GEOLOGY OF THE UPPER CRETACEOUS NACATOCH SAND OF SOUTH ARKANSAS

By

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Bachelor of Science

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Norman, Oklahoma

1977

Submitted to the Faculty of the Graduate College
of the Oklahoma State University
in partial fulfillment of the requirements
for the Degree of
MASTER OF SCIENCE
May, 1980

GEOLOGY OF THE UPPER CRETACEOUS NACATOCH

SAND OF SOUTH ARKANSAS

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PREFACE

This thesis is primarily a local study of the geometry and trends in the subsurface, internal features, and vertical section exposed in the surface outcrop of the Upper Cretaceous Nacatoch Sand. A structural contour map, log map, correlation cross sections, and outcrop measured sections were prepared in this study.

The author is grateful to Anadarko Production Company, Oklahoma City, Oklahoma, for assistance in the work on this study. Dr. Nick Sommer with Anadarko Production Company suggested the thesis topic. Dr. Nowell Donovan, Dr. Gary Stewart, and Dr. Nick Sommer made helpful suggestions, comments, and criticism, and gave time, encouragement, and assistance throughout the research and writing of the study.

Data for this study were provided by Anadarko Production Company. Field expenses, base maps, logs, scout tickets, and other materials were provided by Anadarko.

Special thanks are extended to the writer's parents, Mr. and Mrs. Eugene W. Black, for their financial support in times of need while attending graduate school, and I will be eternally grateful for the encouragement, patience, moral support, and typing of this thesis to my wife, Diane.

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CHAPTER I

ABSTRACT

The Upper Cretaceous Nacatoch Sand is part of the Gulfian Series and Navarro Group of South Arkansas. The Nacatoch overlies the Saratoga Formation of the Taylor Group and is overlain by the Arkadelphia Formation of the Navarro Group. There is some evidence in outcrop sections of unconformity surfaces between these formations but no evidence exists in the subsurface section. The Nacatoch represents an overall regression with evidence of a short period of transgression which divides the two units of the Nacatoch Sand. The Nacatoch is thought to be representative of a regressive nearshore, shoreface, or barrier-bar sand deposit.

Structural features in this area of South Arkansas include an anticline-syncline feature in the central part of the area and the South Arkansas Fault System in the southeastern part of the area. The dip of the section is to the southeast with few exceptions of minor faulting.

The production of hydrocarbons from the Nacatoch Sand and other Cretaceous and Jurassic reservoirs is primarily from structural traps in the southeast part of this area.

CHAPTER II

INTRODUCTION

The study area of approximately 1,872 square miles (T7 to 14S, R19 to 27 W) is in parts of Clark, Hempstead, Nevada, Ouachita, Little River, Miller, and Pike Counties, Arkansas (Fig. 1). The stratigraphic interval of investigation is the Upper Cretaceous Nacatoch Sand of the Gulfian Series and Navarro Group. The type log (Fig. 2) from the study area shows the Arkadelphia Formation on top of the Nacatoch and the Saratoga Formation at the base of the Nacatoch.

Objectives

The objectives of this surface and subsurface study are: (1) to determine outcrop characteristics and subsurface characteristics of the sand, (2) to determine the depositional environment of the sand, using the above mentioned data, and (3) to determine structural characteristics of the Nacatoch in the subsurface and its relationship to petroleum production from the Nacatoch.

Previous Studies

Numerous studies have included the Nacatoch Formation but few have been in detail and most are quite old, e.g. Veatch (1906), Howe (1924), Stephenson (1927), Dane (1929), Spooner (1935), and Weeks (1938). The studies by Veatch and Dane are by far the most comprehensive but are

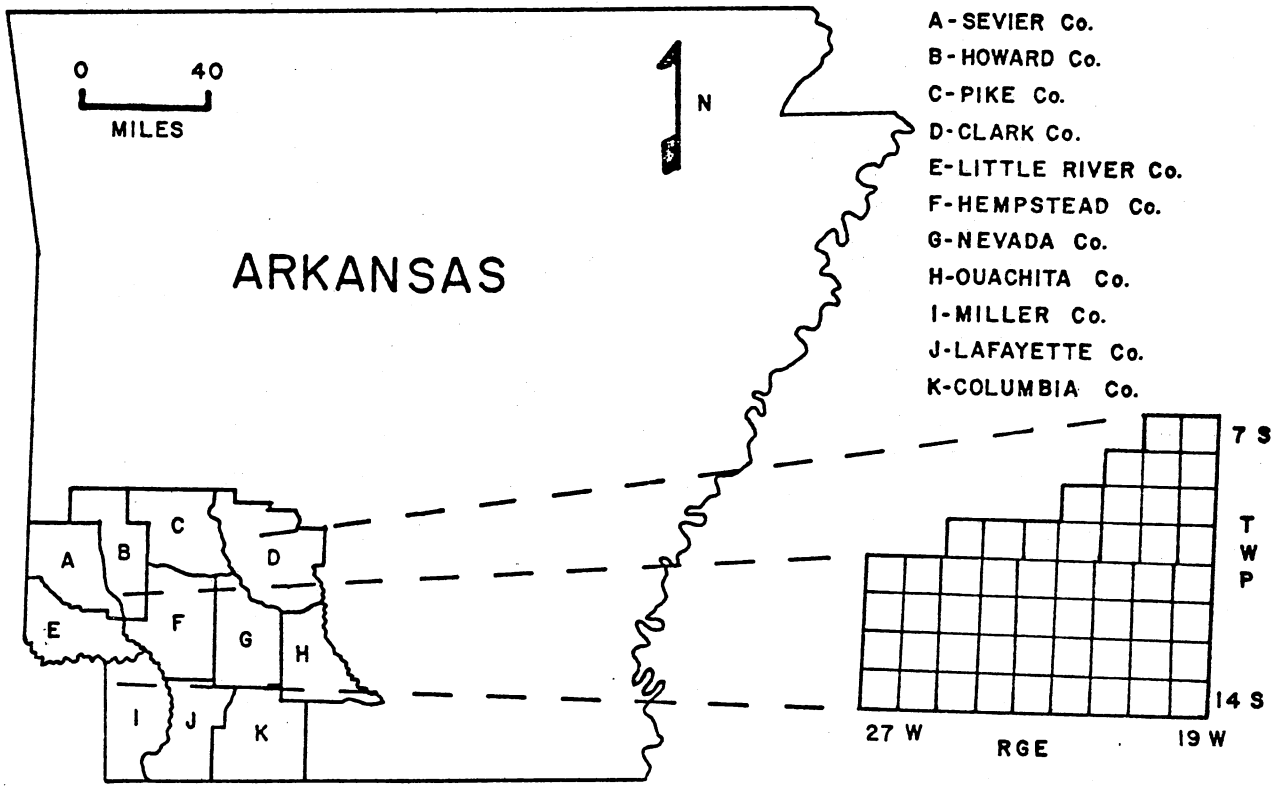


Fig. 1.--Location map of the study area.

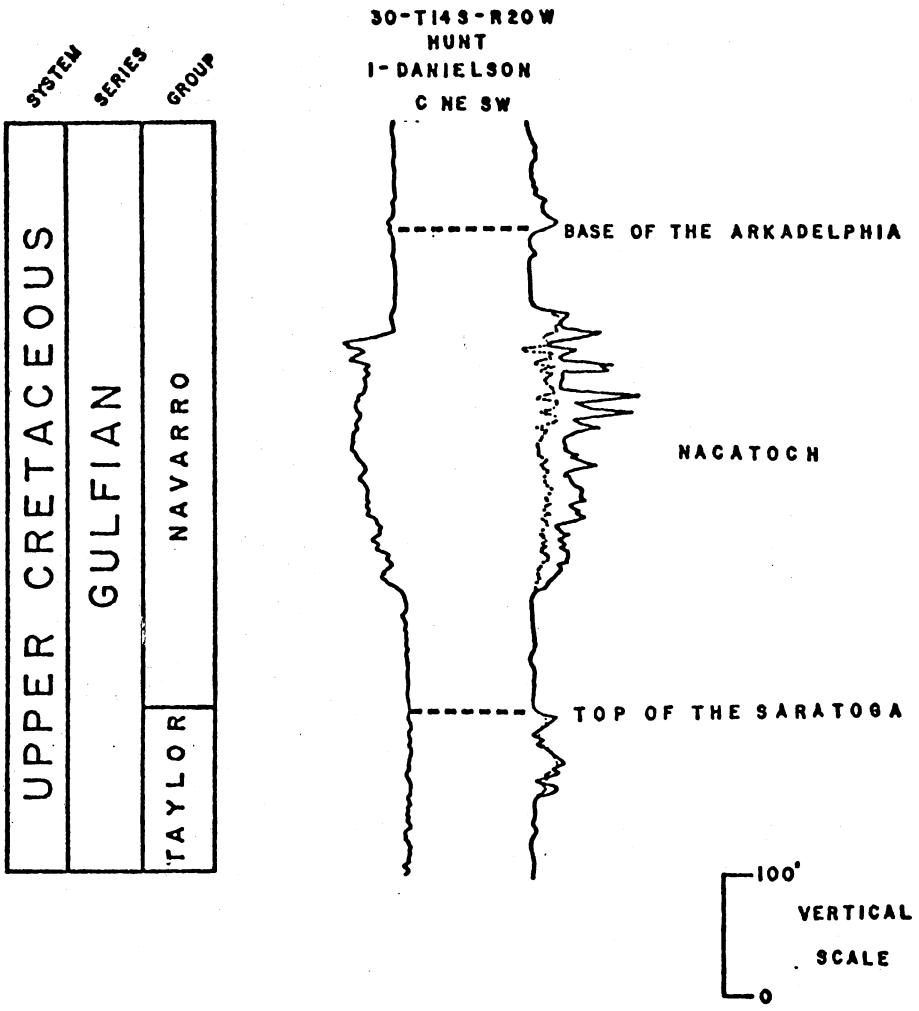


Fig. 2.--Type log of study area.

somewhat outdated by the additional well data, etc., that is available today. Dane (1929) and Veatch (1906) both considered the surface outcrops and subsurface characteristics of the Nacatoch. The other studies reviewed previous work on the general lithologic and, to some extent, subsurface characteristics of the Nacatoch Sand.

The water quality and potential production from the Nacatoch are topics in the papers by Veatch (1906), Boswell (1965), and Ludwig (1972).

Oil and gas production data from the Nacatoch are included in numerous reference reports written and published by the Shreveport Geological Society, Arkansas Geological Commission, and United States Department of the Interior, Bureau of Mines.

Procedure

Field work on the Nacatoch consisted of the detailed measuring of 12 vertical sections. Samples of the sand were taken at five-foot intervals for later laboratory analysis. Detailed descriptions of the measured sections included sedimentary structures, trace fossils, and data on the trend and geometry of individual sand members. Numerous photographs were taken for reference and presentation purposes. Laboratory analysis included grain size sieve analysis and grain mount thin sections of the sand samples.

Subsurface data was obtained from electric logs and scout tickets from wells in the area. A structure map on the top of the Nacatoch Sand was constructed using well data, and in the area south of the dashed line on the map (Plate I), previously published maps, well logs, and tickets were used. Four cross sections are included for correlation of the Nacatoch throughout the area. A log map was constructed using

electric log characters of the Nacatoch Sand in order to show areal distribution and determine the depositional environments.

CHAPTER III

STRUCTURAL FRAMEWORK

Regional Setting

Structurally, the area under consideration is located on the westward edge of the Mississippi Embayment in a zone in transition with the Gulf Coastal Plain. The Ouachita Uplift and Ozark Dome are positive elements to the north. The Mexia-Talco Fault System, East Texas Tyler Basin, Sabine Uplift, Winn Axis, Monroe, Sharkey, and Central Mississippi Uplifts, Jackson Dome, and the Pickens-Gilbertown Fault System are structural elements to the southwest, south, and southeast of the area studied (Fig. 3).

Local Setting

A structural contour map on the top of the Nacatoch Sand shows an overall southeastern dip of 50 feet per mile (Plate 1). The northern portion of the South Arkansas Fault System is located in the southernmost portion of the area. Closure against these faults has resulted in the trapping of oil and gas. An anticlinal-synclinal structure found in T12S, R23W is possibly due either to deeper faulting or ancient igneous activity. This same structure is comparable to that on the structure map (on the same datum) by Veatch (1906).

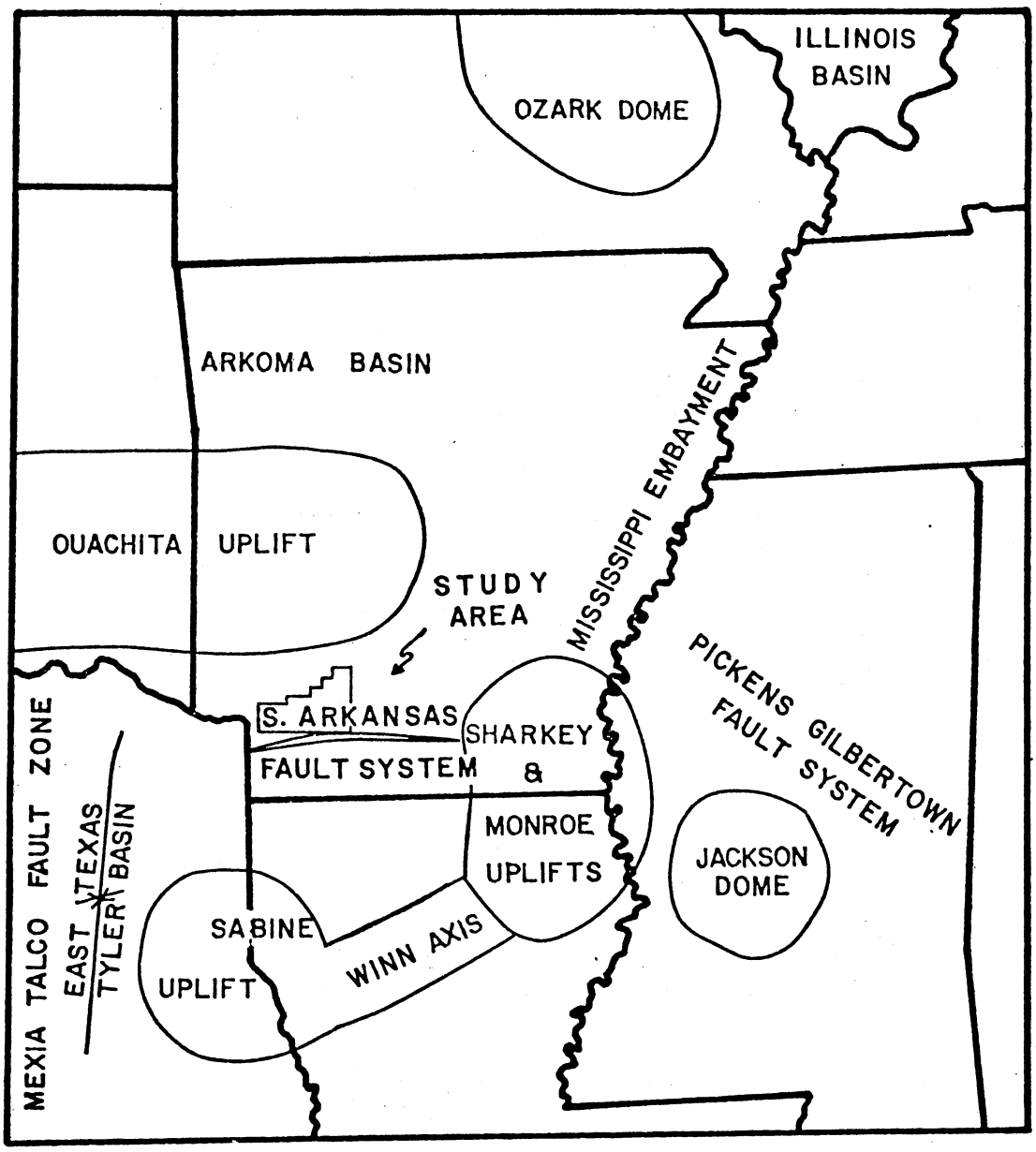


Fig. 3.--Regional tectonic and structural map.

