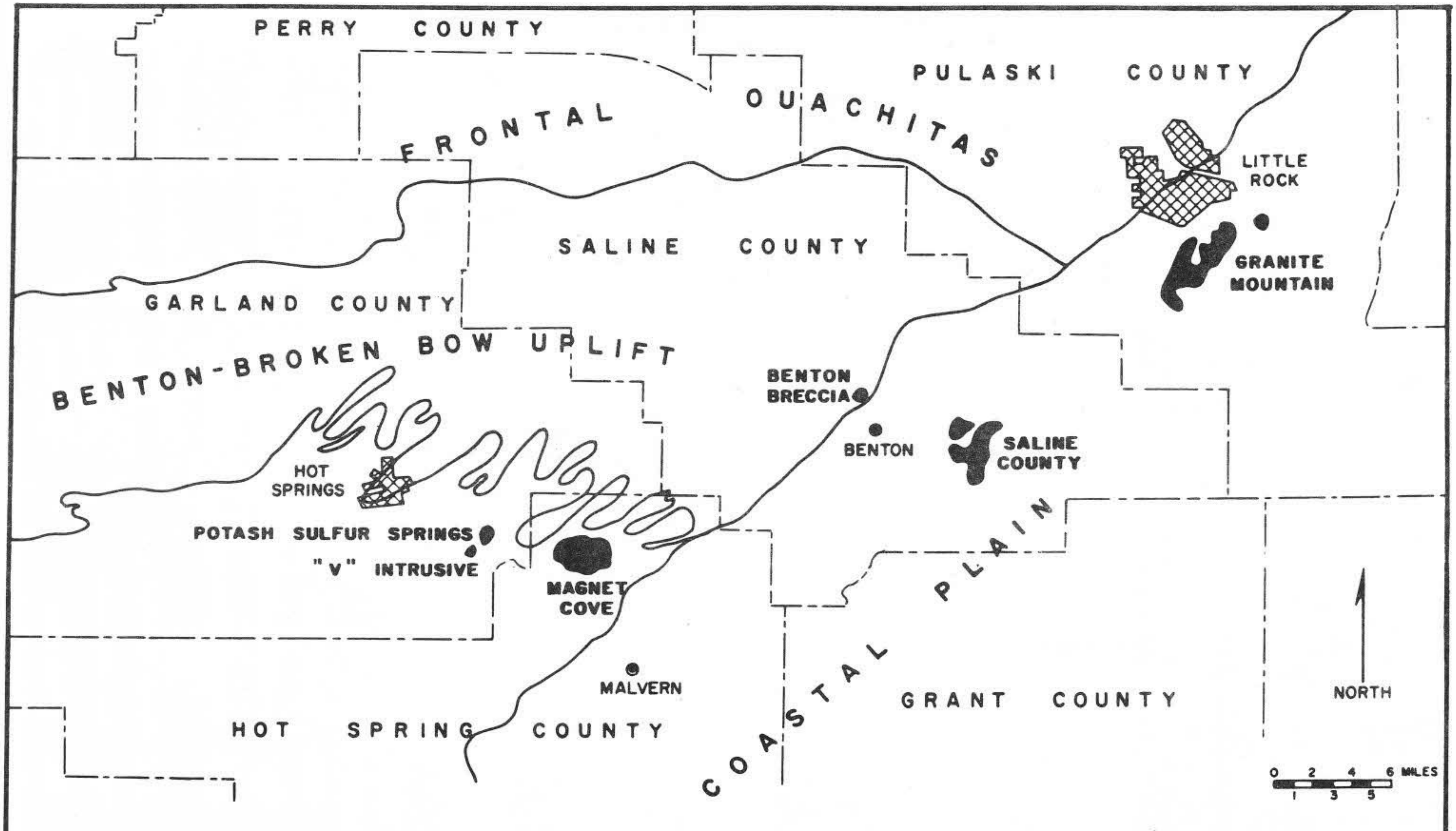
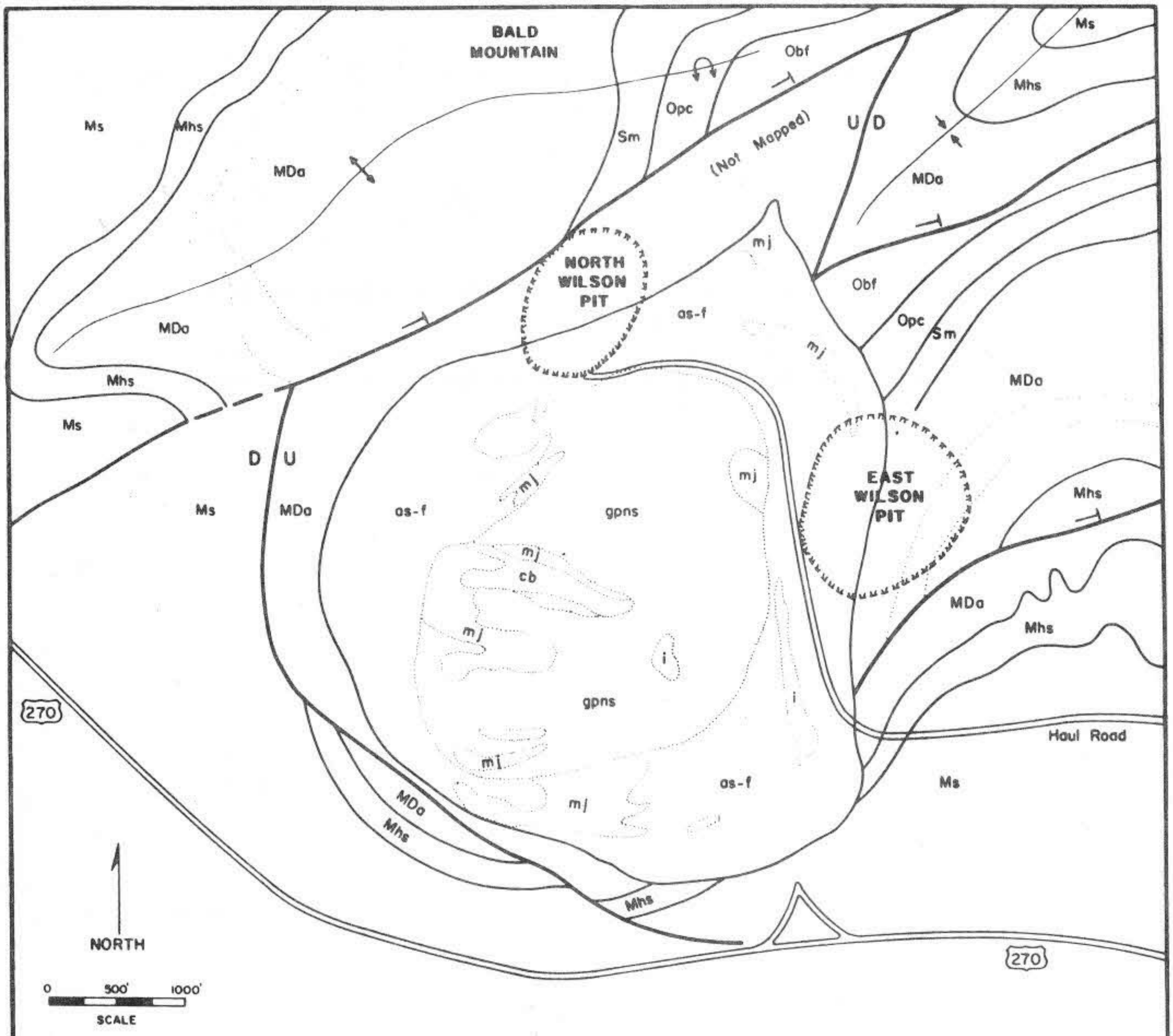
[1] The name Potash Sulfur Springs is used throughout geological literature for the intrusive and is retained herein.



LOCATION MAP SHOWING POTASH SULFUR SPRINGS INTRUSIVE
AND OTHER EXPOSED ALKALIC INTRUSIVES
OF CENTRAL ARKANSAS

Figure 3



GENERALIZED GEOLOGIC MAP OF THE POTASH SULFUR SPRINGS INTRUSIVE AND VICINITY, GARLAND COUNTY, ARKANSAS

MODIFIED FROM PURDUE AND MISER (1923) AND POLLOCK (1966)

SEDIMENTARY ROCKS

MISSISSIPPIAN	Ms	STANLEY SHALE
MISSISSIPPIAN	Mhs	HOT SPRINGS SANDSTONE
DEVONIAN AND MISSISSIPPIAN	MDa	ARKANSAS NOVACULITE upper middle lower
SILURIAN	Sm	MISSOURI MT. SHALE
ORDOVICIAN	Opc	POLK CREEK SHALE
ORDOVICIAN	Obf	BIGFORK CHERT

IGNEOUS ROCKS

as-f	ALKALI SYENITE AND FENITE
gpns	GARNET PYROXENE NEPHELINE SYENITE
i	IJOLITE
mj	MELTEIGITE, PYROXENITE & JACUPIRANGITE
cb	CALCITE CEMENTED BRECCIA
⊣	THRUST FAULT
U/D	FAULT
↕	ANTICLINE
⇅	SYNCLINE

Figure 4

diopside with 14 to 40 percent nepheline. In one variety of melteigite, titanium-rich andradite (garnet) makes up 30 to 60 percent of the rock. Garnet and pyroxene are present in the ijolites. Secondary minerals such as calcite, orthoclase, zeolites, and pyrite may be up to 55 percent of these rocks.

The nepheline syenite contains 7 percent aegirine-diopside and 7 percent garnet with about 32 percent nepheline. Calcite, secondary orthoclase, and zeolites are present in variable amounts.

The alkali syenite and fenite ring represents 51 percent of the exposed complex. The alkali syenites are medium to coarse grained with 80 to 98 percent orthoclase. Much of the rock in this zone is a product of alkali-metasomatism and, therefore, should be termed fenite rather than syenite. The contact between the fenite and the surrounding sedimentary rock is irregular, and residual blocks and zones of metamorphosed sedimentary rocks are frequently found. Relict bedding can be seen in some fenite exposures. Aegirine is a common accessory mineral in the fenite, and occasionally makes up 80 to 90 percent of the rock. Locally, biotite, apatite, or siderite may be major constituents in the border fenites.

Calcite carbonatite has been encountered beneath the saprolite cover by several drill holes in the central part of the complex. Biotite, aegirine, pyrite, pyrrhotite, and magnetite are the most common accessory minerals. A few feldspar-carbonate veins, similar to the veins at Magnet Cove, have been encountered.