CHAPTER IV

STRATIGRAPHY

Saratoga Formation

Faunal and stratigraphic evidence place the Saratoga in the Gulfian Series, Taylor Group, and Upper Cretaceous System (Fig. 4). The Saratoga is named after the town of Saratoga which is located on and near the outcrop. Deposition of the Saratoga occurred during and immediately after a transgression of the Cretaceous sea into this area. As defined by Dane (1929), the Saratoga is a white and gray, very fossiliferous, hard, sandy, somewhat glauconitic chalk with some beds of marly chalk and chalky sand. The depth of the water during deposition has been determined by Foraminifera ratios to be 300 feet or less (Creath and Stelhi, 1964). The section exposed near Saratoga Landing was examined by the writer. It is a very fossiliferous, hard, gray to white biomicrite. This particular outcrop is possibly a section of an oyster bank or buildup. Various species of porifera, echinoderms, mollusks, pelecypods, gastropods, cephalopods, and vertebrates (fish teeth) have been found in the Saratoga.

There is evidence of a local unconformity at the top of the Saratoga. Convincing evidence of such an unconformity is not present in the subsurface (Fig. 5).

			SOUTH ARKANSAS & LOUSIANA
SYSTEM	SERIES	GROUP	FORMATION
Tertiary	Miocene		Fleming Catahoula
	Oligocene		Vicksburg
	Eocene	Jackson	Jackson
		Claiborne	Cockfield Cook Mt. Sparta Cane River
		Wilcox	Wilcox
	Paleocene	Midway	Midway Clayton
Cretaceous	Gulfian	Navarro	Arkadelphia Nacatoch
		Taylor	Saratoga Annona Ozan (Buckrange)
		Austin	Brownstown Tokio (Blossom)
		Eagleford	Eagleford
		Woodbine	Tuscaloosa
	Comanchean	Washita	Georgetown
		Fredericksburg	Kiamichi Goodland
		Trinity	Paluxy Mooringsport Ferry Lake Anhydrite Rodessa James Pine Island
	Coahuilan	Durango	Sligo Hosston
Jurassic		Cotton Valley	Schuler Bossier
			Buckner Smackover

Fig. 4.--Stratigraphic column for South Arkansas and North Louisiana.

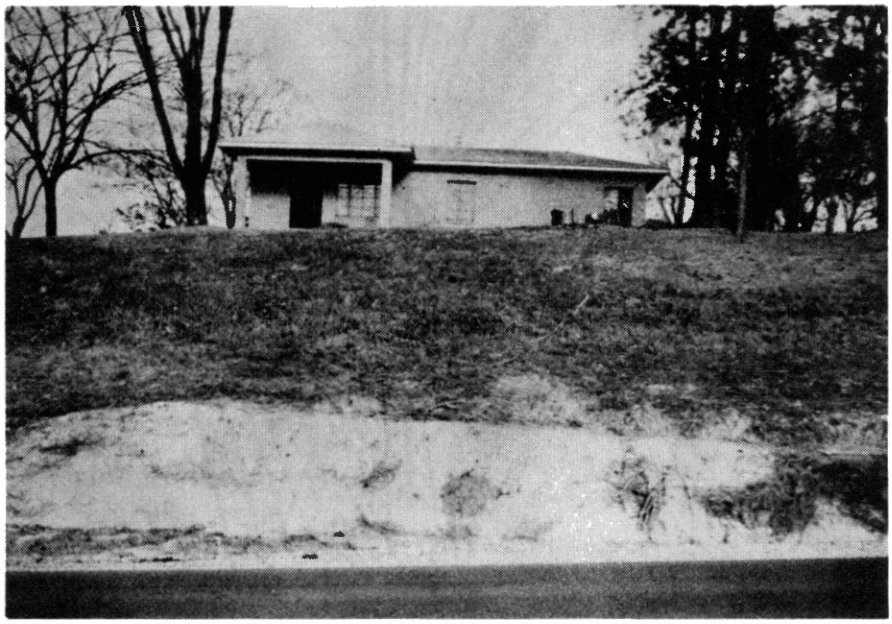


Fig. 5.--Photograph of the Nacatoch-Saratoga contact in the town of Saratoga.

Nacatoch Formation

Deposition of the Nacatoch occurred during the overall regression that followed the deposition of the Saratoga. Dane (1929) describes the Nacatoch as a complex unit made of cross-bedded, yellowish and gray, fine-grained, unconsolidated quartz sand; hard, crystalline, fossiliferous, sandy limestone; coarse, richly glauconitic sand; fine-grained, argillaceous, blue-black sand; and pure light-gray clay and marl. The Nacatoch was named by Veatch (1906) from Nacatoch Bluff on the east bank of the Little Missouri River, in the SW¼ of Sec. 36 of T9S, R22W in Clark County. The section described by Hill (1888) as the "Washington greensand" is now known as the Nacatoch Formation.

Faunal and stratigraphic evidence imply that the Nacatoch is of the Gulfian Series in the Navarro Group of the Upper Cretaceous System. Many species of coelenterata, echinoderms, mollusks, pelecypods, gastropods, cephalopods, arthropods, and vertebrates (shark teeth) have been reported from the Formation. Pelecypods, ophiomorpha, and skolithos trace fossils are the most common.

The Nacatoch unconformably overlies the Saratoga Formation and unconformably underlies the Arkadelphia Marl Formation. Although there is evidence of this present at the surface, no such evidence exists in the subsurface.

Arkadelphia Formation

Deposition of the Nacatoch was followed by the deposition of black and dark-gray shales, marls, and marly clay. Dane (1929) describes the Arkadelphia as a dark and black marl, and marly clay weathering to light

gray. It is reported to contain beds of hard, calcareous, gray sandstone; gray, sandy clay; sandy limestone; dense, concretionary limestone; and white impure chalk. Hill (1888) named this formation after the town of Arkadelphia, near where it outcrops. The Arkadelphia contains various species of coelenterates, pelecypods, scaphopods, gastropods, cephalopods, and vertebrates (shark teeth) (Dane, 1929). The Arkadelphia is not as fossiliferous as the Nacatoch and Saratoga but the faunal relationships are sufficient to establish age relationships.

Cross Sections

Correlation sections were constructed in a north to south and east to west grid. Three north-south sections and one southwest to northeast section have been included (Plate II). A list of well logs used in the correlation sections can be found in Appendix A. The datum for all of the sections is the base of the Arkadelphia. The vertical log scale is one inch equals approximately 220 feet. No horizontal scale is used on the correlation sections. Due to the softness of these formations, the lack of samples and few reliable drillers logs, lithologies on these logs are inferred from log characters. The type of water present in the formations is reflected in the electric log characters. The Spontaneous Potential (SP) log characters are suppressed due to brackish water or inverted due to fresh water. This is mostly seen in the area nearest the outcrop. The logs show a more normal reflection in the southern part of the sections.

In the interval from the base of the Arkadelphia to the top of the Saratoga, section A-A' shows thickening to the southwest. The number of sand units and total sand thickness decreases to the southwest or

basinward. The northeast half of the section has two sand units approximately 300 feet thick, whereas the southwest part of the section has only one sand unit developed which has less than 100 feet of sand.

Section B-B' is a north-south section which shows only a slight increase in thickness to the north in the Saratoga to Arkadelphia section. The Upper Nacatoch Sand unit is thin in this area where the lower sand is developed, but it thickens where the lower sand is not present. The hypothetical time lines indicated suggest time equivalent sections. The time lines are based on the supposition that this is a nearshore or shoreface, prograding, shallow marine sand deposit.

Section C-C' shows a fairly uniform thickness for the Saratoga to Arkadelphia section. Both Upper and Lower Nacatoch Sands are developed. The lower sand does thin slightly to the south, whereas the upper sand thickens to the south. The diagrammatic time lines are as described before. Faulting indicated on the Nacatoch structure map (Plate I) did not affect the thickness of the Nacatoch. The faults are presumed to have been active after the Nacatoch was deposited, and the well bores in these wells did not cut the faults.

Section D-D' is a north-south section showing a southward thickening of the section from the Saratoga to the Arkadelphia. Both the Upper and Lower Nacatoch Sand units are present. The upper sand is not as well developed to the south but is uniform in thickness. The lower sand unit maintains a fairly uniform thickness, except to the far north end of the section where it thins to approximately 200 to 225 feet.

CHAPTER V

CHARACTERISTICS OF THE NACATOCH SAND

Paleogeography

Throughout much of the Cretaceous, the study area, as well as much of North America, was at one time or another under a shallow sea. During the early Upper Cretaceous the interior seaway connected with the Gulf of Mexico. By late Upper Cretaceous time the sea covered most of central North America (Williams and Stelck, 1975). In the western and eastern United States there were mountainous areas as a source of sediment. Stephenson (1928) states that during deposition of the Gulfian Series, there was an island in the Monroe Uplift area of North Louisiana (Stephenson, 1928, Fig. 2).

During early Gulfian time the direction of the source of terrigenous clastics in East Texas was from the northeast and later gradually changed to the west (Stelhi et al., 1972). This interpretation was based on stratigraphic and paleontological evidence, sandstone to shale ratio, isopach and biofacies maps. The Upper Mississippi Embayment had as a source area the Appalachian Mountains. Pryor (1960) also indicates the source to have been from the northeast. The correlation sections constructed in this study area in South Arkansas indicate the possibility that there was a combination of sources, but the most dominant was from the north-northeast. The fact that the Nacatoch Sand thickness decreases in the southwest part of the area, and the Saratoga to Arkadelphia

section is thickest, implies that a westerly source is unlikely. The probability that the sand was carried across the basin in East Texas is slight. There are also many Cambrian and Orodvician sandstones that outcrop in the Ozark Mountains region and may have been an additional source of the Nacatoch Sand. The source for the Nacatoch was probably a combination sediment from the Ouachita Uplift, Ozark Dome, and the large delta complex that existed in the northern portion of the Mississippi Embayment. Tanner (1965) implies that there are two possible areas of sediment source from the Ouachitas. This hypothesis is based on the observance that in the sections studied there are two locations of increased grain size in the sand deposited. Tanner suggests that this is evidence of a source or river draining the Ouachita Uplift. This idea is not well substantiated, but the fact that the Ouachita Uplift was a positive element implies that it is most likely to have been the source of some sediment. The exact position of the northern edge or shoreline is speculative but it may have been only 20 to 30 miles north of the present outcrop (Williams and Stelck, 1975).

Figure 6 is a lithofacies map of the area surrounding the study area. In the Illinois Basin and Upper Mississippi Embayment the McNairy and other equivalent sands were deposited on flood plains, in delta systems, on deltaic platforms, and in shallow marine seas. In Mississippi the Selma chalk, Coffee sands, Monroe and Jackson gas rock, and unnamed Nacatoch equivalent sands and shales were deposited. Chalky sands and interbedded thick shaley sands make up the Nacatoch in North Louisiana (Shreveport Geol. Soc., Ref. V. 5, 1963). The Monroe gas rock was deposited on a shallow water carbonate platform area in South Arkansas, North Louisiana, and Mississippi. The shallow sea surrounded

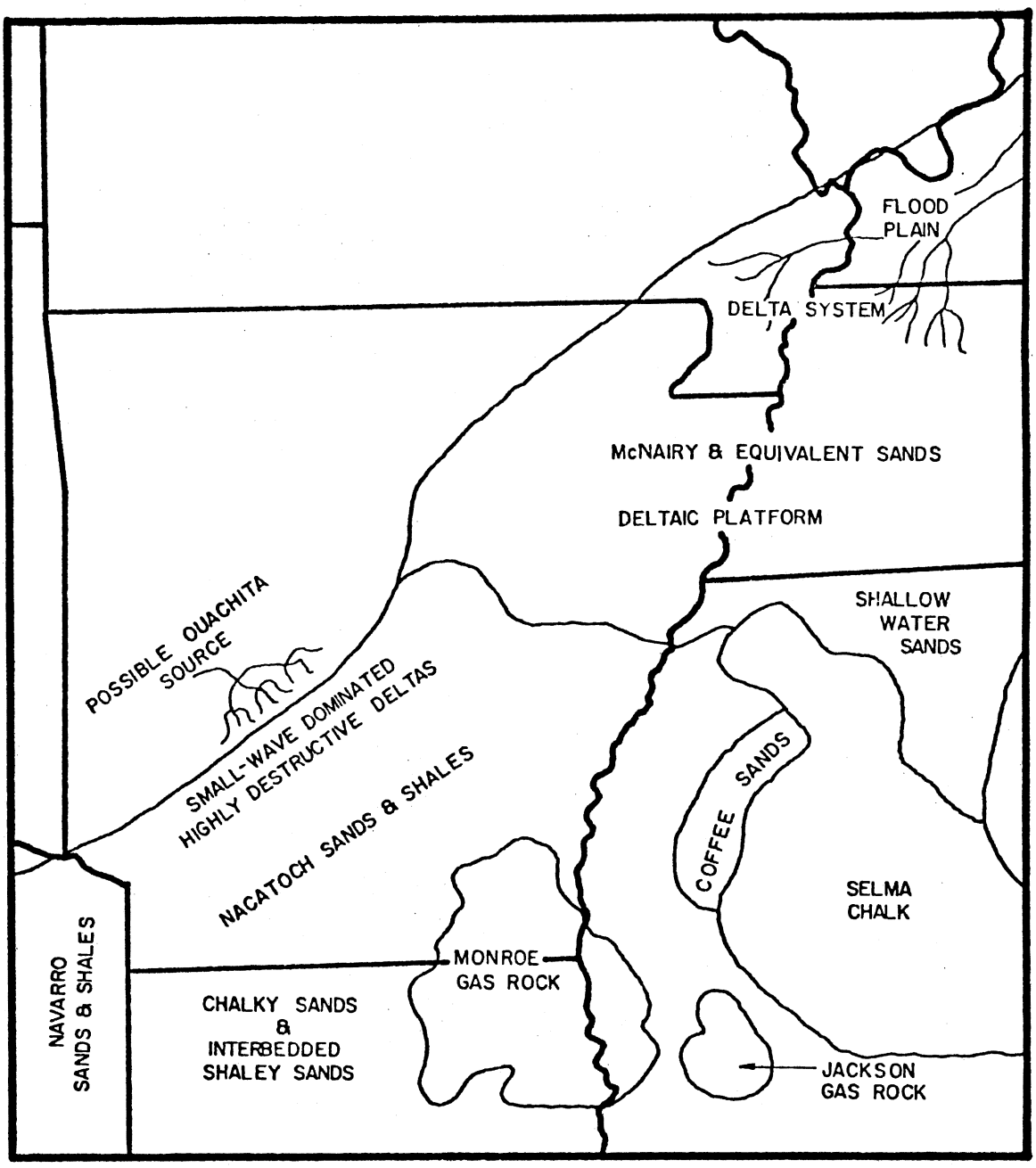


Fig. 6.--Lithofacies map of the Nacatoch Sand.

the Cretaceous island mentioned previously. The Navarro Formation of East Texas is the equivalent of the Nacatoch and Arkadelphia of South Arkansas and is comprised of thin-bedded sands and shales (Whitehead, 1931).