Dikes and sills of various sizes and attitudes are frequent within the igneous mass but appear to be more abundant in the surrounding sedimentary rocks. A large variety of rock types is present ranging from phonolites and trachytes to the very basic varieties including ouachitite, monchiquite, and fourchite. Outside the igneous complex, most of the dikes are partially or completely argillitized, often to depths of several hundred feet—only the texture remains to identify the origin of such clays. Many dikes are xenolithic; a large irregular dike mass in the North Wilson pit contains rounded as well as angular fragments of the adjacent rocks.

Stratigraphy

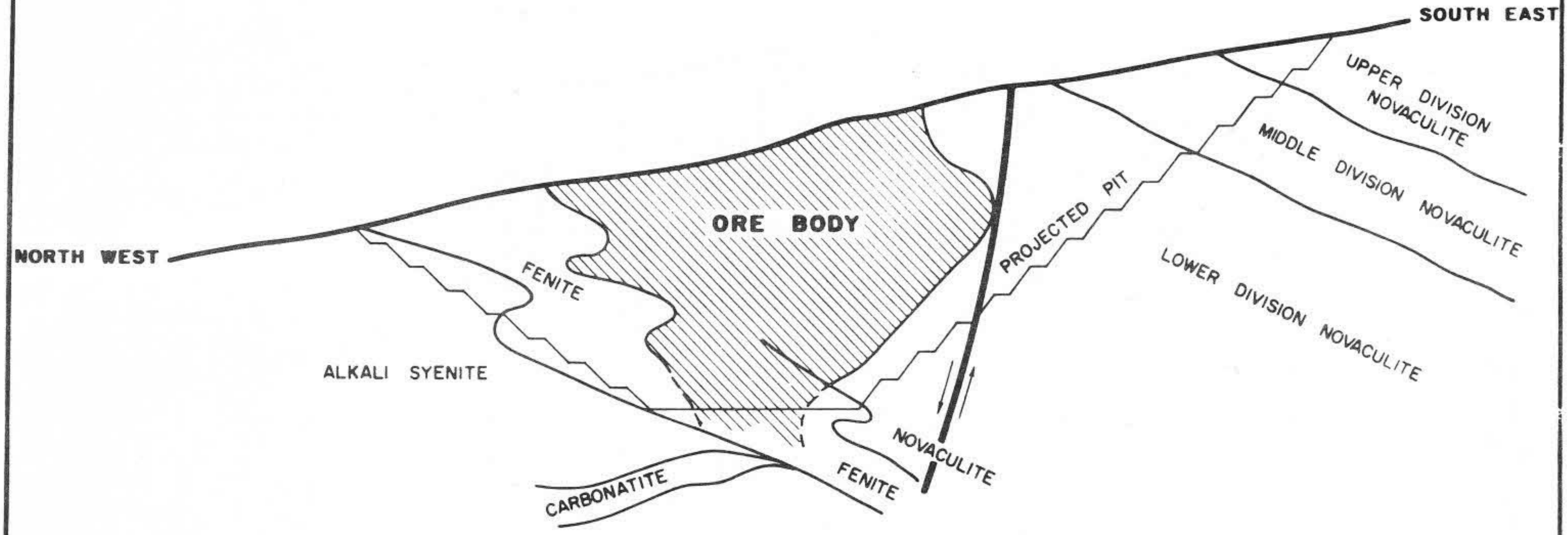
The sedimentary rocks in the immediate vicinity of the Potash Sulfur Springs intrusive range from Ordovician (Bigfork Chert) to Mississippian (Stanley Shale) in age. The approximate observed thicknesses of these units and a brief description are shown in the accompanying table.

Within 1000 feet of the igneous rocks, the Arkansas Novaculite has been recrystallized by thermal metamorphism to a very fine to medium grained quartzite. Closer to the intrusive, the siliceous units contain cristobalite, wollastonite, tremolite, aegirine, miserite, and calcite in a highly variable metamorphic rock suite. The shale units have been metamorphosed to hornfels. Large areas of shale have been argillitized, at least in part by hydrothermal solutions, thus many of the stratigraphic units cannot be distinguished in the immediate vicinity of the ore deposits.

Structure

The Potash Sulfur Springs intrusive is located on a southwest plunging anticlinal nose of the Zigzag Mountains. The sedimentary rocks were intensely folded and faulted during the Late Pennsylvanian Ouachita orogeny. These structures trend about N 65° E. Several anticlines and at least three thrust faults are present in the area (Figure 4). The northernmost anticline at Bald Mountain is overturned to the north for much of its length.

The Potash Sulfur Springs intrusive considerably distorted the older Ouachita structural fabric. Minor faulting is quite common within 1,000 feet of the intrusive contacts. One large concentric fault is shown on the geologic map (Figure 4) and many others have been noted (Figure 5). Some of the older Ouachita faults were re-opened, altered, and mineralized by the intrusive, especially the thrust fault at the north edge of the North Wilson pit.



DIAGRAMMATIC CROSS SECTION
OF THE EAST WILSON PIT

NOT TO SCALE

Figure 5

TABLE I

STRATIGRAPHIC UNITS IN THE VICINITY OF THE POTASH SULPHUR SPRINGS INTRUSIVE

AGE	FORMATION	DESCRIPTION	APPROXIMATE LOCAL THICKNESS IN FEET
Mississippian	Stanley Shale	Dark gray platy shale with thick beds of fine-grained clayey sandstone.	over 1,000
Mississippian	Hot Springs Sandstone	Light gray, very-fine grained sandstone interbedded with dark gray shale.	90
Devonian and Mississippian	Arkansas Novaculite	Upper Division: medium to thick bedded white novaculite and ferruginous sandstones. Some gray shale interbeds are present and the base is marked by 1–2′ of conglomerate.	75
		Middle Division: thin bedded novaculite interbedded with dark gray fissile shale—strongly argillitized in the immediate area.	120
		Lower Division: white and black massive novaculite.	380
Silurian	Missouri Mountain Shale	Pale red to greenish gray shale, 1–2′ of ferruginous fine-grained sandstone at base may represent the Blaylock Sandstone.	100
Ordovician	Polk Creek Shale	Black, fissile, graphitic shale with thin beds of limy chert.	130 to 200
Ordovician	Bigfork Chert	Gray and black chert regularly interbedded with gray siliceous shale.	over 300

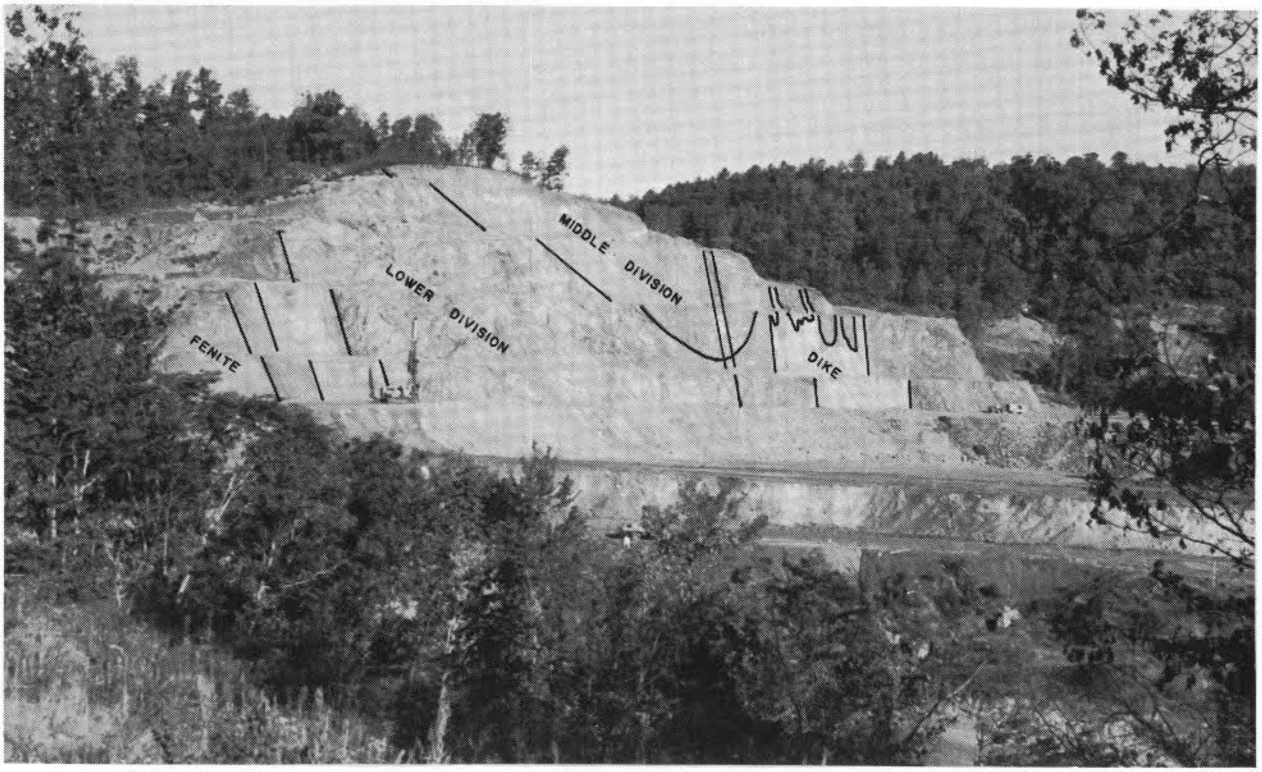


Figure 6 View of the North Wilson Pit looking northwest at the north-south high wall. Description in text.

The high west wall of the North Wilson pit shown in Figure 9 displays the structural complexity of the near-contact areas. On the far right is a shattered zone probably representing an anticline. A broad fault zone left of the xenolithic dike cuts the bottom of a syncline. The contact between the Lower and Middle Divisions of the Arkansas Novaculite in the center marks the north limb of an anticline. Southward the Middle Division shales and cherts reappear in a syncline with two or three small faults and numerous dikes. Farther south fenite replaces the novaculite along an irregular contact.

ORE DEPOSITS

The vanadium ore deposits of the Wilson Springs area occur near the contact between the alkalic igneous rocks and the surrounding sedimentary rocks. Two ore bodies are being developed by separate open pits. Other deposits are present in the area that will be developed at a later date.

The vanadiferous ores occur as local concentrations within large, irregular areas of argillic alteration. Fenite, feldspathic breccias, and metamorphosed sedimentary rocks have all been altered and mineralized in such areas (Figure 8). Iron oxides are common near the present surface, and pyrite is present at depth.

The ores contain about one percent V_2O_5 which very rarely occurs as discrete vanadium minerals. Montroseite ($VO \cdot OH$) and such secondary minerals as fervanite ($2Fe_2O_3 \cdot 2V_2O_5 \cdot 5H_2O$) and hewettite ($CaO \cdot 3V_2O_5 \cdot 9H_2O$) have been noted. The vanadium occurs as a vicarious element in several rock-forming minerals and their alteration products.

Even though the Wilson Springs area has been investigated as a potential niobium deposit (Fryklund, Harner, and Kaiser, p. 55), the niobium content of the ores being mined is low, generally under 0.10% Nb_2O_5. Titanium occurs in minor quantities, mainly as anatase, which contrasts sharply with the higher values in the titanium prospects at the Magnet Cove intrusive.

Close control of the vanadium content must be maintained to derive optimum metallurgical results in the processing of the ore. The varying nature of the ore requires close spaced test drilling, generally 20 foot centers, directly ahead of mining. Visual inspection is of limited value in ore control due to the variability of values and the non-descript nature of the ore.

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The Weyerhaeuser Gypsum Mining Operation

at Briar, Arkansas

Frank L. Pierson
Mining Engineer
Weyerhaeuser Company
Nashville, Arkansas

The gypsum deposit on which the Briar Plant is located, is found in the lower section of the DeQueen Limestone, of the Trinity Formation, of Lower Cretaceous Age. This deposit extends from Murfreesboro, Arkansas, through DeQueen, Arkansas, and on into Oklahoma; striking in a generally east-west direction and dipping approximately 1.5% to the south.

There are in the Briar area three principal gypsum beds, two minor beds and several stringers. At this time, only the three principal beds are mined and used solely as the major constituent in the manufacture of gypsum wallboard.

A typical cross section of the operation would be approximately eighty feet deep, divided as follows:

The topsoil (OB-1 upper) is taken with 621 Cat Scrapers down to Ls "S" which is 18 feet deep and is 25 feet above the Gypsum Bed (B-1). This section is called (OB-1 lower) and is drilled and shot with 25' depth holes on 15'x15' centers and 4 3/4" in diameter blast holes, using milisec delays and ANFO.

Two mining systems are presently in use; a panel operation, utilizing a 6½ yard dragline, and an open pit operation, utilizing a 4 yard shovel and 50 ton trucks. With either the dragline or shovel, depending on which area is being mined, the OB-1 lower is removed.

The production crew drill and blast the six foot thick gypsum bed, called B-1, with 3½" blast holes on a 6'x7' spacing.

The production rate is about 1,500 TPD with a stripping rate of about 3,750 YPD. The 2½' OB-2, underlying Bed 1 is stripped with Scrapers, and Bed 2 is conventionally mined, similar to Bed 1.

At this point the longhole drill is again brought in to drill OB-3, which is 15' thick, and like OB-1 lower, consists of hard limestone strata, with hard sandy shale to soft clay between. The drill pattern and stripping method on OB-3 is the same as described above for OB-1 lower.

Bed 3 which is the lower gypsum bed is eight feet thick and is conventionally mined with the same system as the upper beds, B-1 and B-2, already described.

As mining progresses, whether it be the panel or the open pit operation the mined out area is filled in behind with the overburden, leveled and planted with grasses and trees.

The drainage system in both areas consists of submersible pumps mounted on pontoon floats and operating in drain cuts carried down dip from each mining operation. The water is 100% runoff, there being no ground water in the mining area.

East Texas Iron Ore and Lignite

W. R. Kaiser
University of Texas, Austin
Bureau of Economic Geology

INTRODUCTION

Everyone knows of Texas' preeminence in oil and gas production. Few are aware of the fact that the value of the state's non-hydrocarbon mineral production places it eleventh nationally. Iron ore and lignite are facets of the Texas mineral industry that are unknown to most outsiders and relatively unknown to most Texans. Stop 1 affords an opportunity to see the geology and mining of a Texas iron ore deposit. Interestingly enough, it is linked to the energy crisis for the ultimate product is badly needed tubular goods, crucial to the Texas oil and gas industry. And as oil and gas reserves dwindle, Texans in the past three years have suddenly rediscovered lignite as an energy resource. Stop 2 affords an opportunity to see how one progressive company plans to mine lignite in an environmentally acceptable manner and to review the geology of one type of Texas lignite occurrence.

The Texas half of this trip begins in Texarkana (fig. 1). Stop 1 is at Lone Star, Texas, 50 miles southwest of Texarkana and 6.5 miles south of Daingerfield on U. S. 259. The ore operations office is 1.9 miles east of Lone Star just off FM 250 (fig. 2). Here we'll inspect the iron mine of Lone Star Steel Company. Stop 2 is at Winfield, Texas, 62 miles west-southwest of Texarkana, 23 miles northwest of Daingerfield, and 8.6 miles west of Mt. Pleasant on U. S. 67. The fuel division is 1.9 miles northeast of Winfield just off FM 1734 (fig. 3). Here we'll inspect the lignite mine of Industrial Generating Company.

Acknowledgments

Lone Star Steel Company and Texas Utilities Company, the parent company of Industrial Generating Company, granted access to their properties.

Special thanks go to Eric Ottman of Lone Star Steel and Louis Robinett of Industrial Generating for their participation at the site, providing data on the specific deposits, and stimulating discussion of the local geology.

Illustrations were prepared under the direction of J. W. Macon, Bureau of Economic Geology, The University of Texas at Austin. Elizabeth T. Moore typed the manuscript.

ILLUSTRATIONS FOR TEXAS STOPS

HISTORY AND CURRENT OPERATIONS

Iron Ore

The first published reference to East Texas iron ore deposits appeared in 1839, while in 1855 the first furnace, the Nash furnace, was built in Marion County. During the Civil War the Confederate government operated several existing furnaces and erected new ones as did the private sector. Following the War's end in 1865, all fell into disuse. Production of pig iron resumed in 1870 at the new Kelley or Loo Ellen furnace erected near Jefferson, Texas (Marion County) which operated continuously until 1886 and was the last of the old, low capacity (2 to 10 tons per day) furnaces. In the 1880's and 90's, four furnaces, romantically named Old Alcalde, Star and Crescent, Tassie Belle, and Lone Star, operated having capacities of 7,000 to 20,000 long tons per year. The Old Alcalde was built by the State of Texas at Rusk, Texas (Cherokee County) and used convict labor from the earlier constructed Rusk penitentiary. The Tassie Belle was located at New Birmingham, 1.5 miles southeast of Rusk. Promoters called New Birmingham the "Iron Queen of the Southwest" and for a while the town prospered, drawing such notable visitors as Grover Cleveland, Jay Gould, and James Hogg, the first native born governor of Texas. Today New Birmingham is a ghost town with a little slag, some charcoal, and a few bricks the only reminders of its former glory.

Pig iron was produced in Texas until 1911; iron ore was mined until 1921. Total iron ore production for the years 1855 to 1921 was about 700,000 long tons, ranging from 500 to 118,000 tons annually, and averaging 12,500 tons (Eckel, 1938, p. 14-15). The decline of this first phase of the iron industry in Texas was due almost entirely to the fact that modern iron production requires coke. Coal suitable for making coke is not available in Texas.

The second phase of the Texas iron industry began in 1940 when iron ore mining resumed from one mine in Cass County. World War II stimulated the industry causing mills to be built at Lone Star, Texas (Lone Star Steel Co.) and Houston (Armco Steel Corp.) which utilized East Texas iron ore. Ore was mined from three mines, one each in Morris, Cass, and Cherokee Counties, and totaled 200,000 to 300,000 long tons of usable ore per year. In 1950 ore production reached one million usable tons for the first time and continued at approximately that level to 1957 when production was concealed. In the 50's the principal products were tubular goods for the oil and gas industry. The 60's saw a diversification of product line to lessen dependency on the pipe markets of the oil and gas industry.

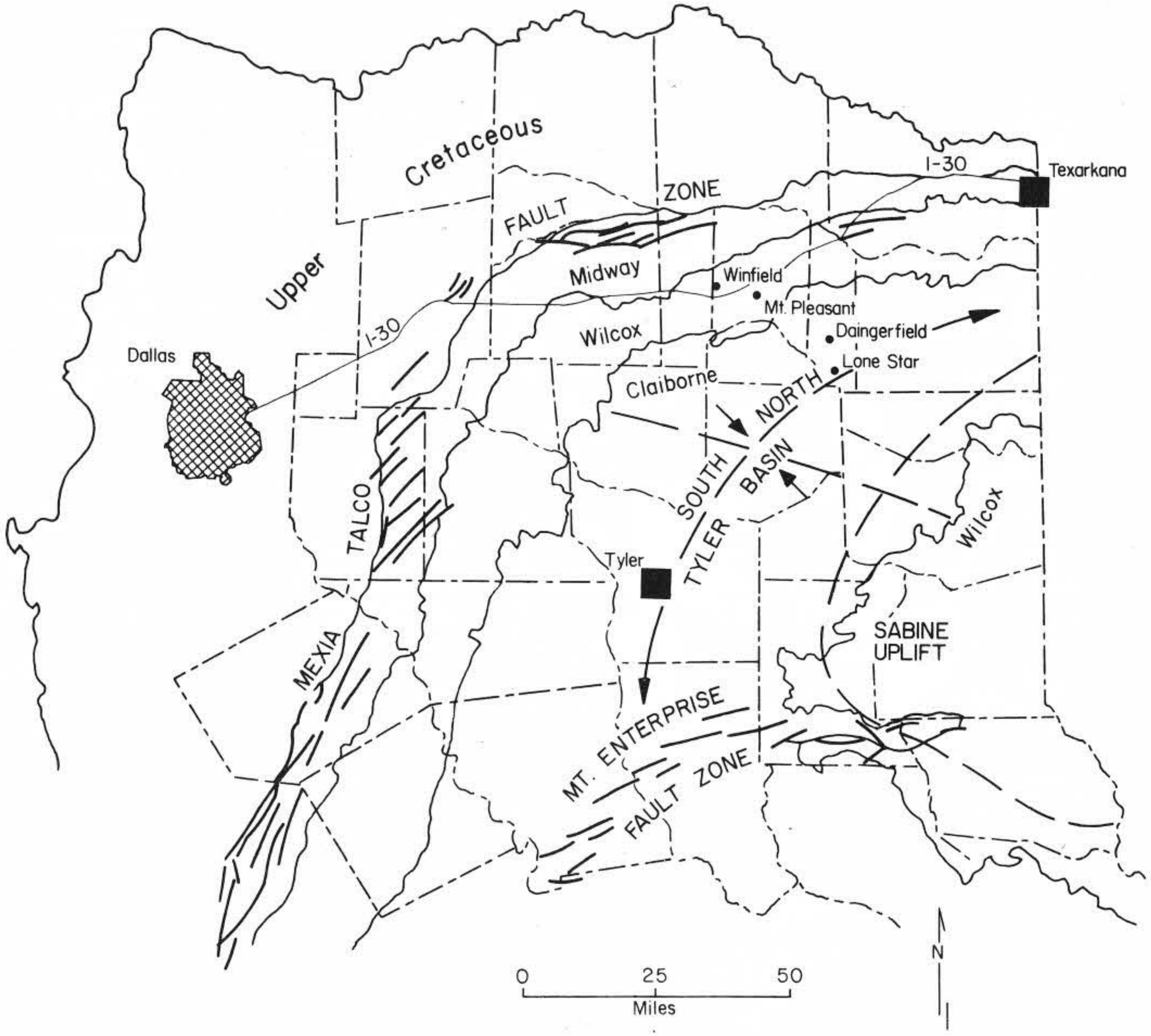


Figure 1

Geologic map of East Texas. Geology from Eckel 1938 and Renfro 1973.