Discussion of Measured Sections

The Nacatoch Sand is more resistant to erosion and weathering than the Saratoga and Arkadelphia Formations. For that reason it forms a topographic ridge from the town of Saratoga to the town of Arkadelphia. Figure 7 shows a typical Nacatoch Sand outcrop which is 4.3 miles north of McNab on Highway 355. Eleven outcrops of the Nacatoch Sand were examined. The exposed sections were measured, described, sampled, and photographed. Samples were collected at five-foot intervals or when accessible and were then sieved for a size analysis. Grain mount thin sections were prepared from seven of the samples. Due to the low amount of cementation, the sand is too friable to yield undisturbed oriented samples. Figure 8 is an explanation of symbols used in the measured sections vertical profiles.

The Beard's Bluff measured section outcrop is located 0.3 mile east of the east end of Millwood Lake Dam on the west side of the road in the SE ¼ of Sec. 18, T12S, R27W (Fig. 9). Eight feet of the Nacatoch Sand is exposed with little vegetation covering the outcrop. The base of the Nacatoch is not exposed. The section consists of fine-grained, yellow and gray, wavy bedded, friable, highly bioturbated and burrowed sands interbedded with gray clay laminae. Skolithos, "plural curving tubes" trace fossils, and inoceramus shell fragments were also found. The upper 1.5 to 2 feet is fine-grained, yellowish, horizontally-bedded

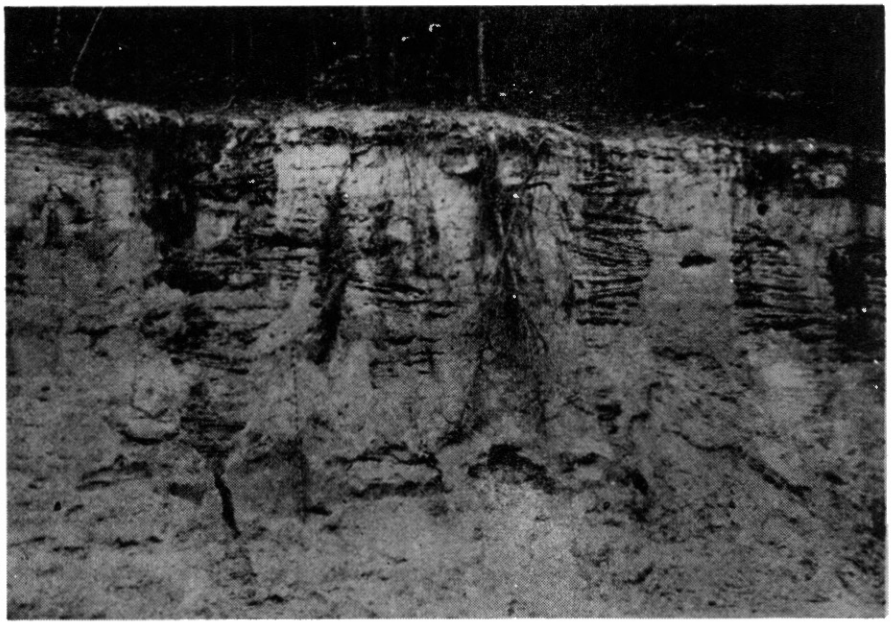


Fig. 7.--Photograph of a typical Nacatoch outcrop, 4.3 miles north of McNab on Highway 355.

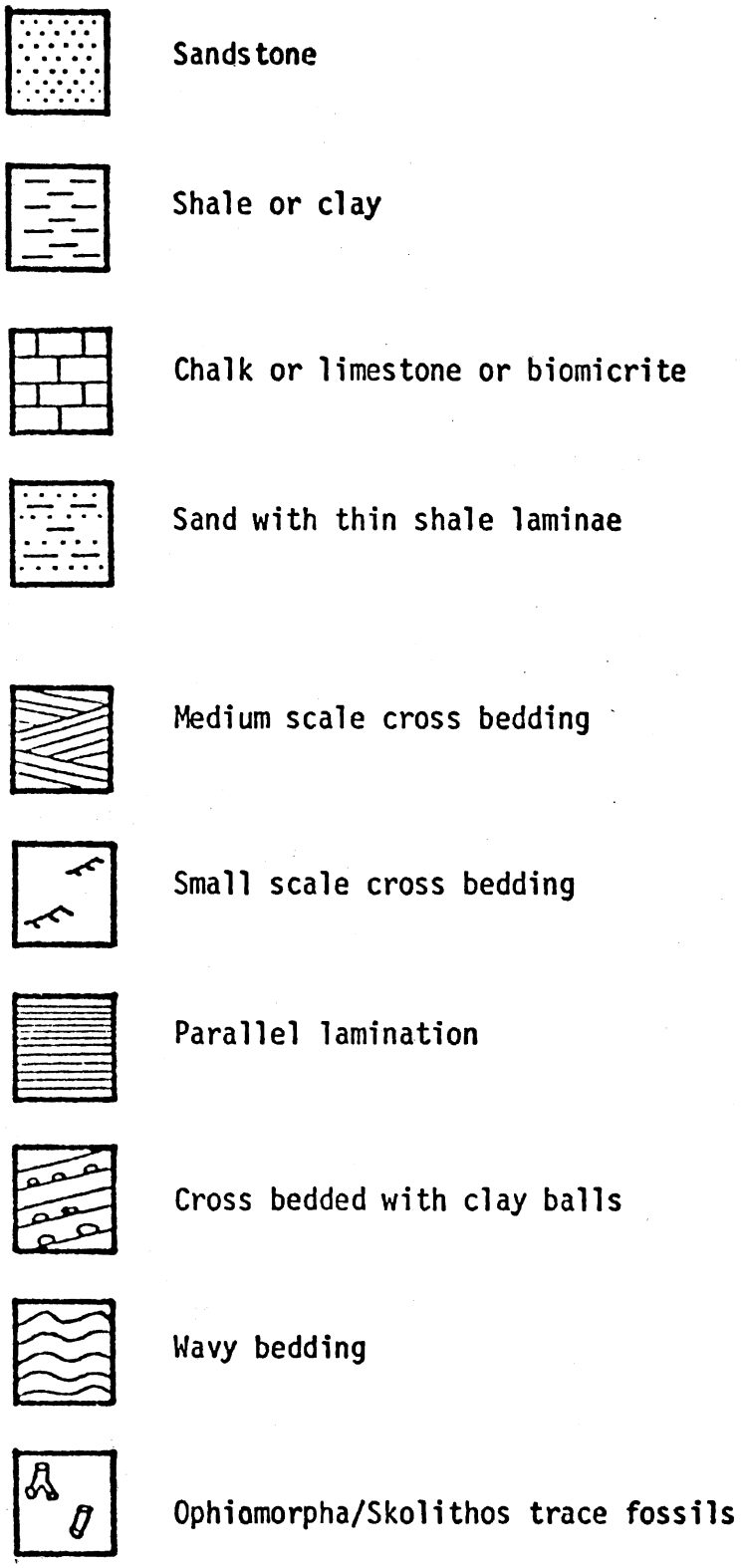


Fig. 8.--Explanation for measured sections.

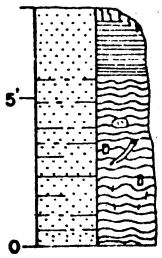
Beard's Bluff Measured Section

Location: 0.3 miles east of the east end of Millwood Lake Dam, west side of the road, SE 1/4 Section 18-T12S-R27W.

Trend: N 20° W Length: 125' approx.

Section thickness: 8'

General Condition: Easily accessible, very little to no vegetation, good outcrop.



Sample 2

Sand, fine grained, yellow, horizontally bedded, some roots at the top.

Sample 1

Sand, fine grained, yellow, with gray clay laminae, wavy bedded, bioturbated and burrowed, Skolithos, and plural curving tubes.

Base of Nacatoch not exposed.

Fig. 9.--Beard's Bluff measured section.

sand with roots at the top. The grain size and degree of sorting increase upwards in the section.

The Big Gurdon measured section outcrop is an abandoned quarry one-half mile south of the intersection of Interstate 30 and Highway 53 north of Gurdon in the S ½ of Sec. 6, T9S, R20W (Fig. 10). The outcrop is easily accessible and has little vegetation cover. The base of the Nacatoch is not exposed. The lower 15 feet of the 25 feet exposed is a series of fine-grained, soft and friable, medium-scale, crossbedded, yellow and light-gray sands with gray clay laminae. The clay laminae are more resistant to weathering and are generally found in the crossbed sets. At the base of the section there are some horizontally- and wavy-bedded clay laminae. Ophiomorpha and skolithos trace fossil burrows and other evidences of bioturbation and burrowing were recorded (Figs. 11 and 12). Three feet of yellow and light-gray, horizontally-bedded, fine-grained, soft, friable sand interbedded with gray clay laminae and skolithos burrows are immediately above the 15-foot section. The upper seven feet is composed of fine-grained, yellow and gray, bimodal, medium-scale, crossbedded, friable sand interbedded with clay laminae. The top portion of the seven-foot section has no crossbedding but does have some horizontal clay laminae and clay balls. The section has an overall upward increase in grain size and sorting. There is a decrease in the number of clay laminae upward in the section.

At the southeast end of the Gurdon Quarry another section was measured, the Little Gurdon measured section (Fig. 13). This section is equivalent to the lower 16.5 feet of the Big Gurdon section. The bottom two feet of the Little section are interbedded, fine-grained, gray and yellow, wavy-bedded, bioturbated and burrowed sands and gray

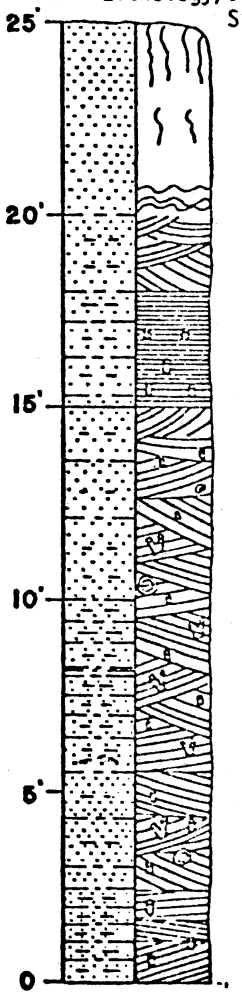
Location: 1/2 mile south of Interstate 30 on Highway 53, north of Gurdon in a Quarry on the NW side of the road, S 1/2 Section 6-T9S - R20W.

Trend: N 57° E

Length: 150' approx.

Section thickness: 25'

General Condition: Easily accessible, good exposure.



Sand and surface soil, roots and some clay balls.

Sand, fine grained, crossbedded, yellow and gray, some clay laminae.

Sand, with clay laminae, horizontally bedded, Skolithos burrows, fine grained, yellow and gray.

Sand, fine grained, crossbedded, yellow and light gray, Ophiomorpha and Skolithos trace fossils, clay laminae.

As above, with more clay laminae.

As above.

Base of Nacatoch not exposed.

Fig. 10.--Big Gurdon measured section.

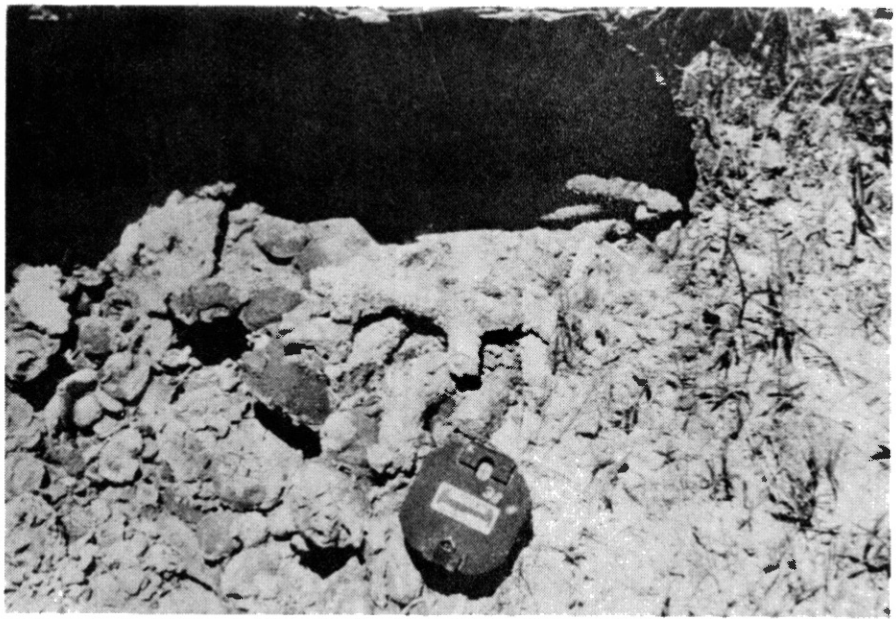


Fig. 11.--Photograph of an ophiomorpha trace fossil.