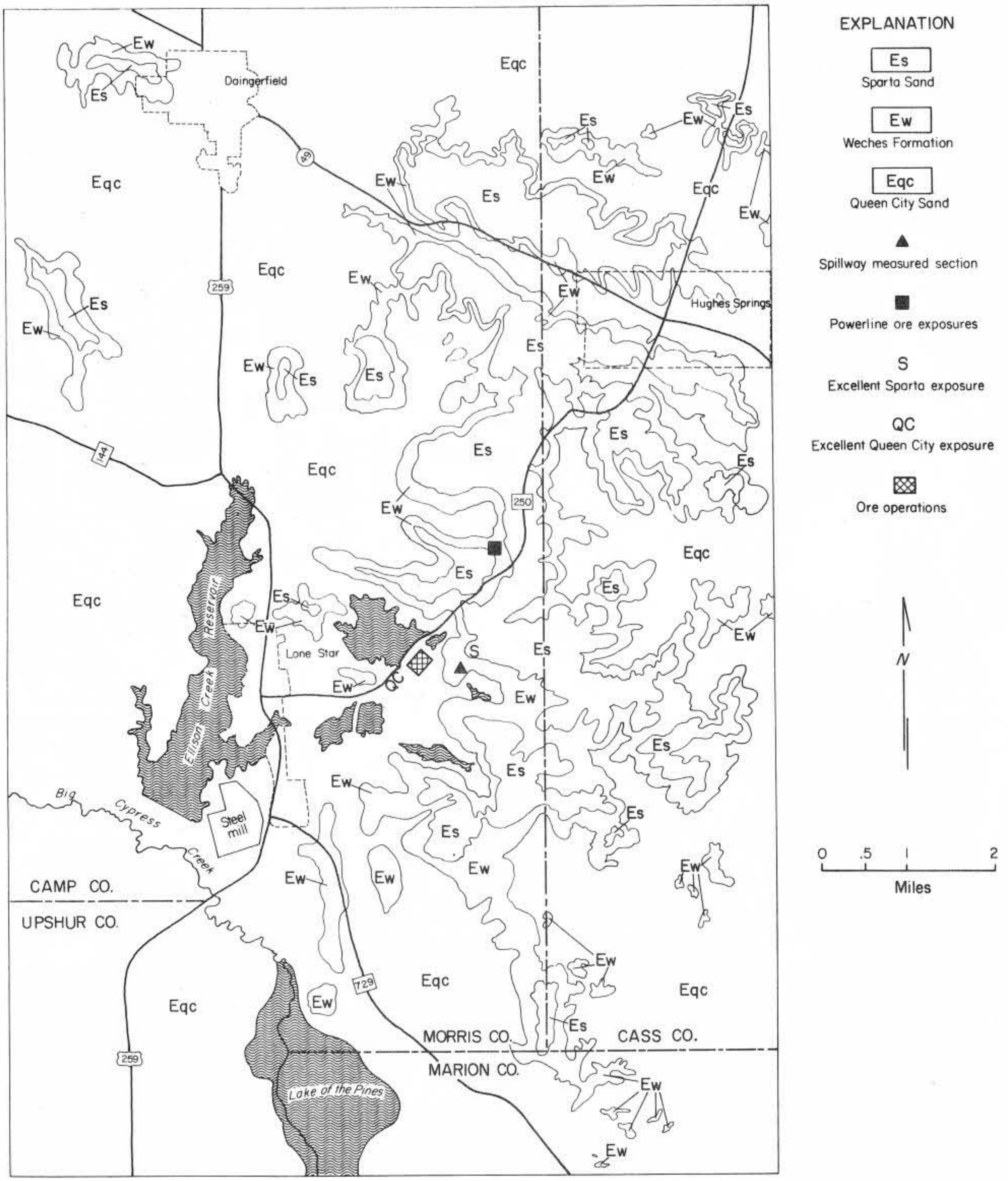


Figure 2

Geologic map of the Lone Star area. Geology from Eckel 1938 and Barnes 1964, 1966.

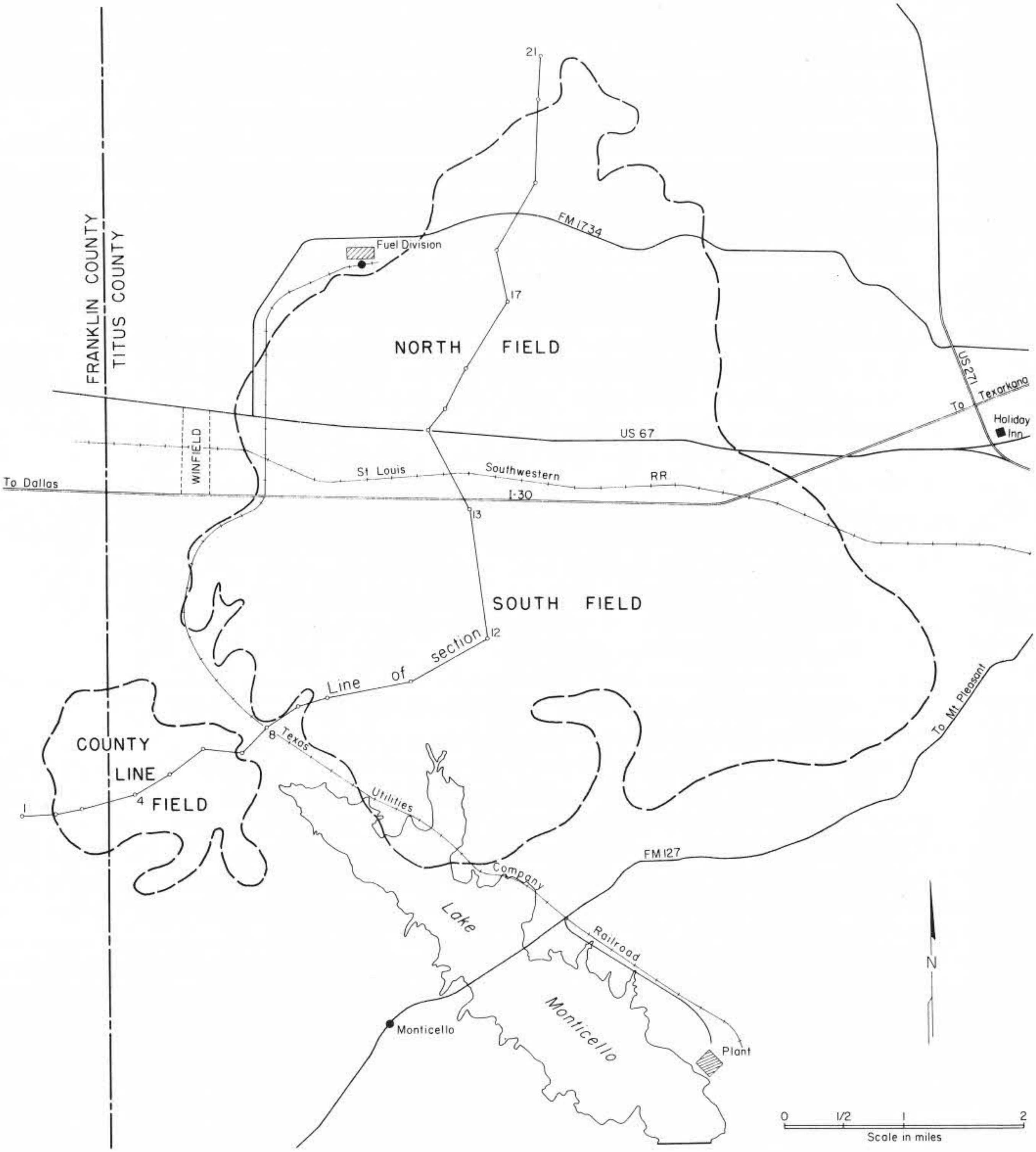


Figure 3 Geologic map of the Winfield area.

Armco Steel Corp. in the early 60's began to use foreign iron ore and domestic pelletized ore and today all its iron ore is non-Texas ore. Lone Star Steel Co. continues to utilize Texas iron ore mined from its Morris and Cass County mines. Lone Star's production is about three million crude tons of ore annually (Eric Ottman, personal communication). Total statewide production has been held confidential by Texas operators since 1957. Current production comes from three or four counties: Cass, Cherokee, Morris, and Nacogdoches; however, ore deposits occur in 22 East Texas counties with other potential producing counties being Anderson, Henderson, Smith, and Upshur.

Eckel (1938, p. 67) estimated reserves at approximately 177 million long tons, 110 million in the North Basin and 67 million in the South Basin (fig. 1). Perkins and Lonsdale (1955) estimated reserves at approximately 217 million long tons, 157 million in the North Basin and 60 million in the South Basin. Their higher value is due primarily to the larger reserves of siderite ore outlined in the North Basin since World War II.

At Lone Star mining is by a combination of open pit and strip methods in which the overburden is normally removed by scraper or much less commonly by dragline casting. Ore is loaded by dragline into trucks for transport to the beneficiating plant where limonite and siderite ore are processed separately in two parallel and similar circuits. The crude ore is crushed, washed free of mud and sand, wet screened, and sized. The finer, less than one-half inch fraction, are mixed with coke fines and sintered on a downdraft strand, while the greater than one-half inch material is calcined in 300-foot long, gas fired rotary kilns. Following screening to remove fines, the ore products are shipped to the blast furnace (Brown and others, 1969). Clarified tailings water is disposed of in compliance with existing water quality standards. No extensive reclamation program is carried out at Lone Star. Any comprehensive reclamation program must be planned with the possibility that the greensands underlying the iron-ore pits may someday be economically exploited (Groat, 1973).

Lignite

Prior to 1930 and the advent of natural gas and oil as principal energy raw materials lignite was a major energy source in Texas. Though utilized since the 1850's significant use of lignite began in the 1880's when production stood at about 20,000 short tons per year. Production increased to a peak of 1.4 million tons in 1914, averaged about one million tons per year from 1915 to 1930, declined from 1930 to 1940 and by 1940 was 600,000 tons annually, until by 1950 annual production had dropped to less than 20,000 tons. Most of the production during this period was from 100 underground mines in 35 Texas counties (Fisher, 1963, p. 8). This early, underground phase of lignite mining was ushered out by a complete shift to natural gas and oil in the early 50's. Apparent large reserves of clean natural gas appeared to spell the end to significant lignite use.

In 1954 a large-scale lignite strip-mining operation was initiated near Rockdale, Texas, about 45 miles northeast of Austin, where lignite fuels a steam plant to generate electricity for Alcoa's aluminum smelter. This was the only large lignite mining operation until 1971 when Industrial Generating Company began operations at Fairfield, Texas (Freestone County). The same company has two more plants under construction at Monticello (6.5 miles southeast of Winfield) and Martin Lake (Panola County) that will come on line in 1974 and 1977. The 1954 development was the forerunner of this second phase of lignite mining. Production figures since 1950 have been held confidential by Texas operators, but statewide production is estimated at 8 to 10 million short tons in 1973.

The fundamental reason for the resurgence of lignite use is the shortage of oil and gas and favorable economics. In addition much of Texas' extensive resources, estimated at approximately 10 billion short tons, are easily stripped, moderately low in sulfur and ash content, and located in areas with adequate water resources for large mine-mouth operations near large population centers (e.g., Dallas-Fort Worth). Clearly the modern era of lignite use in Texas, characterized by large-scale strip mining, is just beginning.

All the lignite currently mined in Texas is strip mined using the area stripping method. Electric draglines (up to 70 cubic yard buckets) are used to expose the lignite, removing the generally unconsolidated overburden and piling it, to cover recently mined out areas, in conical spoil rows. Electric shovels load the lignite into trucks (up to 180 cubic yard capacities) for haulage to the plant or to conveyor-belt or rail terminal. At the plant lignite is pulverized to minus 200 mesh (0.074 mm) and directly blown into the furnaces. Industrial Generating Company is carrying on an extensive reclamation and environmental program remolding the spoil to the original topography. The reclaimed land is sprigged with Coastal Bermuda or seeded with clover and fertilized. Runoff waters are kept on the property and monitored in holding ponds before being allowed to drain into area streams (Kaiser and Groat, 1973).

GEOLOGY

Texas iron ore and lignite occurs in lower Tertiary (Eocene) rocks. The iron ores are associated with the Weches Formation (middle Eocene Claiborne Group) and are genetically related to the glauconite contained in this marine, transgressive unit. The principal lignite deposits are found in the Wilcox Group (lower Eocene) with deposits of secondary importance in the Yegua Formation and Jackson Group (upper Eocene) (fig. 4). Lignites occur as a component facies of three ancient environments: deltaic, fluvial, and lagoonal. Only deltaic and fluvial lignites are of commercial size and grade. Lignite mined at Winfield is fluvial and occurs in the Wilcox Group.

Regional Framework

Principal structural elements influencing Eocene sedimentation in East Texas are the Tyler Basin and Sabine Uplift (fig. 1). The Tyler Basin is the northern extremity of the East Texas Embayment and is defined primarily by a thickening of Cretaceous and Eocene sediments. The trough-like basin is 30 to 50 miles wide and bounded on the east by the Sabine Uplift, on the south by the Mt. Enterprise Fault Zone, and on the northwest by the Mexia-Talco Fault Zone. The Tyler Basin is divided into a North and South Basin generally along a line extending west-northwest from the northern tip of Gregg County and approximately parallel to the Sabine River (Eckel, 1938).

Cyclic deposition is the fundamental style of sedimentation in the Gulf Coast Eocene (Fisher, 1964). The motif is an alternation of transgressive, marine dominated units and regressive, fluvial-deltaic dominated units (fig. 5). Though less than 100 feet thick at the outcrop and therefore quantitatively insignificant, the richly fossiliferous glauconitic sands, muds, and marls of the transgressive units are highly distinctive Eocene units. A typical example is the Weches Formation of Texas which extends from East Texas southward into South Texas, to the Frio River, where it loses its identity. Represented are facies deposited in inner shelf, middle shelf, and paralic environments (Shafiq, 1969). In the Eocene, units like the Weches separate quantitatively significant, thick, lignite bearing regressive units dominated by facies deposited in deltaic, fluvial, and paralic environments (Fisher and McGowen, 1967; Fisher, 1969; Fisher and others, 1970; Guevara and Garcia, 1972). Typical Texas Eocene examples are the Wilcox Group, Queen City Sand, Sparta Sand, Yegua Formation, and upper Jackson Group (fig. 5). Among these the Wilcox Group is the thickest and most extensive regressive unit.

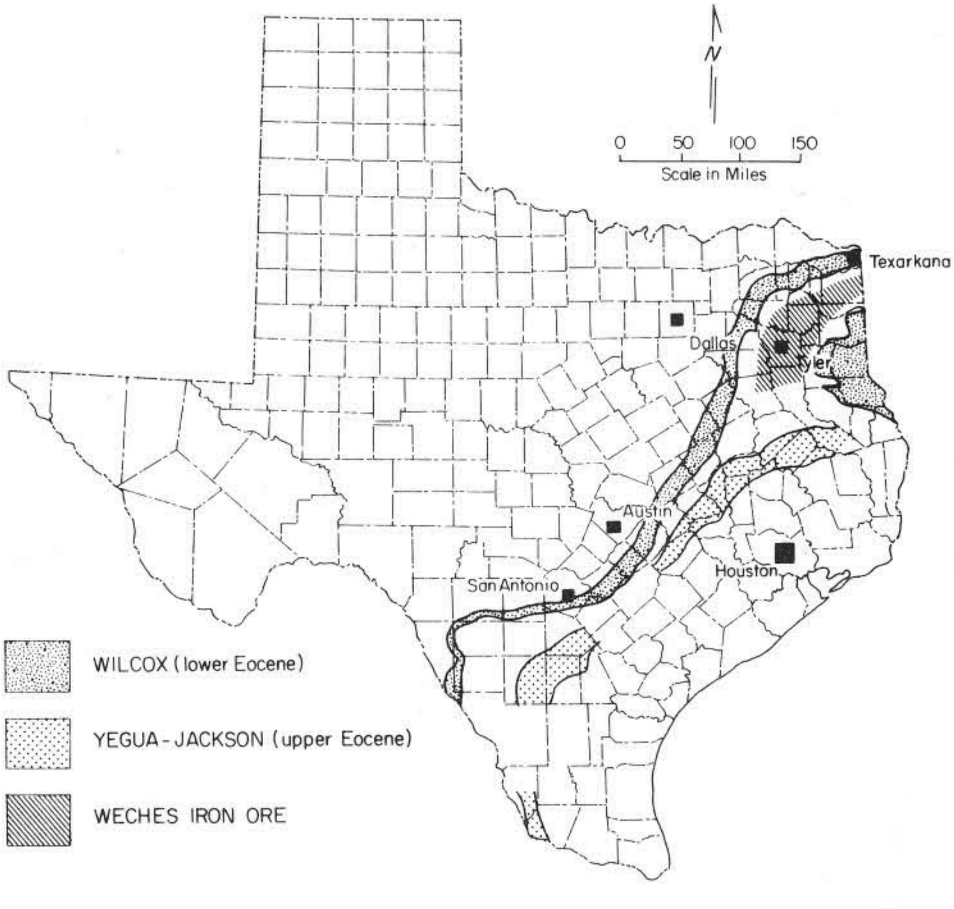


Figure 4

Index map showing the distribution of iron ore and lignite-bearing stratigraphic units.

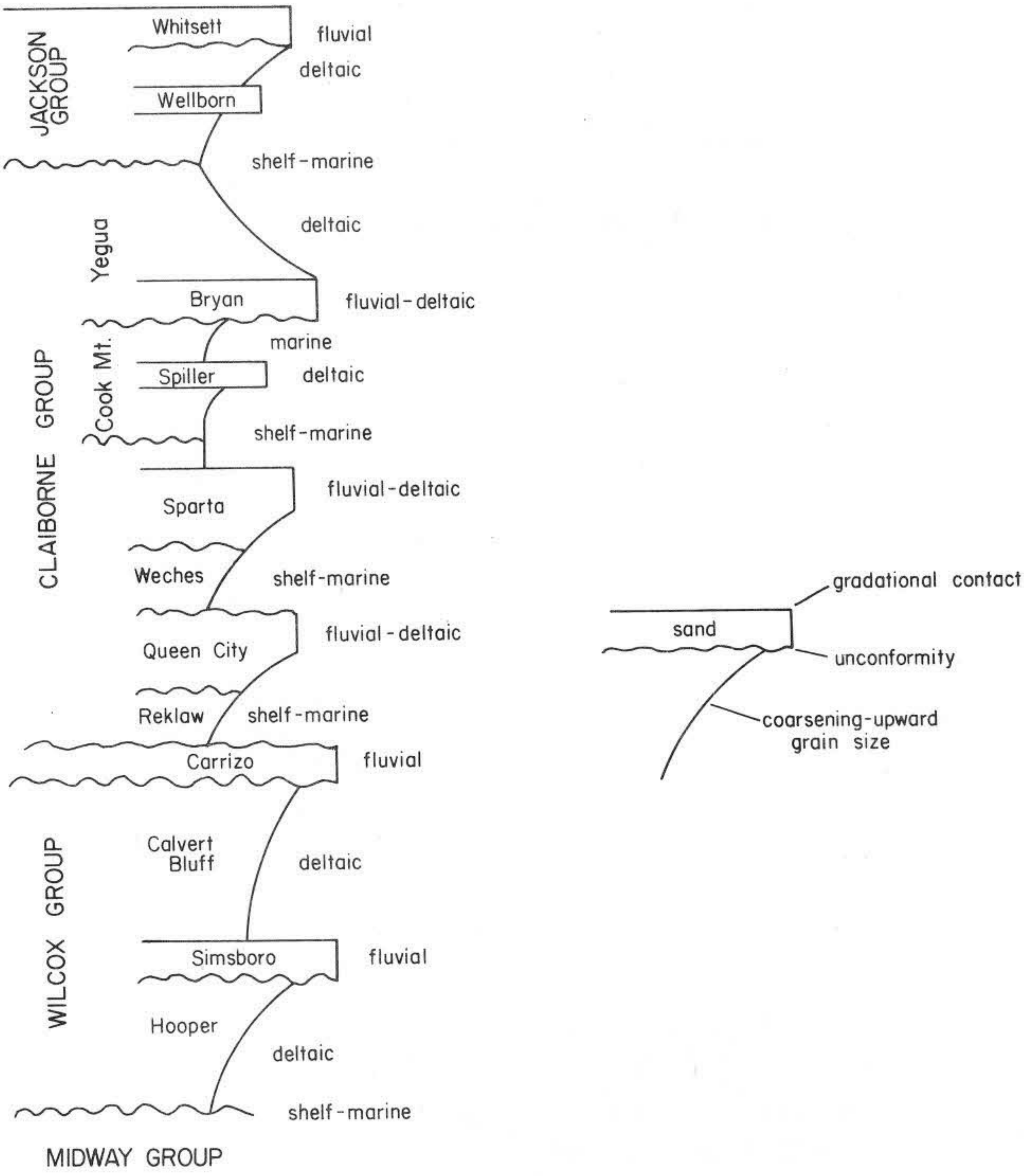


Figure 5

Cyclic deposition in the Texas Eocene. Terminology from Stenzel 1952 and Fisher 1964.