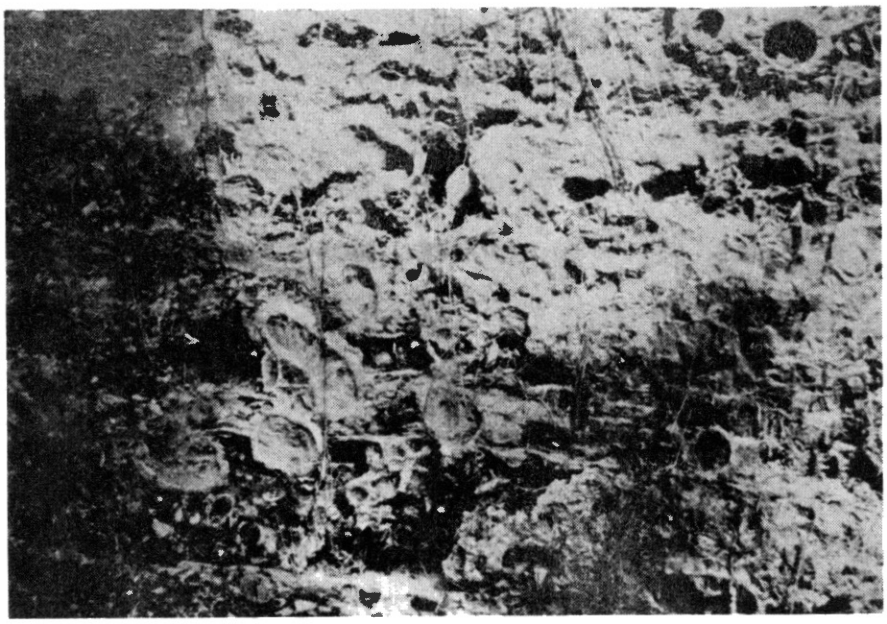


Fig. 12.--Photograph of bioturbation and burrows in the Big Gurdon Quarry.

Location: 1/2 mile south of Interstate 30 on Highway 53, north of Gurdon in a Quarry on the NW side of the road, S 1/2 Section 6-T9S-R20W.

Trend: N 40° W Length: 75'

Section thickness: 13'

General Condition: Almost vertical exposure, easily accessible at base, difficult at the top, good exposure, little vegetation.

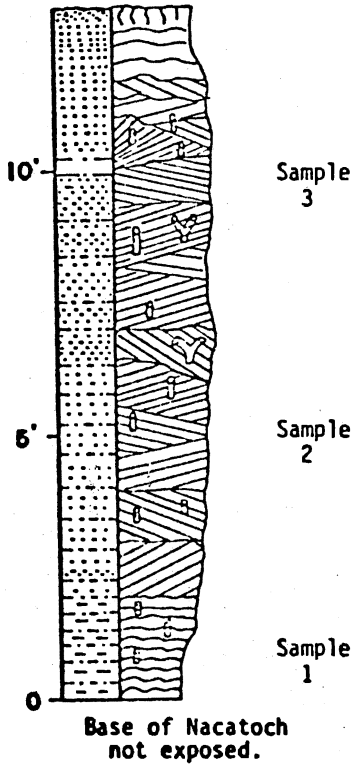


Fig. 13.--Little Gurdon measured section.

clay laminae. Skolithos burrow tubes were found in this bottom two feet.

The Corps of Engineers measured section outcrop is located one-third mile southeast of the east end of Millwood Lake Dam in the NW¼ of Sec. 19, T12S, R27W (Fig. 14). The outcrop is easily accessible and has little vegetation cover. Because the clay laminae are numerous and resistant, the outcrop was virtually impossible to trench properly and descriptions are limited. Numerous samples and photographs were taken. The base of the Nacatoch is not seen. A total of 30 feet is exposed and comprises fine-grained, yellow and light-gray, bioturbated and burrowed, wavy-bedded sands and dark- and light-gray clay laminae. Skolithos and ophiomorpha trace fossils and numerous "mound" structures (Fig. 15) were noted. These latter structures are resistant to weathering, average 10 to 12 inches in diameter and 6 to 8 inches in height. They have bioturbated clay outer shells and a fine- to medium-grained, gray sand in the center. The average distance between structures is 6.2 feet. They are randomly scattered throughout the 15- to 22-foot interval of the section.

The Gum Springs Quarry measured section outcrop is located on the north side of Interstate 30 approximately one-quarter mile northeast of the Gum Springs exit in the S½ of Sec. 5, T8S, R20W (Fig. 16). This exposure is the best of the outcrops examined (Fig. 17). The lower shaley facies of the Nacatoch is exposed but the Nacatoch-Saratoga contact is not. A total of 36 feet of Nacatoch is exposed. The bottom eight feet of the section consists of interbedded, fine-grained gray sands and gray laminated shale and clay, both of which are highly bioturbated and burrowed (Fig. 18). The clay and shales of this entire section are more resistant to erosion than the sands. Skolithos and

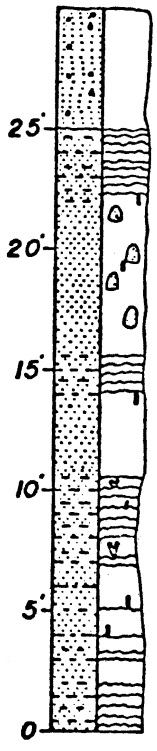
Location: 1/3 mile SE of East end of Millwood Lake Dam, NW 1/4 of Section 19-T12S-R27W.

Trend: N 70° E Length: 0.4 mile

Section thickness: 30'

General Condition: Easily accessible, clay content and sand compaction make trenching very difficult. Some bedding may be present but not easily seen or recognized.

Lithology/Sedimentary Structures



Surface soil, some iron concretions.

Sand, interbedded with clay laminae, fine grained, gray

Sample 6

Sand as above. Mound structures center of which is gray sand. Outer shell is clay, bioturbated. Some traces of Skolithos.

Sample 5

Sample 4

Sand, fine grained, gray, interbedded with clay laminae, wavy bedding, bioturbated.

Sample 3

Sand, as above, more bioturbated.

Sample 2

Sand and clay laminae as above.

Sand, fine grained, gray, stained red, wavy bedded, interbedded with clay.

Sample 1

Base of Nacatoch not exposed

Fig. 14.--Corps of Engineers measured section.

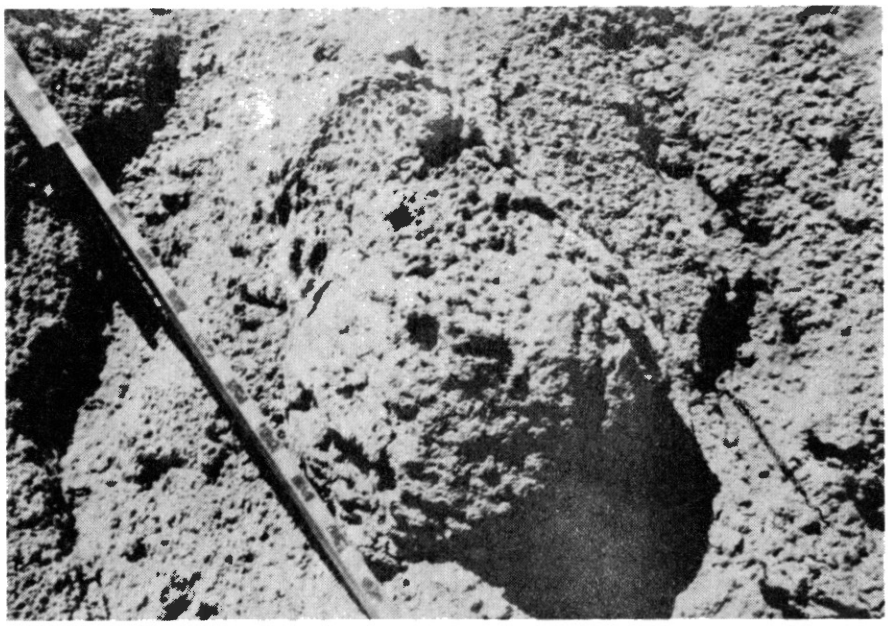


Fig. 15.--Photograph of mound structures at the Corps of Engineers outcrop.

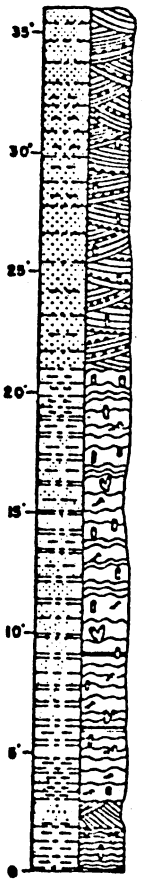
Location: North side of Interstate 30, approximately 1/4 mile NE of the Gum Springs Exit, S1/2 of Section 5-T8S-R20W.

Trend: N 70° E Length: 800'

Section thickness: 36'

General Condition: Good exposure, some spots covered, some areas are too steep and soft to climb for close examination.

Lithology/Sedimentary Structures



Sample 3

Sand, gray, yellow, fine grained, biomodal medium scale crossbeds. Clay balls and clay laminae in crossbeds. Many Skolithos burrows.

Sample 2

Sand, gray, yellow, fine grained, wavy and horizontal bedding. Some small scale crossbeds. Skolithos and Ophiomorpha burrows. Bioturbated clay laminae, gray, very fine grained.

Sample 1

Sand, gray, fine grained, with clay laminae. Clay laminae, gray, interbedded with thin sands, bioturbated and burrowed.

Base of Hacatoch not exposed.

Fig. 16.--Gum Springs Quarry measured section.

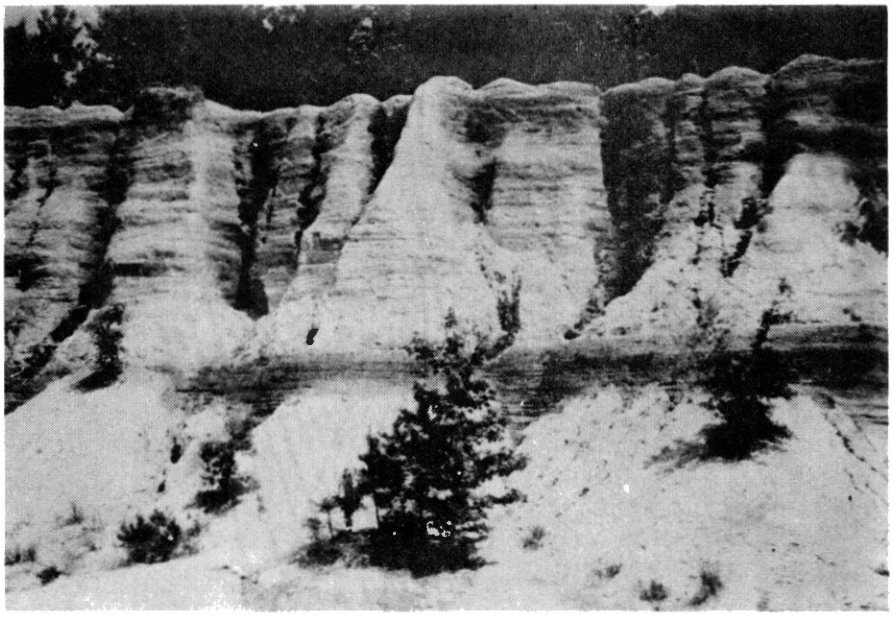


Fig. 17.--Photograph of the Gum Springs Quarry outcrop.

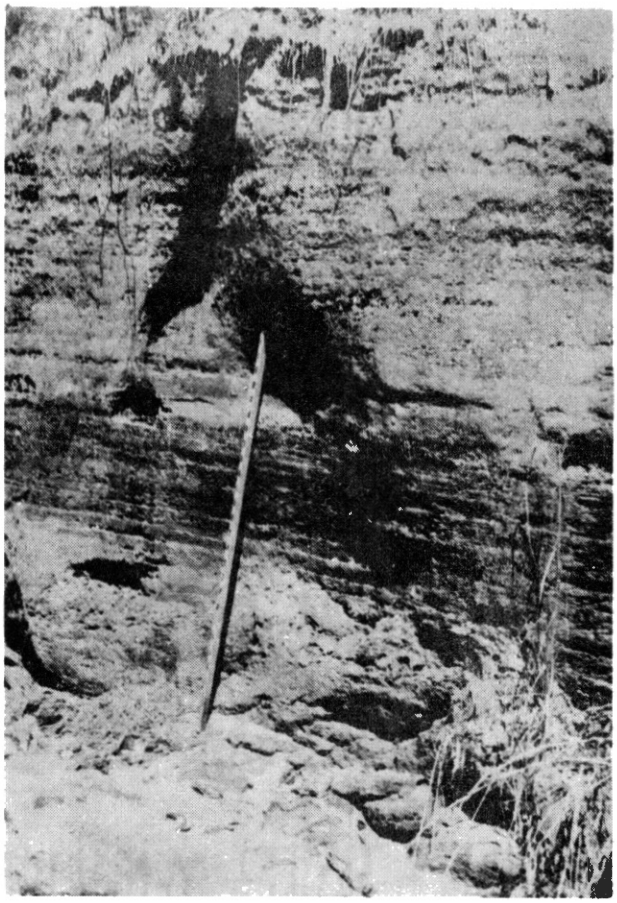


Fig. 18.--Photograph of the lower facies of the Nacatoch at the Gum Springs Quarry.

ophiomorpha trace fossil burrows are differentially weathered and are easily identified. The overlying 13 feet of section is much like the bottom but has less clay laminae. Much of this portion is covered by talus derived from the sand above. Mostly it is fine-grained, gray to yellow, wavy-bedded, horizontally-bedded, small-scale, crossbedded sands and gray clay laminae, both of which are intensely bioturbated. The upper 15 feet consists of light-gray and yellow, fine-grained, bimodal, medium-scale, crossbedded sand with gray clay balls and clay laminae in the crossbeds (Figs. 19 and 20). This section contains many skolithos tubelike burrows. There is an overall increase in grain size and cleaner or better sorted sand upwards in the section.

At the northwest end of the Gum Springs Quarry another section was measured, the Gum Springs Quarry Northwest measured section (Fig. 21). This section is 26 feet thick. The bottom 20 feet are equivalent to the previous section. The upper six feet is composed of fine-grained, horizontally-bedded, gray and yellow sand with interbedded clay laminae. Some skolithos burrows were found. The 12- to 20-foot interval contains small amounts of glauconite. This outcrop also shows an increase in grain size and degree of sorting upwards in the section.