Bounding the Weches Formation, at the base and top, respectively, are the thinner and less extensive Queen City and Sparta Sands.

Depositional systems and facies developed in the lignite-bearing Eocene stratigraphic units are directly comparable to the Holocene Mississippi fluvial-deltaic system and related strike systems of the northwestern Gulf of Mexico (Fisher and others, 1970, p. 258-259). The dominant elements in the Holocene and Eocene are large delta systems fed by fluvial systems with source areas of continental proportions and high sediment discharge dominated by silt- and clay-sized suspended load. Like the Holocene Mississippi delta, the Eocene deltas consist chiefly of fluvial or fluvially influenced facies little modified by marine reworking. The areal extent of the Wilcox (24,000 sq. mi.), Yegua (15,000 sq. mi.), and Jackson (10,000 sq. mi.) delta systems is similar to the Mississippi delta system (20,000 sq. mi.). Maximum thickness reaches 12,000 feet in the lower Wilcox delta system and one-tenth that in the Jackson delta system (Fisher and others, 1970). In the Texas Eocene delta systems are extensively developed in the subsurface of Central and East Texas north of the Guadalupe River. Updip and rimming the Gulf basin are the fluvial facies of these delta systems. In the Texas Eocene fluvial deposits are especially well developed north of the Colorado River in Central Texas and northeast of the Trinity River in East Texas where Wilcox, Queen City, and Sparta fluvial deposits are conspicuous. Associated lignites accumulated on the alluvial plain in fresh water swamps located between stabilized meanderbelts or in abandoned stream courses. Lateral to the Holocene and Eocene delta systems and supplied by them are extensive strike-fed systems. In the Holocene these include the chenier or strandplain system of southwest Louisiana and the barrier bar system of the upper Texas coast. In the Texas Eocene comparable systems are extensively developed in South Texas, particularly south of the Guadalupe River.

Weches Formation

Tyler Basin. The Weches Formation is typically 25 to 80 feet thick, ranging to 150 feet thick, and consists predominantly of clay, silt, quartz sand, greensand and mud (glauconite), and ironstone. It rests unconformably upon the Queen City fluvial-deltaic sands. Basically the Weches has two facies; a paralic quartz-rich facies below and a shelf-marine glauconite facies above. The former is typically parallel laminated very fine- to medium-grained glauconitic and nonglauconitic quartz sand and burrowed, flaser bedded, very fine- to fine-grained quartz sand, silt, and brown to gray mud. The latter is massive and/or crossbedded, fossiliferous, pelletized glauconite sand and glauconite mud with siderite nodules, sideritic ironstone ledges, and limonitic brown ore. The glauconite occurs dominantly as fine- to medium-grained sand-sized ellipsoidal pellets of faecal origin having a surface that is polished or dull, smooth or fractured. Siderite and limonite occur as discontinuous and continuous ledges 2 to 30 cm thick. Normally the glauconite facies is unconformably overlain by Sparta fluvial-deltaic sands; however, in some cases it may be gradationally topped by sparsely fossiliferous, slightly glauconitic, lignitic, brown mud and sand. This unit coarsens upward and probably represents subaqueous delta sediments associated with the Sparta progradation. Its erratic distribution in the South Basin and general absence in the North Basin is attributed to post-depositional Sparta fluvial scour. Moreover, the intense weathering of the uppermost Weches beds makes recognition difficult if not impossible.

Regionally the Weches is coarser grained and more quartz rich along the western flank of the Tyler Basin and thinner with abundant quartz sand near the northern flank of the Sabine Uplift. From north to south, the quartz-rich facies thins, while the glauconite facies becomes thicker, less crossbedded, finer grained, more intensely bioturbated, and more fossiliferous. In addition it is postulated that the erratic brown mud and sand thickens southward. The differences between the Weches in the North and South Basins are presented in table 1. Briefly the differences reflect a change from shallow-marine, near-shore deposition in the north to shelf-marine, off-shore deposition in the south; an interpretation based on the dominance in the south of intensely bioturbated, uncrossbedded glauconite bearing a rich and diverse marine fauna. Vertically in the Weches there is a change upward from shallow-water clastic sedimentation to shelf-marine chemical sedimentation in response to increasing water depths and decreasing rates of clastic sedimentation.

Iron sedimentation. The genesis of glauconite raises a two-part problem of accumulation and geochemistry. Obviously the accumulating iron-rich sediment must not be diluted or masked by clastics. Several workers (Huber and Garrels, 1953; Hunter, 1960, p. 202-231; Sheldon, 1965; Hallam, 1966) have appealed to a "clastic trap" (e. g., paralic lake or lagoon) to effect the separation of iron and clastics. Weches coarse-grained siliceous clastics remained at the rim or shoreline of the Tyler Basin under transgressive conditions, essentially unreworked and untransported shelfward by the prevailing low energy regime. Under these conditions iron and iron-rich sediment

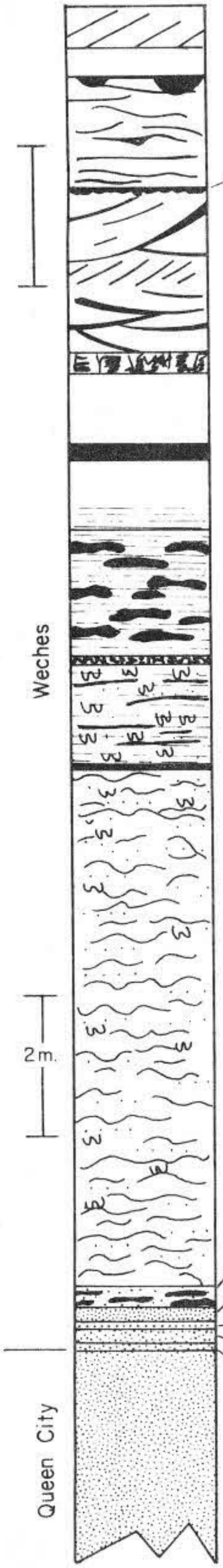
Table 1. Comparison of the Weches Formation in the Tyler Basin.

NORTH BASIN	SOUTH BASIN
1. Facies: quartz-rich, glauconite - present brown mud and sand - absent	1. Facies: quartz-rich, glauconite - present brown mud and sand - rare
2. Crossbedding common, channels present	2. No crossbedding or channels
3. Quartz sand abundant, mud clasts common, lignite fragments common to rare	3. Quartz sand rare to common, mud clasts rare or absent, lignite fragments rare or absent
4. Glauconite pellets medium to very coarse-grained	4. Glauconite pellets very fine- to medium-grained
5. Abrupt changes in formation thickness	5. Gradual changes in formation thickness
6. Body fossils very rare - low species diversity (Mollusks: robust, thick shelled, coarse ribbed)	6. Body fossils abundant - high species diversity (Mollusks: small, thin shelled, delicately ribbed)
7. Trace fossils common to rare, bioturbation moderate	7. Trace fossils very abundant, bioturbation intense
8. Limonite and siderite ores in upper half of formation	8. Limonite ore only and at top of formation

would be free to accumulate off-shore, undiluted by clastics, under the very slow rates of sedimentation indicated by the intensely bioturbated glauconite sand and mud. The iron is supplied by sluggish rivers draining a thoroughly weathered sourceland and is transported primarily in true solution, as suspended colloidal ferric iron (hydroxides and oxides), and as amorphous ferric iron absorbed on clay-sized sediment (Carroll, 1958). Ferrous iron never reaches the open marine environment being precipitated as ferric hydroxide upon contact with oxygenated, higher pH marginal-marine water. Furthermore, positively charged ferric colloids will be neutralized by anions and precipitated. Thus the deck is stacked in favor of relatively nearshore accumulation of iron.

Weches glauconite is primarily chamosite (septechlorite, a 7Å ferrous iron-silicate) with secondary amounts of mixed-layer montmorillonite (Roe, 1961; Wermund, 1961). Chamosite is considered a product of sea-bottom reaction of ferrous iron and detrital clay minerals (James, 1966). Chamosite is not stable in normal marine surface waters. Ferric minerals are the only minerals in true equilibrium with these waters. Chemical conditions favoring chamosite stability are: Eh less than 0 volts, low $a_{S^{2-}}$, low $a_{HCO_3^-}$, saturation with respect to amorphous SiO_2, high $a_{Fe^{2+}}$ and $a_{Al^{3+}}$, and pH greater than 7 (Kaiser, 1972, p. 109-112). Weches glauconitic sediments contain a rich bottom fauna which can only mean that the basin bottom was well oxygenated. Under these conditions ferric minerals are formed yet it is ferrous minerals which abound. In no way can it be suggested that the bottom waters were stagnant or reducing; however, the necessary chemical conditions for chamosite stability are readily attained below the sediment-water interface (Baas Becking, Kaplan, and Moore, 1960, fig. 13). To reconcile the contradiction of an oxygenated basin bottom and the presence of ferrous minerals it is proposed that the Weches chamosite formed in equilibrium with sediment pore water by diagenetic alteration of a faecal pellet precursor.