The Nacatoch-Saratoga Contact measured section outcrop is located in a streamcut on the southeast side of Interstate 30 in the S ½ of Sec. 27, T7S, R20W near the town of Arkadelphia (Fig. 22). The lowest two feet of the section are under water. The Saratoga Formation is a gray sandy clay that is 2.5 feet thick. The Nacatoch is a light-gray, very fine to fine-grained, massive sand. The Nacatoch is eight feet thick. There is 1.5 feet of surface soil, sand, and alluvium (with some cobbles at the base) directly on top of the Nacatoch.

Fig. 19.--Photograph of clay laminae and trace fossils in the Upper Nacatoch at the Gum Springs Quarry.

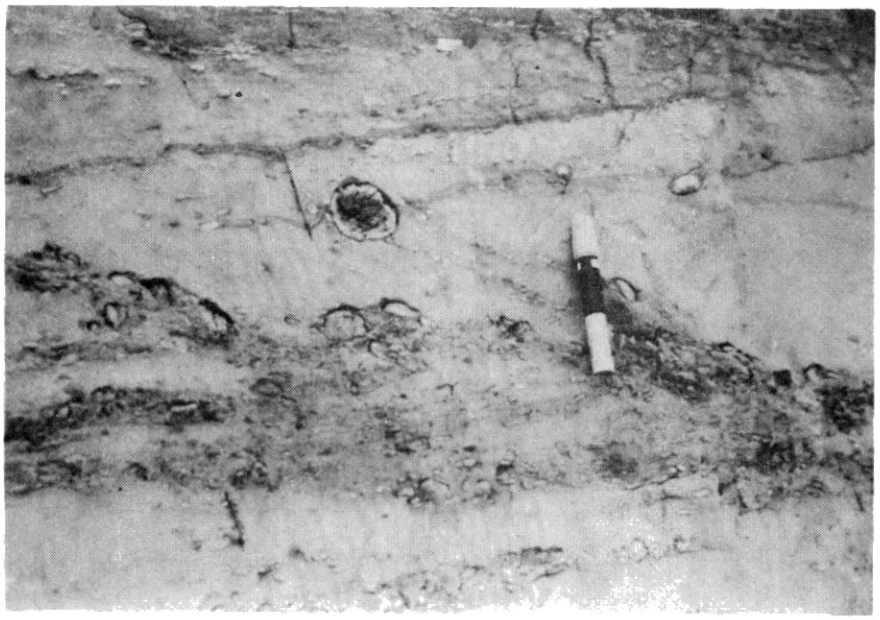


Fig. 20.--Photograph of clay balls in the Upper Nacatoch at the Gum Springs Quarry.

Location: North side of Interstate 30 approximately 1/4 mile north of the Gum Springs exit, S 1/2 Section 5-T8S-R20W.

Trend: N 30° E Length: 250'

Section thickness: 26'

General Condition: Good exposure, easily accessible at the base, steeper at the top.

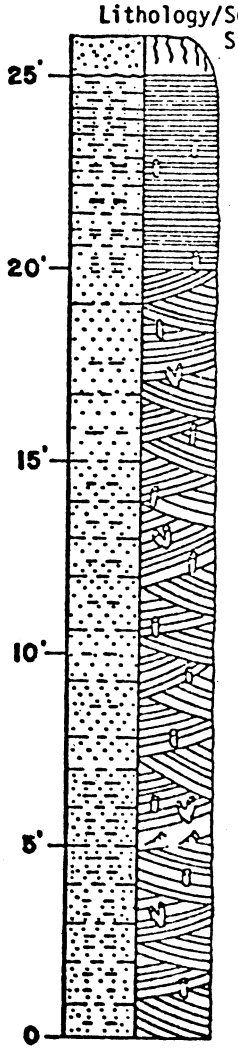


Fig. 21.--Gum Springs Quarry (NW) measured section.

Location: In stream cut on SE side of Interstate 30, S 1/2 Section 27-T7S-R20W near the town of Arkadelphia.

Trend: N 20° W Length: 60' approx.

Section thickness: 12.0'

General Condition: Water at base can cause some difficulty but generally good condition.

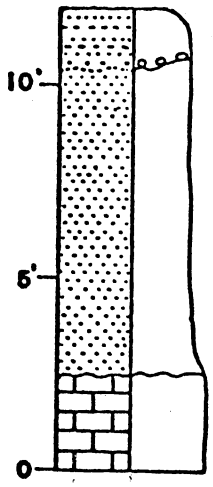


Fig. 22.--Nacatoch-Saratoga contact measured section.

The North McNab measured section outcrop is located 4.3 miles north of McNab on Highway 355 on the west side of the road in the NE¼ of Sec. 23, T12S, R27W (Fig. 23). This is a good exposure and is easily accessible. A total of 15 feet of section is exposed. The section consists of 14 feet of fine-grained, yellow and light-gray, medium- and small-scale, bimodally crossbedded, friable sands. Numerous thin gray clay laminae, ophiomorpha and skolithos burrows were found in the crossbeds. The top one foot of the section is surface soil and sand with numerous roots.

The McNab railroad cut measured section outcrop is located one-third mile west of McNab on the St. Louis and San Francisco Railroad right-of-way in the SW¼ SE¼ of Sec. 36, T12S, R27W (Fig. 24). The section was measured at the thickest exposed portion. This outcrop is easily accessible except for the upper 12 feet. The base of the Nacatoch is not exposed. Of the 21.5 feet exposed, the lowermost two feet is a highly bioturbated and burrowed, fine-grained, wavy-bedded, yellow and light-gray sand interbedded with light-gray clay laminae. Ophiomorpha, skolithos, and "plural curving tubes" trace fossils make up most of the bioturbation and burrowing. This section contains 8 to 10 percent glauconite. From the 2- to 12-foot levels the section consists of fine-grained, medium-scale, bimodal, crossbedded, yellow and light-gray sands with clay laminae and skolithos tube burrows in the crossbed sets together with a few ophiomorpha trace fossils. The 12- to 17-foot interval consists of fine-grained, yellowish to light-gray, wavy and small-scale, crossbedded sands with a few skolithos burrows and little to no clay laminae. The top 4.5 feet is surface soil and sand that contains no structures or trace fossils. There is a slight increase

Location: 4.3 miles north of McNab on Highway 355, west side of the road, NE 1/4 Section 23-T12S-R27W.

Trend: N 50° E Length: 150'

Section thickness: 15'

General Condition: Easily accessible, good exposure.

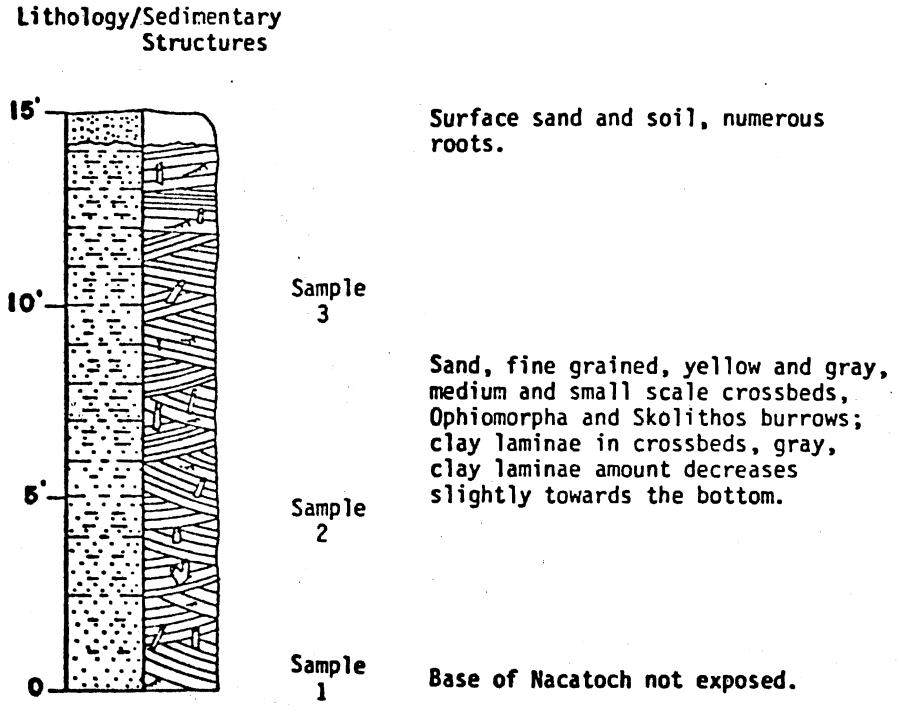


Fig. 23.--North McNab measured section.

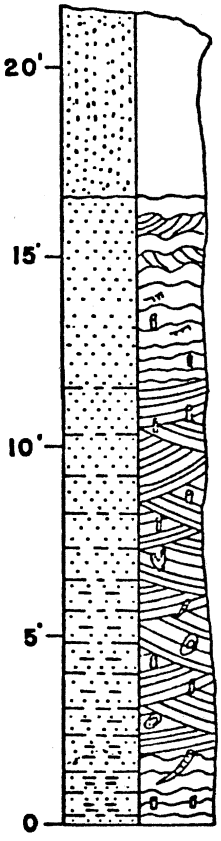
Location: West of McNab on the St. Louis and San Francisco Railroad right of way, section was measured at the thickest exposure, 1/3 mile from McNab, southside of the tracks, SW 1/4 SE 1/4 Section 36-T12S-R-27W.

Trend: N 85° W

Length: total - 1/2 mile, 150' where section was measured.

Section thickness: 21.5'

General Condition: Easily accessible except for upper 12' which is almost vertical, otherwise an excellent exposure.



Surface sand and soil.

Sand, fine grained, wavy bedded, small scale crossbeds, a few Skolithos burrows, mostly yellow but some gray.

Sand, fine grained, crossbedded, yellow and gray, clay laminae, bioturbated and burrowed, Ophiomorpha and Skolithos.

Sand, fine grained, wavy bedded, yellow and gray, bioturbated and burrowed, clay laminae, plural curving tubes.

Base of Nacatoch not exposed.

Fig. 24.--McNab railroad cut measured section.

in grain size and sorting upward in the section.

The Millwood East measured section outcrop is located 1.2 miles east of the east end of the Millwood Lake Dam on the north side of the highway in the SE¼ SE¼ of Sec. 18, T12S, R27W (Fig. 25). The outcrop is easily accessible but some parts are covered with vegetation. The exposed section is 19 feet thick with 15 feet being the Nacatoch Sand and the upper four feet are surface soil and sand with numerous roots and a few cobbles. The base of the Nacatoch is not exposed. The lower ten feet of the section is composed of interbedded, fine-grained, light-gray, bioturbated and burrowed, horizontally-bedded sands and light-gray clay laminae. Skolithos, ophiomorpha, and "plural curving tubes" are present. The upper five feet above is composed of fine-grained, light-gray, wavy and horizontally-bedded sands interbedded with gray clay laminae. The grain size and sorting increase towards the top of the section.

The Saratoga Landing measured section outcrop is located one-third mile south of Saratoga Landing on Millwood Lake in the center of the E½ of Sec. 7, T12S, R27W (Fig. 26). The outcrop is a very steep, unstable cliff exposure with a large amount of slumping due to the slope. Because of attempts by land owners to stop the slumping, much of the exposure is covered by wire and concrete. The total thickness of accessible section is 19.5 feet; the bottom three feet of which is assigned to the Saratoga Formation. The Saratoga is a light-gray to white biomicrite in this area. One foot of Nacatoch Sand, fine-grained, crossbedded, with clay balls lies on top of the Saratoga. In various places this sand is covered by ripped up clasts of Saratoga. The measured section has one-foot thick ripped up Saratoga clast on top of

Location: 1.2 miles east of the east end of Millwood Lake Dam on the north side of the highway, SE 1/4 SE 1/4 Section 18-T12S-R27W.

Trend: N 50° E Length: 200'

Section thickness: 19'

General condition: Easily accessible, some parts covered with vegetation.

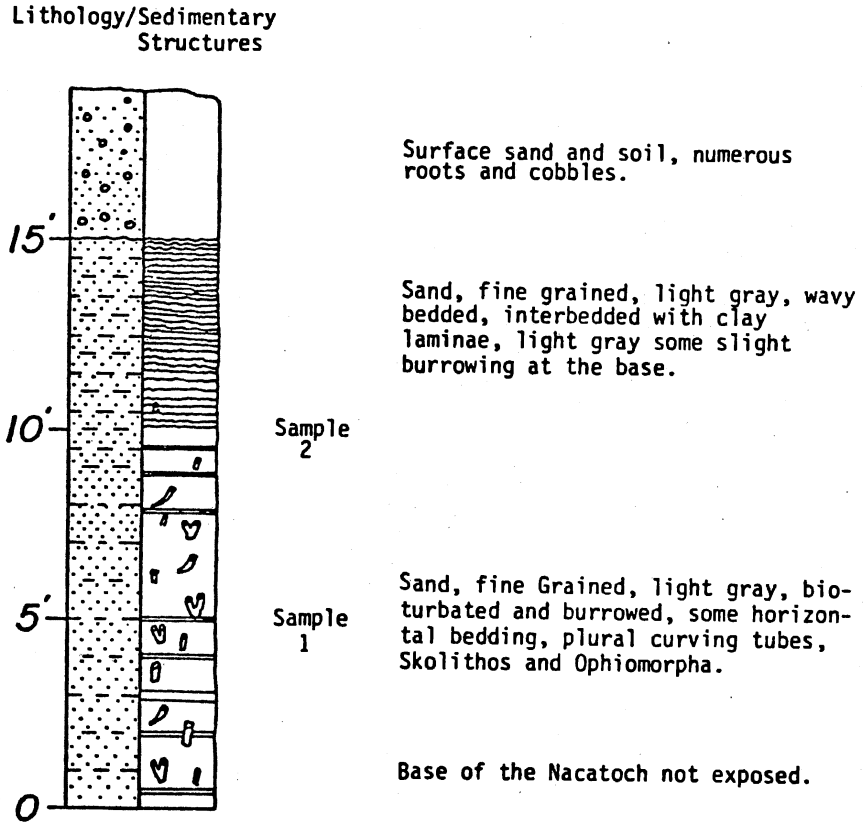


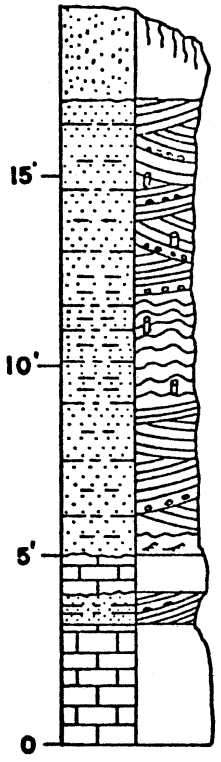
Fig. 25.--Millwood East measured section.

Location: Approximately 1/3 mile south of Saratoga Landing on Millwood Lake, CE 1/2 Section 7-T12S-R27W.