Lone Star iron-ore deposit. The iron ore is associated with the glauconite facies of the Weches Formation. An angular unconformity marked by a five degree discordance separates the Weches from the Queen City. There is an upward gradational change from flaser bedded quartz sand, silt, and brownish-gray mud to ore-bearing, bioturbated glauconite sand and mud topped by ore-bearing cross-bedded greensand (fig. 6). Reflected is a change from intertidal sedimentation to marine-shelf and shallow subtidal sedimentation.



Red overburden

Limonitic ore, base of ore botryoidal, underlain in places by kaolinized green sand. Ledges 2-10 cm. thick separated by 10-30 cm. weathered green sand. Brecciated, botryidal, and box-work structures

Botryoidal base

Medium - grained, argillaceous trough cross-bedded (sets 10-40cm.) green sand (fills symmetrical channels 1-2m. deep by 10-20m. wide) quartz sand minor to absent, 5-15mm. mud and lignite clasts common. Ledges of siderite cemented green sand 10-30 cm. between co-sets, along foresets, and along inclined bedding planes

Rubbly sideritic ironstone with vertical tubes (burrows) 10 mm. by 10-15 cm.

Massive, bioturbated glauconitic mud and sand

Sideritic ironstone with relict medium-coarse grain glauconite pellets

Massive, fine-grained green sand with very coarse-grained mud grains

Laminated blue-gray mud with 10-20cm. by 1-2m. pancake-like siderite nodules

Nodular (bioturbated ?) laterally continuous ironstone

Ironstone lenses (2-3cm. thick) interbedded with mud and very fine-fine grain quartz sand and medium grain green sand beds (about 10cm. thick)

Sideritic ironstone, botryoidal undersurface

Flaser bedded very fine - fine grained micaceous quartz sand, silt, and brownish gray mud. Laminated and very thin bedded, horizontal burrows at bedding planes, lignite fragments rare to common

Medium grained glauconitic quartz sand with 2-5 cm. siderite lenses

Cross-bedded medium grained quartz sand with glauconite, lignite fragments, mud clasts (5-10mm.), phosphate ? nodules (2-3cm.)

Micaceous very fine-fine grain quartz sand with abundant, medium grain glauconite grains

Brown laminated, argillaceous, very fine grain sand with lignite fragments to 10mm.

Micaceous, argillaceous, glauconitic, very fine grained quartz sand: Angular unconformity (5° discordance) between Queen City and Weches

Laminated, argillaceous, gray, sub-angular, very fine-grained sand

Figure 6

Measured section at Spillway, Lone Star Mine (see fig. 2 for location).

The thickest and richest limonite ore commonly occurs in relatively small outliers where the Weches is exposed or carries only a very thin cover of Sparta overburden. Next in importance are the narrow, thinly covered spurs or ridges that project from larger hills. In large areas where the Weches is covered by 15 feet or more of overburden, good limonite ore is not abundant at the outcrop and little or no limonite ore is encountered in boreholes (Eckel, 1938). Siderite ore occurs below the water table and under the limonite ore when it is present. Siderite ore is widely distributed under spurs and larger hills, beneath varying thicknesses of overburden, with the better siderite ore under thicker overburden (Eric Ottman, personal communication).

Limonite ore occurs in an approximately three meter zone above the water table. The ore occurs in nodules and layers (ledges) displaying brecciated, botryoidal, and box-work structures resembling those developed in tropical laterites. Nodules are a few cms to 60 cm in length having irregular, spherical, ellipsoidal, or square shapes. Many contain a residual core of siderite while a few are hollow and filled with liquid and CO_2 (Eckel, 1938). Ledges are typically 2 to 8 cm thick, continuous for 1 to 3 meters, and separated by 10 to 30 cm of kaolinized cross- and flat-bedded greensand (chamosite). Irregular masses of brecciated crumbly ore commonly cut across bedding. Botryoidal masses have individual convex-down, spherical, 5 to 10 cm diameter, concentrically layered, protrusions. Goethite (α-FeOOH) is the dominant mineral of the limonite ore perhaps accounting for 80 percent of the total. Lepidocrocite (γ-FeOOH) is next in importance. Hematite (α-Fe_2O_3) and maghemite (γ-Fe_2O_3) are present in small amounts (Roe, 1961). The mined crude ore is 44 percent Fe and 24 percent SiO_2 and Al_2O_3 (Brown and others, 1969, p. 32). Lone Star beneficiates the ore to 52 to 55 percent Fe (Eric Ottman, personal communication).

The contact between limonite ore and the approximately five meter thick siderite ($FeCO_3$) ore zone is the water table. The siderite ore occurs in nodules and layers (ledges) set in a chamosite matrix. Nodules are pancake-like in shape and 10 to 20 cm by 1 to 2 m in size. Ledges are typically 2 to 10 cm thick, continuous for 1 to 3 m, and separated by 10 to 40 cm of cross- and flat-bedded greensand. Ledges occur between crossbed cosets, along foresets, and along inclined bedding planes. Fresh siderite is gray and is rapidly weathered to limonite upon exposure to the atmosphere. The mined crude ore is 40 percent Fe and 14 percent SiO_2 and Al_2O_3.

Siderite ($FeCO_3$) origin is the key to understanding ore genesis. The fact that siderite ore parallels the present water table and the ample field and microscopic evidence of origin by replacement rules out a primary origin. Furthermore, siderite is thermodynamically unstable in sea water because it cannot form in water rich in dissolved Ca^{2+}. In low-calcium anaerobic fresh water $a_{Fe}2+$ is often much higher relative to $a_{Ca}2+$ so that here siderite is stable relative to calcite (Berner, 1971, p. 200). For example, calculation based on a Hughes Springs' water shows siderite to be stable relative to calcite and supersaturated with respect to siderite at a pH of greater than six. Only surface waters with good circulation are oxidizing while confined waters rapidly lose their oxygen content by reaction with ferrous silicates or carbonate and organic matter. Deoxygenation tends to be accompanied by a lowering of pH as CO_2 is generated. Low -pH water is ideally suited for maintaining relatively high concentrations of Fe^{2+} (5 to 15 ppm). As organic matter is destroyed and hydrolysis of silicates (chamosite) continues pH tends to rise so that the environment becomes alkaline as well as reducing. Below the water table the environment is assumed to be alkaline and reducing (Garrels and Christ, 1965, p. 382-383). Thus in the case of the Hughes Springs' water siderite will be precipitated in a zone just below the water table. Later fluctuation of the water table places previously deposited siderite in the zone of aeration and the stage is set for the formation of limonite by the oxidation and hydration of siderite.

The geochemistry of siderite, limonite, and ground water and the field relations of the two ores to the present water table and topography indicate that the ores have been derived from chamosite by ordinary weathering processes. It is believed that ground waters leach iron from the chamosite and deposit it as $FeCO_3$, which is later altered to limonite (Galbraith, 1937; Eckel, 1938). Briefly the sequence of events in ore genesis is: diagenetic formation of chamosite, its exposure to fresh water, its hydrolysis and the release of Fe^{2+}, downward transport of Fe^{2+} to the water table and precipitation as $FeCO_3$ (siderite), oxidation, and hydration of siderite forming limonite.

Wilcox Group

Tyler Basin. The Wilcox Group is 500 to 1,500 feet thick and consists of silt, clay, and sand; it is unconformably underlain by the Midway Group and overlain by the Carrizo Sand (fig. 5). Commercial lignites occur mainly in the middle and upper Wilcox as a component facies of the Mt. Pleasant fluvial system (Fisher and McGowen, 1967, fig. 2, p. 108). The pattern of sedimentation is cyclic; that is, multistacked, thick, fining-upward sequences or

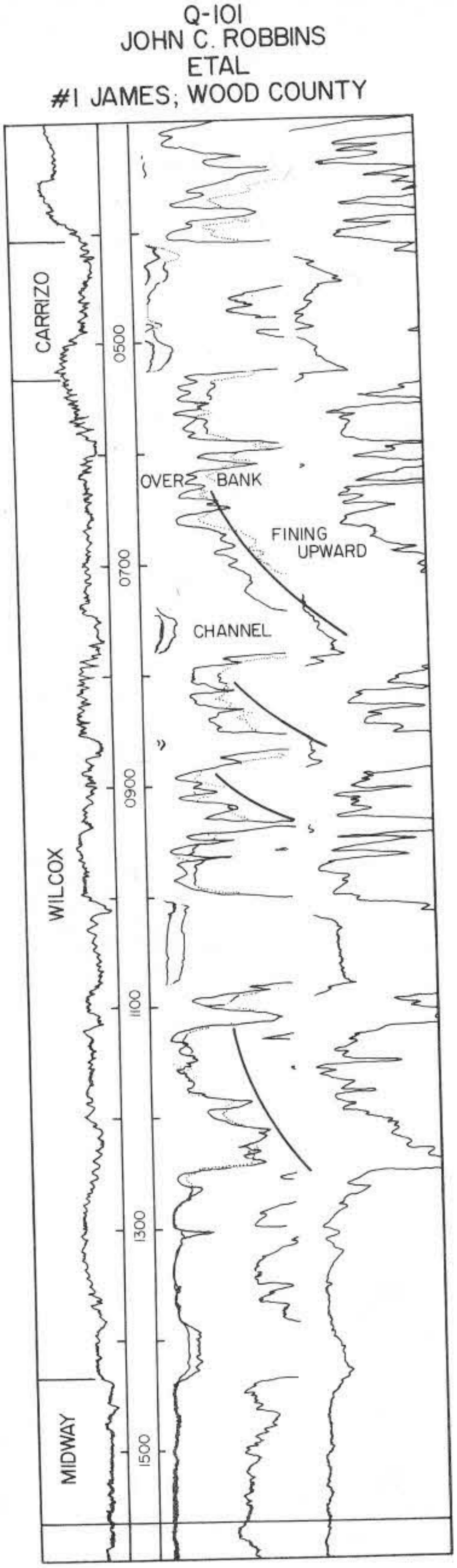


Figure 7

Representative electric log illustrating Tyler Basin Wilcox fluvial cycles (see fig. 8 for location).