Trend: N 30° W Length: 900'

Section thickness: 19.5'

General Condition: Very steep exposure, much slumping, easily accessible at base with increasing difficulty toward the top, attempts by landowners to stop slumping with re-bar wire and concrete have failed and sand is eroding from underneath concrete, which covers most of the exposure of Nacatoch.



Surface soil and sand, numerous roots.

Sand, fine grained, crossbedded, clay laminae and balls, bioturbated and burrowed, gray, yellow.

Sand, fine grained, wavy bedded, gray, bioturbated and burrowed, clay laminae.

Sample 3 — Sand, fine grained, crossbedded, gray. Some clay laminae.

Saratoga chalk - ripped up, possible clast.

Sample 2 — Nacatoch sand - fine grained with clay balls.

Sample 1 — Saratoga chalk - Biomicrite, , shallow water, generally 300 but possibly 10' of water.

Fig. 26.--Saratoga Landing measured section.

which are four feet of fine-grained, gray, medium-scale, crossbedded, soft, friable sands with some clay balls and laminae. These beds are overlain by three feet of fine-grained, wavy-bedded, gray, friable, bioturbated and burrowed sand with dark- and light-gray clay laminae. Five feet of fine-grained, soft, yellow and gray, medium-scale, crossbedded, bioturbated and burrowed sand interbedded with clay balls and laminae form the top of the Nacatoch exposure. Two and one-half feet of surface soil and sand with numerous roots are at the top of the section.

The Washington measured section outcrop is located east of Washington on the south side of the section line road of Sec. 22 and 27, T11S, R23W (Fig. 27). This is a steep outcrop but it was possible to climb to examine and sample. This is the location of the "Washington greensand" (Fig. 28). A total of 20 feet is exposed, 18 feet of Nacatoch greensand and two feet of horizontally-bedded surface sand and sandy clay. The base of the Nacatoch is not exposed. The section is very fine-grained, glauconitic, yellow-green and gray, wavy and massive-bedded, burrowed sands with light- and dark-gray clay laminae interbedded. The glauconite is pelletoidal and forms 50 to 60 percent of the sand at the base, decreasing to ten percent of the sand at the top. Skolithos and ophiomorpha burrows were found. Grain size and sorting vary little throughout the outcrop.

Internal Features

Predominate features of the Nacatoch Sand include bimodally oriented, medium- and small-scale crossbeds, clay balls and clay laminae in the crossbeds; interbedded, thin, fine-grained sands and clay laminae,

Location: East of Washington, south side of section line road, Sections 22 and 27-T11S-R23W.

Trend: N 80° E

Length: 25-30' approx.

Section thickness: 20'

General Condition: Somewhat steep, easily accessible at the base increasingly more difficult at the top.

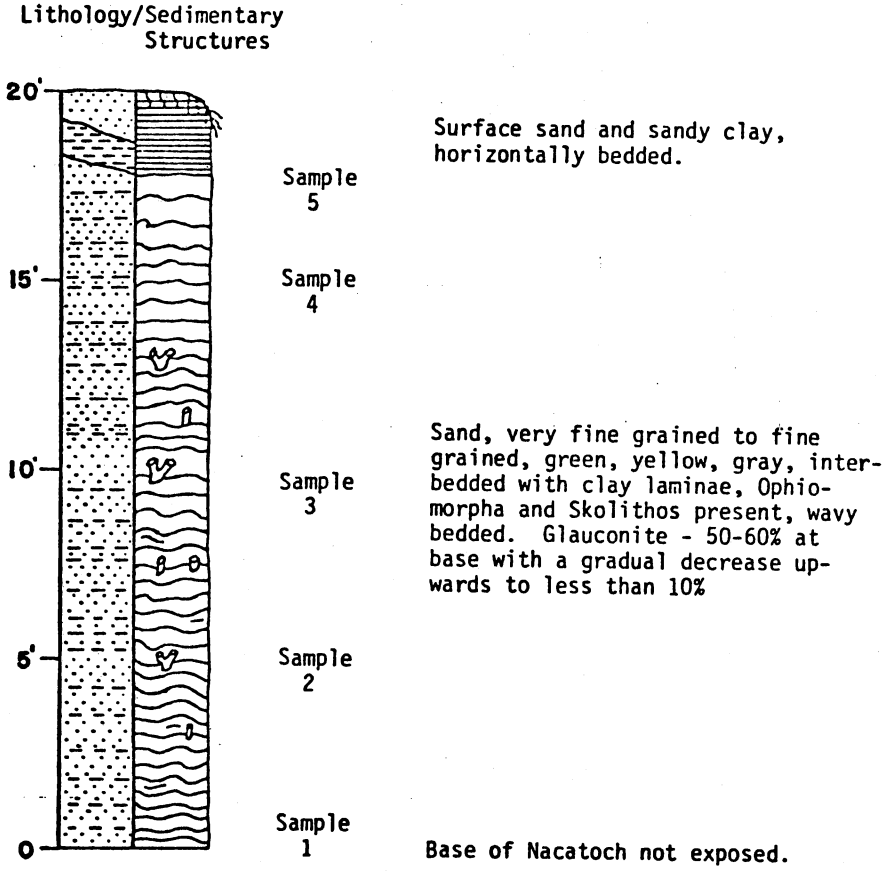


Fig. 27.--Washington measured section.

Fig. 28.--Photograph of the Nacatoch "Washington greensand" outcrop.

horizontal and wavy-bedded, bioturbated and burrowed sands and shales. There is little cement material present to hold the grains together and thus the sand is very friable. The sands are generally very fine to fine-grained and moderate to very well sorted.

Grain size sieve analyses were performed on all of the Nacatoch Sand samples collected. A total of 35 samples were air dried, split, weighed, sieved, re-weighed and statistical analyses were run on the results. The results of these analyses can be found in Table I. The sample location, number, median, mean, maximum diameter, standard deviation, skewness, and kurtosis are the statistical parameters included. Of the median values calculated, the high was 3.29 Ø and the low was 1.95 Ø. The high mean value was 3.44 Ø and the low was 1.32 Ø units. The greatest standard deviation was 0.77 Ø and the least standard deviation was 0.26 Ø. Geographic distribution of the sorting, as defined by the standard deviation, suggests that the sands are sorted slightly better in the samples from the southwest end of the outcrop belt.

Grain mount thin sections of seven of the samples were used to determine the sphericity, angularity, mineralogy, and possible cementation of the Nacatoch Sand. The sand grains have, in general, moderate to high sphericity and are subangular to subrounded. Mono- and polycrystalline quartz, microcline and plagioclase feldspars, glauconite, hematite, clay fragments, sedimentary rock fragments, and possibly some micro-crystalline chert fragments were found in the thin sections (Fig. 29). A small number of quartz grains had thin coats of hematite. Evidence of any other significant cementation was not seen.

Porosity and permeability of the Nacatoch sand appear to be

TABLE I

GRAIN SIZE STATISTICAL ANALYSES RESULTS

Sample Location and Number	Median	Mean	Maximum Diameter	Standard Deviation	Skewness	Kurtosis
Beard's Bluff						
1	3.09	3.18	2.12	0.61	0.149	0.752
2	3.29	3.44	2.39	0.54	0.278	0.888
Big Gurdon						
1	2.28	2.43	1.59	0.52	0.291	0.961
2	2.91	3.05	2.15	0.54	0.259	0.861
3	1.95	1.99	1.33	0.37	0.096	1.082
4	2.01	2.11	1.51	0.38	0.267	0.933
Corps of Engineers						
1	3.04	3.12	1.90	0.59	0.136	0.924
2	2.79	2.91	1.79	0.68	0.176	0.743
3	2.68	2.59	1.74	0.42	-0.214	0.976
4	2.78	3.01	2.01	0.49	0.469	1.214
5	2.60	2.77	2.21	0.29	0.586	1.793
6	2.90	3.15	2.34	0.49	0.510	1.365
Gum Springs Quarry						
1	2.38	2.52	1.78	0.42	0.337	0.952
2	2.90	3.03	2.11	0.39	0.333	1.346
3	2.40	2.25	1.10	0.67	-0.224	0.7910
Gum Springs Quarry (NW)						
1	2.55	2.64	1.93	0.34	0.269	1.597
2	2.10	2.37	1.66	0.42	0.643	0.964
3	2.71	2.62	1.73	0.49	-0.204	0.918
Little Gurdon						
1	2.25	2.46	1.61	0.54	0.388	0.852
2	2.93	3.02	2.26	0.30	0.300	1.933
3	2.00	2.12	1.32	0.46	1.261	0.913
McNab						
1	2.80	2.84	2.24	0.26	0.154	1.365
2	2.80	2.83	2.35	0.28	0.107	1.000
3	2.78	2.77	2.19	0.29	-0.344	1.172
4	2.70	2.64	2.14	0.29	-0.207	1.120
5	2.56	2.49	1.95	0.31	-0.226	0.968
McNab North						
1	2.76	2.77	2.15	0.77	0.013	1.35
2	2.71	2.75	1.97	0.42	0.095	3.642
3	2.71	1.755	2.00	0.47	0.097	3.408
Millwood East						
1	2.78	2.89	2.22	0.42	0.253	3.048
2	2.86	3.09	2.33	0.34	0.687	1.627
Saratoga Landing						
1	3.04	3.13	2.47	0.33	0.277	1.323
2	3.07	3.22	2.41	0.53	0.283	0.698
Washington						
1	2.79	2.85	2.21	0.36	0.179	1.298
2	2.77	2.87	2.14	0.35	0.289	1.348
3	2.73	2.73	2.02	0.32	0.0	1.453
4	2.72	2.95	1.98	0.58	0.396	0.845

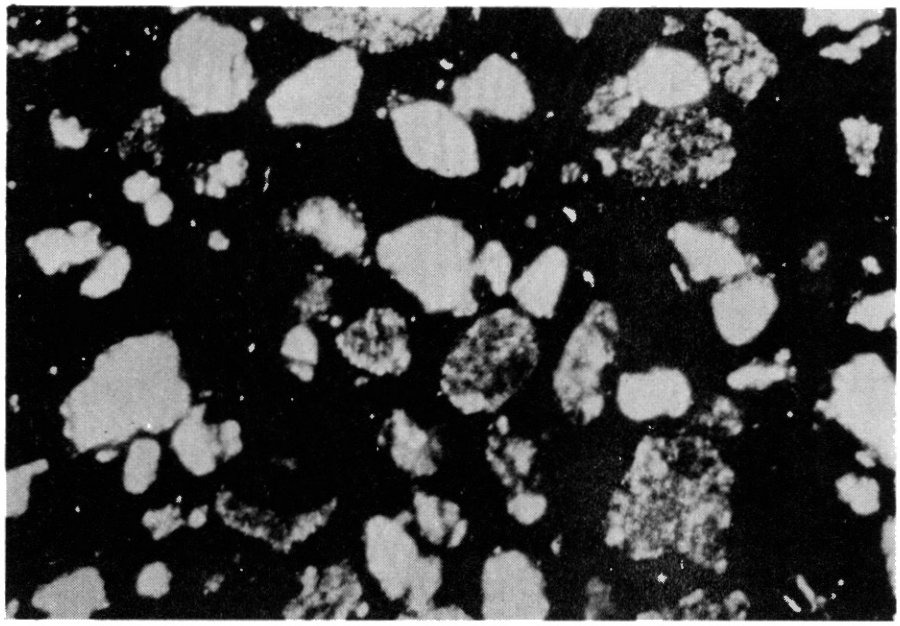


Fig. 29.--Photograph of a grain mount thin section of the "Washington greensand."

moderate to high. The Nacatoch in Irma Field is reported to have 40 percent porosity (Park, 1969). Log characters of the Nacatoch Sand and the lack of great amounts of cementation and compaction of the sand support this.

Trace fossils found in abundance in the Nacatoch include ophiomorpha, skolithos, and "plural curving tubes." Howard (1972) discusses the use of trace fossils in the determination of depositonal environments. Ophiomorpha trace fossils are nubby, branching, cylindrical, horizontal, and vertical tubes ranging in diameter from 1 to 3 to 4 inches. The ophiomorpha may be found in the offshore, offshore-shoreface transition, lower and upper shoreface, shoreface-foreshore transition, and foreshore facies units of a nearshore environment but may be found occasionally elsewhere. "Plural curving tubes" trace fossils are a series of subvertical curving tubes of various sizes. These are often seen in lenthwise cross sectional views in outcrops. Plural curving tubes are primarily found in the upper and lower shoreface, shoreface-foreshore transition and foreshore facies. Figure 30 shows various trace fossils, megafossils, tracks and trails, and the nearshore environments where they are found.

Dane (1929) describes the various species of megafossils found in the Nacatoch. Appendix B is a list of fossils found. The present-day marine invertebrates of Galveston Island (Bernard, 1972) are much like the invertebrates found in the Nacatoch.

Geometry

The thickness of the Nacatoch Formation increases and the amount and number of sand units decreases to the southwest. The trend is

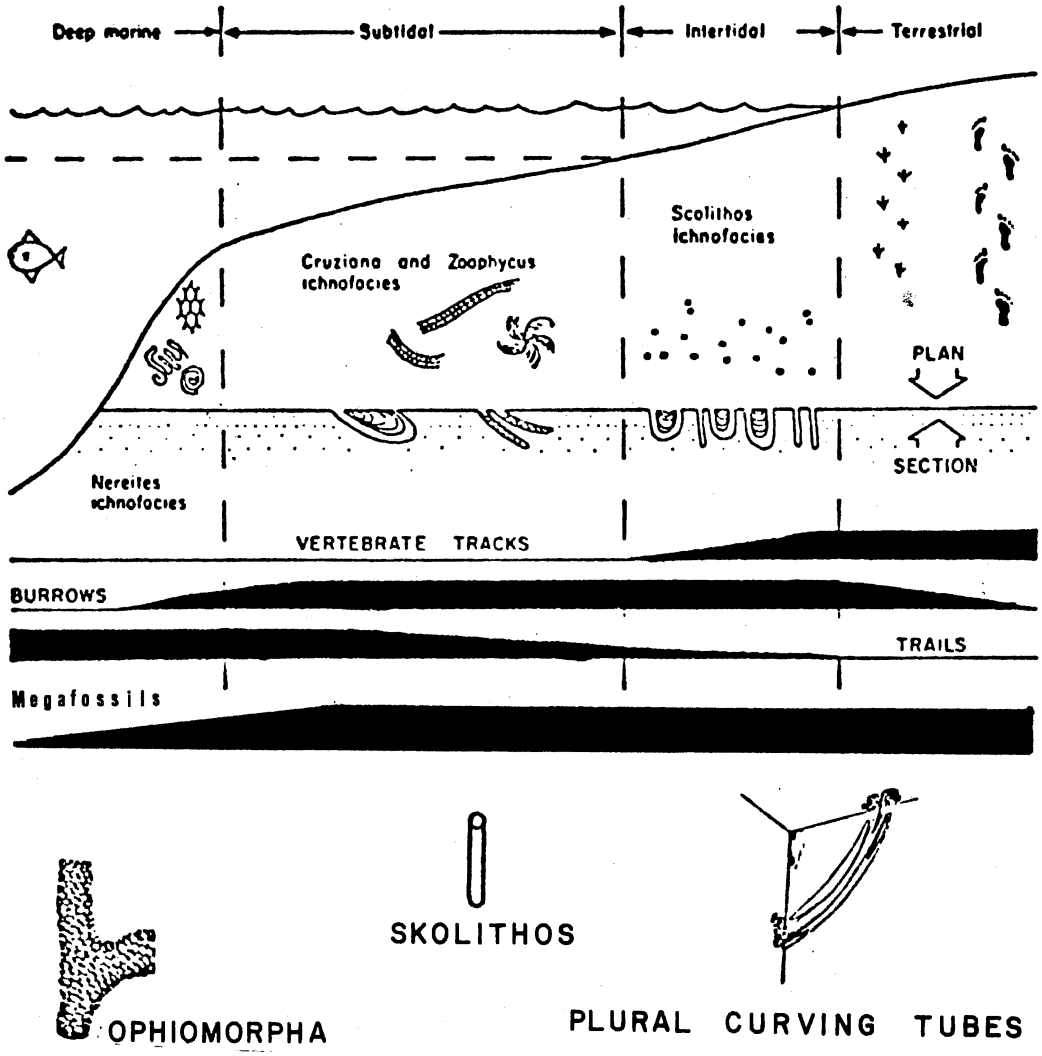


Fig. 30.--Diagram of nearshore environments and associated fossil evidence (after Selley, 1978; Howard, 1972).

parallel to the inferred depositional strike. The length of the outcrop is approximately 60 miles and the main portion of the sand in the subsurface is approximately 15 to 18 miles wide. Plate III shows the location of the outcrop pattern (yellow), the location of the measured section outcrops, their vertical profiles, and the Spontaneous Potential (SP)/resistivity curves of numerous electric logs of the Nacatoch. Selley (1978) explains the type of log characters characteristic of various depositional environments. The lateral variations and distributions of log characters are used to determine the geometry and depositional environments of the formation. The log characters of the Nacatoch are generally a "carrot" shape. The "carrot" shape log has a gradational base and a sharp top. This implies an increased grain size and sorting or cleanness upwards. The southeast part of the study area has characters that are somewhat imperfectly "carrot" shaped. The log characters of the Nacatoch depict three types of section. The first type of log character indicates two sand units divided by a thin shale break. The upper unit is believed to be the equivalent to the sand at the outcrop. The upper sand can be found in all parts of the study area. The lower sand is generally found in the center of the study area. The second log character type indicates a section with one sand unit that is equivalent to the outcrop sand and the upper sand of the first log character type. This log character is found most in the southwest part of the study area. In this area the sand thins to approximately 50 feet. The third log character type consists of an offshore or more shaley equivalent of the others. This third type is generally found in the southeast part of the study area.

Depositional Environment

Numerous physical characteristics may be used to determine the environment of deposition of a formation. The characteristics that should be examined are trend, length, relative location, width, thickness, boundaries, sedimentary structures, textures, and constituents (Shelton, 1967; Selley, 1978). These characteristics are then considered in light of various environments.

The presence of glauconite, shallow marine fauna, and calcium carbonate in the Nacatoch Sand indicates that the sand is not of continental, alluvial valley, or plain or estuarine environments. The shallow marine fauna in the Nacatoch suggests that it was not deposited in a deep marine environment. The trace fossils and megafossils indicate that the Nacatoch was probably deposited in a nearshore, shallow marine environment (Howard, 1972). The absence of any evidence of channelling implies that the Nacatoch had little if any fluvial, deltaic, or tidal channel influence. An upward increase in grain size eliminates deltaic distributary, tidal flat, and transgressive or stationary barrier-bar-beach environments as possible for the Nacatoch. The lack of a sharp basal contact with conglomerates on brackish water or continental deposits also implies that the environment is not a transgressive or stationary beach-barrier-bar. The presence of clay pebbles in the bimodal, crossbedded, fine-grained sandstone in the Upper Nacatoch indicates a beach or upper foreshore type environment and thus rules out the delta fringe type of deposit for most of the Nacatoch. The initial dip reflects the slope of the shoreface and/or beach. The presence of (1) glauconite, (2) shallow marine fauna (amount decreasing upward), (3) upward increase in grain size and

sorting, (4) clay pebbles, (5) gradational lower and lateral contacts, (6) intense bioturbation and burrowingin the Lower Nacatoch, and (7) lagoonal-type deposits on the top of the section and the absence of fluvial channel evidence, implies that the environment of deposition was a nearshore, prograding, regressive, barrier-bar-beach system. The absence of marine shales immediately above the Nacatoch rules out the possibility of the sand being of offshore bar origin.

The Ouachita Uplift to the north suggests the possibility that several small wave-dominated deltas may have contributed to the deposition of the Nacatoch. Highly wave-dominated deltas (Fisher, 1969) can be used to explain the sediment source to the north and the absence of channel evidence. The present-day trends of the Ouachita, Antoine, and Missouri Rivers may have been inherited from the Upper Cretaceous. Log characters of the Nacatoch in T11 to 12S, R29W reflect the possibility of a slight deltaic influence in this area (Plate III). Long shore currents are believed to have transported some sediment from the northeast into the study area.

The stratigraphic section and geometry of the Nacatoch is much like the section and geometry described in various depositional models. Davies et al. (1972), Dickinson et al. (1972), Selley (1978), Shelton (1967), Visher (1965), Walker (1979), and Weimer (1961) have written on the determination of regressive barrier-bar-beach environments. The stratigraphic sections of Kauffman (1977) and Walker (1979) show a sequence much like the section exposed in the Nacatoch. One difference between the examples and the Nacatoch is that the shale and clay offshore facies in the Nacatoch is resistant to weathering but is shown as non-resistant in the examples cited.

The Upper Cretaceous Gallup sandstone of northwestern New Mexico (Campbell, 1971) is interpreted as a regressive beach sandstone. The Gallup has physical characteristics much like the Nacatoch. It is unconformably overlain by an upper Gallup transgressive offshore bar sand facies. Coal, swamp, and lagoonal facies are associated with the lower regressive sand on the landward side. The inoceramus oyster fragments, sharks teeth, and shallow water marine Foraminifera of the lower sand are similar to the Nacatoch fauna. The sedimentary structures, grain size distribution, and biogenic structures are also similar to ones found in the Nacatoch.

The Lower Cretaceous Muddy Sandstone in the Bell Creek field of southeast Montana (Berg and Davies, 1968) is another close analogue to the Nacatoch Sand. The Muddy Sandstone is interpreted as a barrier-bar sand with lagoonal siltstone and shale on the top and to the southeast. Marine shales are found in the northwest. The sharp upper and lower contacts of the log character may imply that it was an offshore bar.

The Upper Cretaceous Hygiene and Terry Sandstones of Weld County, Colorado (Moredock, 1977), display sedimentary structures, constituents, grain size relationships, and biogenic structures that are similar to those of the Nacatoch Sand. The Hygiene and Terry Sandstones are classified as offshore bar sands and not barrier-bar-beach nearshore sands. The presence of a marine shale facies on top of the Hygiene and Terry as opposed to the lagoonal facies on top of the Nacatoch is the key factor in the difference between the two environments.

The Upper Cretaceous Shannon Sandstone of the Powder River Basin, Wyoming, has a stratigraphic section much like the Nacatoch but is classified as an offshore bar (Spearing, 1976). Although the sedimentary

structures, textures, constituents, grain size distribution, and biogenic structures are much the same in both sections, there are some aspects of the Shannon Sand that indicate it is not a shoreface deposit. The presence of marine shales on all sides of the sand, plus the absence of beach-type stratification, soil zones, and roots and clay laminae or clay clasts are evidences that the sand was deposited in an offshore environment. The lack of clay laminae implies that the area was turbid most of the time. The absence of soil zones and roots suggests that the sand was never above sea level.

In summary, the depositional environment of the Nacatoch Sand can be determined by closely examining its gross geometric physical features. It is suggested that the Nacatoch was deposited in a nearshore, regressive, prograding, barrier-bar-beach environment system. Figure 31 is a model of nearshore environments that may be applicable to the Nacatoch. The relationship of a measured section profile of the Nacatoch to hypothetical sections are shown in the diagram modified after LeBlanc (1972) (Fig. 32).

Diagenetic Modification

The lack of cement and the fact that the Nacatoch is unconsolidated throughout much of South Arkansas is an unresolved problem. There are many characteristics of the Nacatoch that suggest why the sand is unconsolidated. The Nacatoch lacks signs of compaction. Glauconite grains in the samples examined showed no signs of compaction and are spherical or ellipsoid in shape. The feldspars are not corroded and are generally angular to subangular. None of the mineral constituents showed signs of corrosion. The fluids in the Nacatoch flow to the southeast or in a down-dip direction. This implies that the water coming

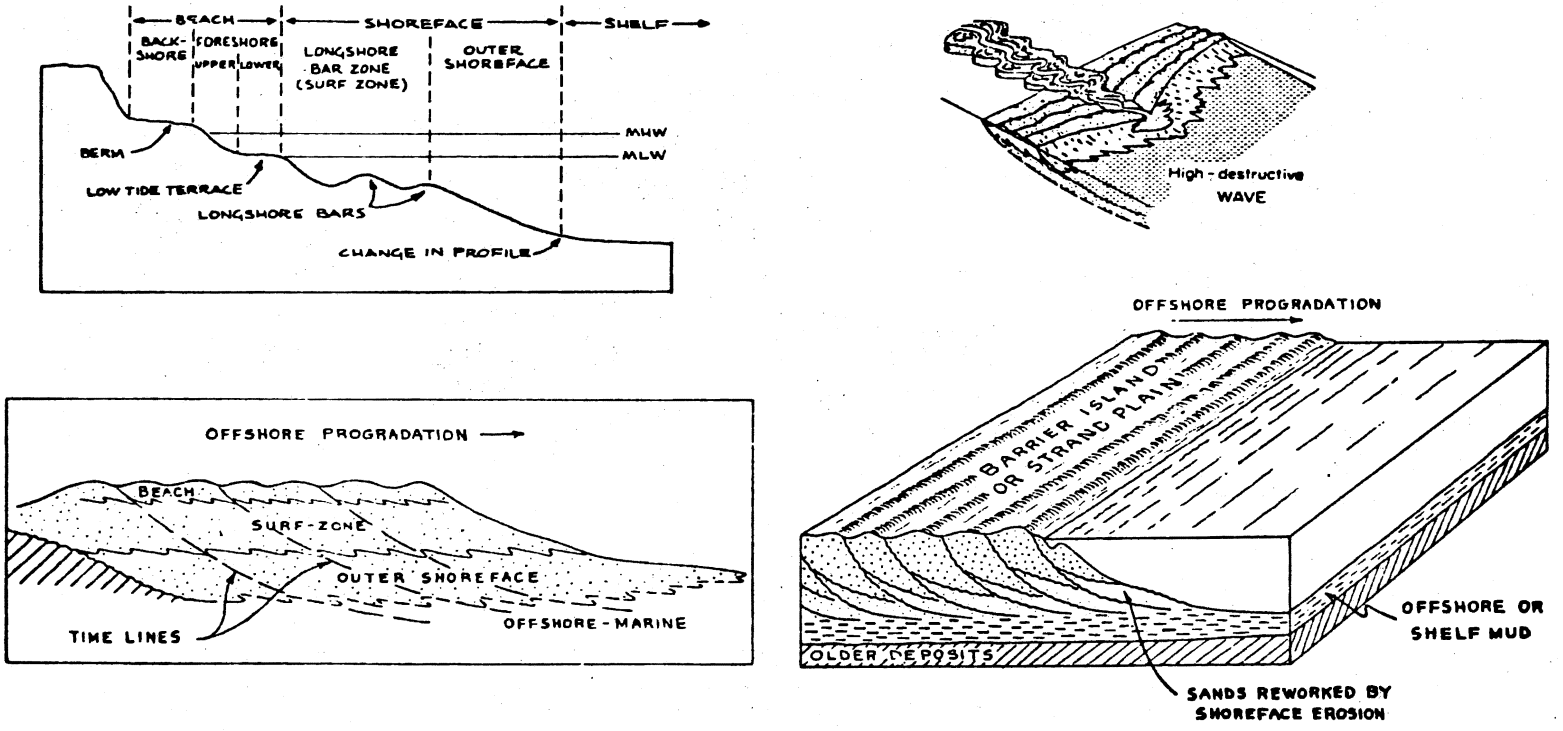
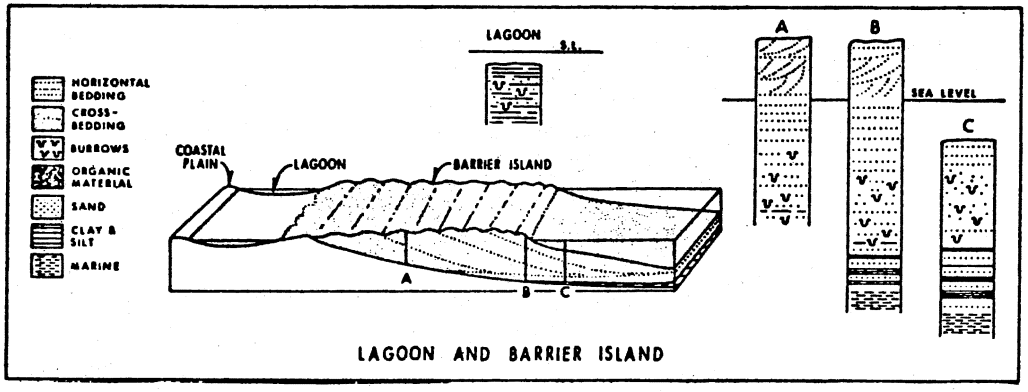
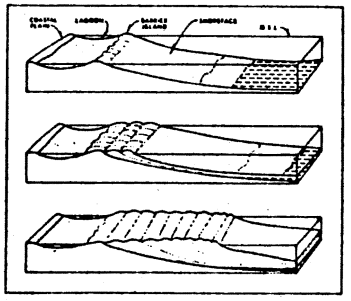
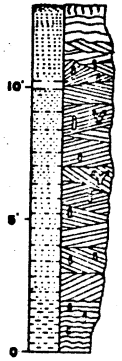


Fig. 31.--Diagrams of regressive nearshore and shoreface depositional environments.