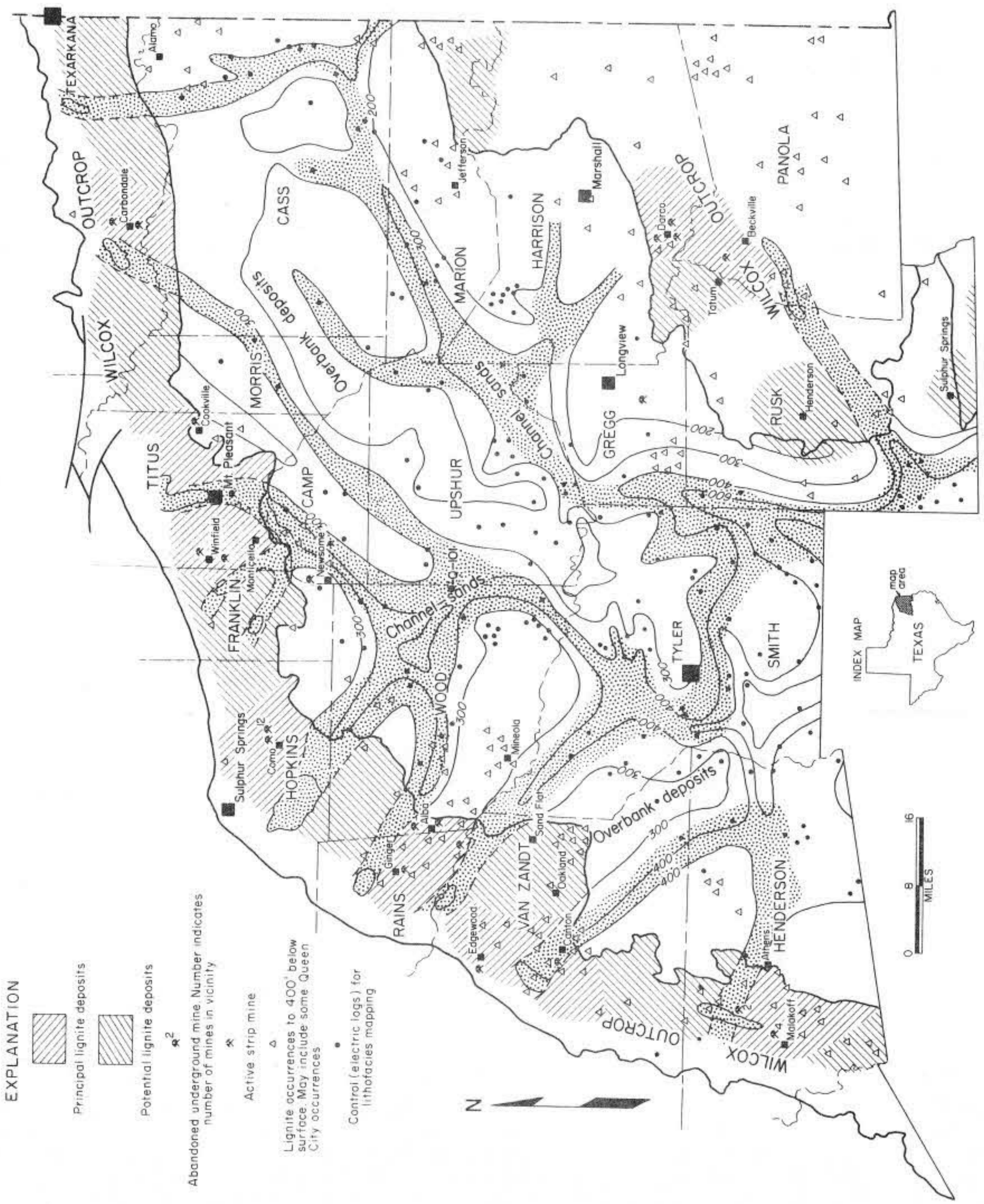


Figure 8

Geologic map showing distribution of East Texas Wilcox lignite. Lithofacies mapping from Fisher and McGowen 1967.

Table 2. Composition of Wilcox fluvial lignites.[1]

	Volatile Matter		Fixed Carbon		Ash		Sulfur		Btu/lb	
$\overline{X}$	35.70	47.44	26.76	38.50	9.95	13.78	0.81	1.01	7,705	10,482
S	6.97	7.95	7.54	7.80	5.80	5.62	0.34	0.40	622	1,014
N	89	44	87	44	89	44	82	41	59	49

$\overline{X}$ = arithmetic mean

S = standard deviation

N = number of analyses

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[1] as-received basis in left-hand column (moisture ± 30 percent); dry basis in right-hand column

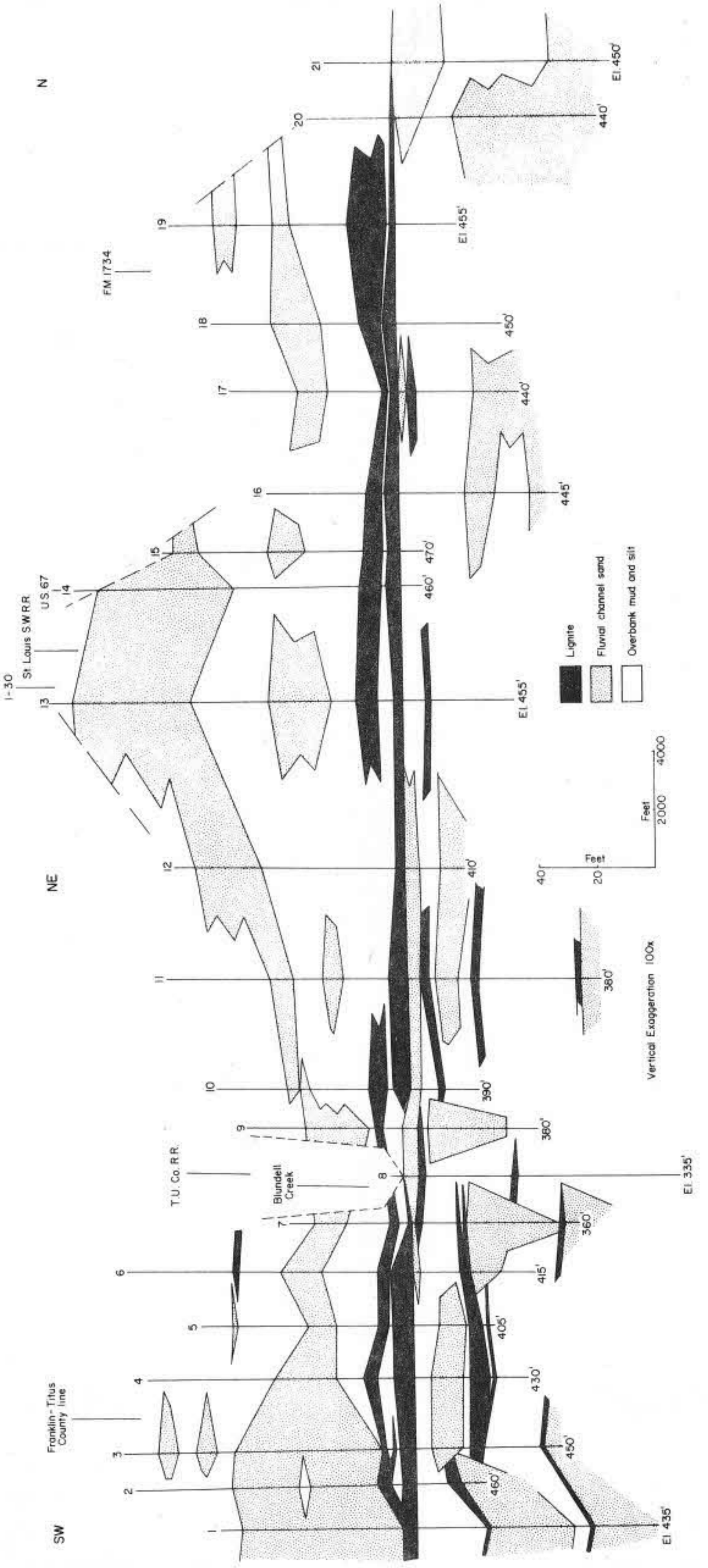
fluvial cycles (fig. 7). Lignites are associated with the fine-grained upper parts (overbank deposits) of these cycles (Fisher, 1964, fig. 8, p. 167). In most cases commercial lignite deposits occur between paleochannels or interchannel areas (fig. 8); however, other workers (Fisher and McGowen, 1967, p. 110; McGowen, 1968, p. 159) disagree and believe that commercial lignites are uncommon in interchannel areas.

Fluvial lignites have a high percent of woody material. Dumble (1892, p. 163) reports stumps in growth position and tree trunks (16 to 20 feet by 18 to 20 inches) in these lignites. Their low sulfur content (table 2), dominantly woody composition (Fisher, 1968), and palynoflora support forested, fresh-water swamps as sites of accumulation (Nichols and Traverse, 1971). Apparently commercial fluvial lignites formed as back-swamp peats in broad, isolated flood basins separated by stabilized meanderbelts. The Mississippi River alluvial plain is a good Holocene analogue. On the alluvial plain swamps and peats occur between meanderbelts established by major ancient and modern Mississippi River courses (Frazier, 1967, figs. 7 and 8, p. 298-299). Frazier and Osanik (1969) describe back-swamp peats up to 20 feet thick, composed of cypress-gum vegetation, flanking natural-levee ridges. Swamps persist because peat accumulation keeps pace with subsidence and are sufficiently far removed from active channels to be free of large sediment influx which inhibits vegetation growth. Evidently Wilcox swamps were similarly located for the lignites are moderately low in ash (table 1).

<u>Winfield lignite deposit</u>. The main lignite deposit sits astride Interstate 30 just east of Winfield, Texas extending about 3 miles north and south of the highway. A satellite deposit sits astride the Titus-Franklin County line 2.8 miles south of Winfield (fig. 3). Minable lignite underlies about 21 square miles and has been informally divided into three areas--North, South, and County Line fields--by the mining company. Overburden ranges from 20 to 170 feet thick and averages 75 feet thick. Total reserves are estimated at approximately 200 million short tons with about 50 percent of these in the South Field. Analyses of the Winfield lignites fall within the limits shown in table 2 for Wilcox fluvial lignites.

At Winfield the Wilcox Group strikes N 63° E and dips 0.4° (37 feet per mile) south; its average thickness is 700 feet. Based on regional mapping (Barnes, 1966), the lignite-bearing strata are informally assigned to the middle Wilcox. The lithology is an interbedding of

Figure 9



Cross section through the Winfield lignite deposit (see fig. 3 for location). Subsurface data from drillers' logs supplied by Industrial Generating Company.

sand and mud-silt with lignite, interpreted as fluvial channel and overbank interchannel deposits accumulated on an ancient alluvial plain. Individual lignite seams are 4 to 8 feet thick, tabular to lenticular, and continuous for 2 to 5 miles occurring in a zone 4 to 17 feet thick broken by one or more splits (probable overbank units) 1/2 to 6 feet thick (fig. 9). This zone is primarily bounded by mud-silt and can be traced throughout the Winfield deposit. Abundant woody material in the lignite reflects a swamp origin while the low sulfur content indicates fresh water.

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