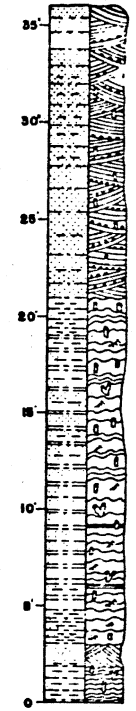


Fig. 32.--Comparison diagrams of hypothetical and Nacatoch Sand vertical profiles (LeBlanc, 1972).

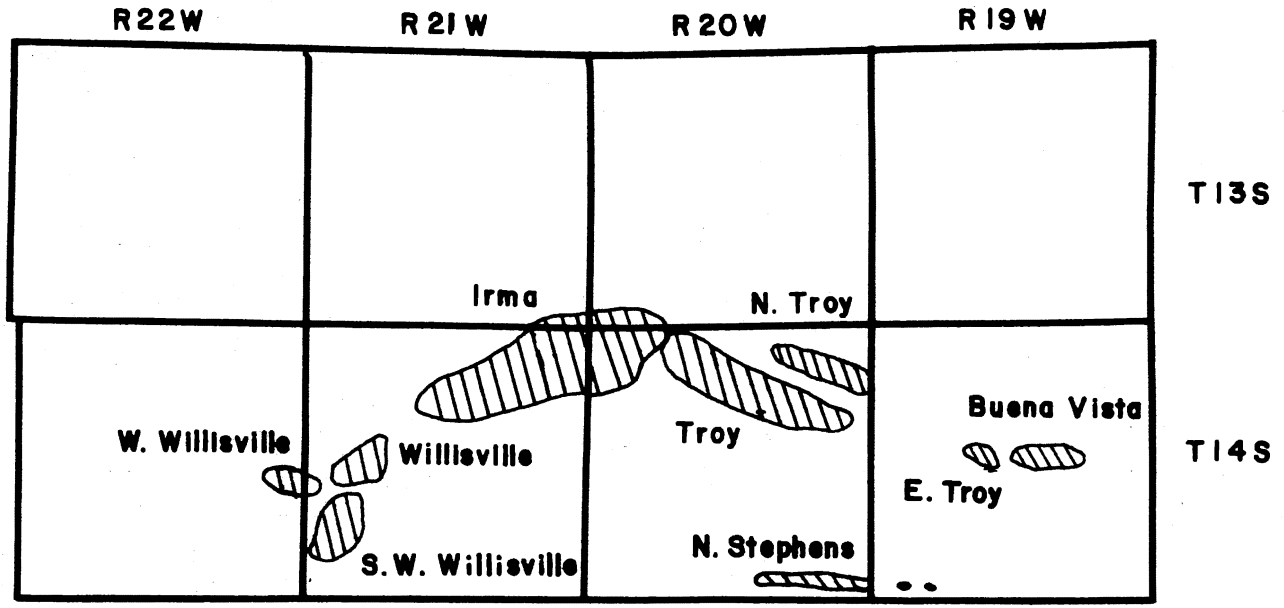
into the formation is and has been fresh water and thus probably lacks the necessary ion concentrations needed for cementation. The water associated with the oil production in Irma Field is brackish and the sand in this area, at a depth of 1,100 to 1,300 feet, is unconsolidated. This fact further implies that the ion concentration has not been sufficient for cementation. There are interstitial clay and calcite particles present in the sand but because of limited compaction and low ion concentration, these particles have not been altered to cement. The Saratoga Formation below the Nacatoch is a fossiliferous biomicrite with a high percentage of Foraminifera. It is surprising that this limestone has not provided carbonate cement to the Nacatoch.

CHAPTER VI

PETROLEUM GEOLOGY

Upper Cretaceous and older rocks have produced hydrocarbons in the study area (Fig. 33 and Table II). Reservoirs include the Upper Cretaceous Nacatoch, Buckrange, Blossom, and Tokio Sands plus the Lower Cretaceous Paluxy, Glen Rose, Rodessa, Kilpatrick, Hill, Hogg, and Travis Peak Formations. The Jurassic age Smackover Limestone is the oldest productive formation. To July 1, 1978, the Nacatoch has produced 14,693,798 barrels of oil in the study area (Table III).

The largest field producing from the Nacatoch Sand is Irma Field. The Nacatoch is the reservoir in a structural trap with closure against the fault on the south side (Plate I and Fig. 33). This field was discovered in 1921, and to July 1, 1978, has produced many millions of barrels of oil. Water produced with the oil is anomalous in that it is brackish water and not salt water as would be expected. The Tokio Sand a few hundred feet below the Nacatoch has salt water. This presence of brackish water indicates that the dilution occurred prior to the period of maximum faulting (Teas, 1927). The Nacatoch Sand in Irma Field is described as being 310 feet of gray and green calcareous sand with clay and marl at the base. Other fields in the study area include the Buena Vista, Troy, North Troy, East Troy, Willisville, West Willisville, Southwest Willisville, and Stephens-North Fields. Table II outlines the data on these fields. The Bureau of Mines Circular No.



INDEX MAP OF OIL FIELDS

Fig. 33.--Index map of oil and gas fields in the study area.

TABLE II

OIL AND GAS PRODUCING FORMATIONS
IN THE STUDY AREA

Formation	Age
Nacatoch Sand	Upper Cretaceous
Buckrange Sand	Upper Cretaceous
Blossom Sand	Upper Cretaceous
Tokio Sand	Upper Cretaceous
Paluxy Sand	Lower Cretaceous
Glen Rose Sand and Limestone	Lower Cretaceous
Rodessa Sand and Limestone	Lower Cretaceous
Kilpatrick Limestone	Lower Cretaceous
Hill Sand	Lower Cretaceous
Hogg Sand	Lower Cretaceous
Travis Peak Sand	Lower Cretaceous
Smackover Limestone	Jurassic

TABLE III

SELECTED STATISTICS ON OIL AND GAS FIELDS OF THE STUDY AREA

Field	Year Discovered	Approximate Depth to the Nacatoch	Producing Formation(s)	Cummulative Production B.O. to 7-1-78
Irma	1921	1,150'	Nacatoch	10,341,936
			Tokio	2,982,735
			Paluxy	254,959
			Glenrose	40,278
			Travis Peak	615,377
			Smackover	902,433
Buena Vista	1956	1,270'	Nacatoch	161,758
			Buckrange	159,116
Troy	1936	1,200'	Nacatoch	402,183
			Blossom	754,366
			Tokio	64,136
			Glenrose	66,412
			Travis Peak	932,251
			Smackover	263,739
North Troy	1956	1,700'	Nacatoch	16,078
			Blossom	57,449
			Tokio	63,948
			Rodessa	29,493
			Paluxy	63,568
East Troy	1956	1,309'	Nacatoch	93,039
West Willis-ville	1955	1,200'	Nacatoch	368,524
			Tokio	222,956
			Hogg	123,467
Southwest Willisville	1956	1,140'	Nacatoch	3,106,566
			Blossom	116,028
			Tokio	10,900
Willisville	1951	1,211'	Travis Peak	4,630
			Nacatoch	203,709
			Blossom	171,169
Stephens-North	1958	1,500'	Buckrange	466,434
			Blossom	184,647

8428 and numerous Shreveport Geological Society publications have more detailed information on the oil and gas fields in this area as well as other areas of South Arkansas.

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APPENDIXES

APPENDIX A

ELECTRIC LOGS OF WELLS USED IN CORRELATION SECTIONS

Operator and Well Number	Location
SW-NE Correlation Section A-A'	
Plains Production Co., #1-Stricklin	CNW SW SE 33-14S-27W
Horizon Oil and Gas, #1-Rhodes	CSE SE 35-14S-27W
A. L. Willis, #1-Hervey	NE SE NE 33-14S26W
Sunray Mid. Cont. Oil, #1-Cato	CNW SW NW 15-14S-25W
Mobley and Gibralter Oil, #1-Basye	330 FNL & FEL SW SW 26-13S-24W
Arkoma Oil, #1-Matthews	CSW SE 8-13S-23W
McAlester Fuel, #A-1-Kizer	SW SW 15-12S-22W
Barnwell Drilling, Co., #1-Sandusty	CNE NE 8-11S-21W
J. H. Coker Oil, #1-Jones	CNE SE 2-11S-21W
J. A. Funston, #2-Ross	CNW SW NW 32-10S-20W
W. S. King, #1-McKenzie	NW SW NE 30-10S-19W
North South Correlation Section B-B'	
Broday Drilling Co., #1-King Est.	SE NW SE 35-12S-25W
L. C. Collins, #1-Emory Thompson	SW SE NE 10-13S-25W
Lee and Burnett, #A-1-Ollar	CSE SE NE 27-13S-25W
Sunray Mid. Cont. Oil, #1-Cato	CNW SW NE 15-14S-25W
Atlantic Refining Co., #1-Owen Est.	CNE SE 26-14S-25W
North South Correlation Section C-C'	
J. K. Wadley, #1-Moore	CSE NW 11-12S-23W
Union Drilling, #1-Reyenga	CSW NE 21-12S-23W
Arkoma Oil, #1-Matthews	CSW SE 8-13S-23W
N. A. Hardin, #1-Mitchell	CNE SW 35-13S-23W
Barndall Oil, #1-Stuart	CNW SW 12-14S-23W
Ashland Oil, #1-Pelt	CNW SW 24-14S-23W
Hunt-Arkansas Fuel, #1-Bodcaw Oil	CSW NW 36-14S-23W
North South Correlation Section D-D'	
Ed-Ren Oil, #1-Ross	CSE SE SW 34-9S-21W
Coker Oil, #1-Jones	CNE SE 2-11S-21W
Murphy Oil, #1-Corehole	2310' FSL & 330' FWL 34-12S-20W
Lamar Hunt, #1-Shell Blakely	2710' FWL & 1802' FSL 14-13S-20W
Continental Oil, #1-Humphreys	CSE SE NE 30-13S-20W
Guy Smith, #2-Groves Land & Timber	50' FNL & 200' FWL NE NW 5-14S-20W
Crow Drilling, #1-Rinehart	SE SW 28-14S-20W

APPENDIX B

FAUNAL LIST OF THE NACATOCH SAND

(DANE, 1929)

Coelenterata:
- Coral

Echinodermata:
- *Hemiaster* sp.
- *Linthia* cf. *L. variabilis* Slocum
- *Cassidulus* (?) sp.

Molluscoidea:
- Bryozoa

Vermes:
- *Serpula* sp.
- *Hamulus onyx* Morton

Pelecypoda:
- *Nucula* sp.
- *Cucullaea* sp.
- *Glycymeris* sp.
- *Pteria* sp.
- *Inoceramus* aff. *I. barabini* Morton
- *Inoceramus* sp.
- *Ostrea tecticosta* Gabb
- *Ostrea plumosa* Morton
- *Ostrea falcata* Morton
- *Ostrea mesenterica* Morton
- *Ostrea owenana* Shumard
- *Gryphaea vesicularis* Lamark, variety
- *Gryphaea* sp. (small)
- *Exogrya costata* Say
- *Trigonia* aff. *T. eufalensis* Gabb
- *Trigonia* sp.
- *Pecten simplicius* Conrad
- *Pecten mississippiensis* Conrad
- *Lima reticulata* Forbes
- *Lima acutilineata* Conrad
- *Lima* sp.
- *Anomia argentaria* Morton
- *Paranomia scabra* (Morton)
- *Spondylus* sp.
- *Crenella serica* Conrad
- *Pulvinites argentea* Morton
- *Liopistha protexta* Conrad
- *Liopistha (Cymella) bella* (Conrad), variety (?)
- *Veniella conradi* (Morton)
- *Trapezium* (?) sp.
- *Crassatellites* sp.
- *Lunatia* sp.
- *Epitonium* sp.
- *Cardium (Criocardium) dumosum* (Conrad) (?)
- *Cardium (Criocardium) kummeli* Weller (?)
- *Cardium (Criocardium) tippanum* Conrad
- *Cardium (Criocardium)* sp.
- *Cardium (Pachycardium) spillmani* Conrad (?)
- *Tenea pinguis* (Conrad) (?)
- *Legumen* sp.

Aphrodina (?) sp.
Corbula crassiplica Gabb
Corbula sp.

Scaphopoda:
Dentalium sp.

Gastropoda:
Pleurotamaria (?) sp.
Gyrodes cf. *G. altispire* (Gabb)
Turritella trilira Conrad
Turritella vertebroides Morton
Turritella sp.
Anchura (?) sp.
Capulus (?) sp.
Anisomyon (?) sp.
Solidula riddilli Shumard
Liopeplum canalis (Conrad)
Volutomorpha sp.

Cepholopoda:
Nautilus sp.
Pachydiscus sp.
Baculites sp.
Scaphites sp.
Nostoceras sp.
Belemnitella americana (Morton)

Anthropoda:
Crustacean claws (crab?)

Vertebrata:
Shark teeth

VITA

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Master of Science

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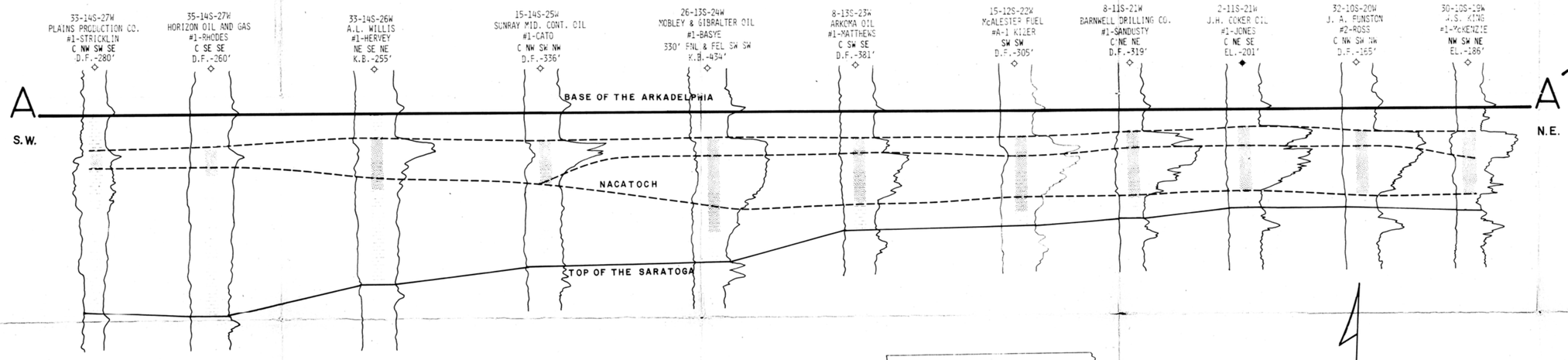
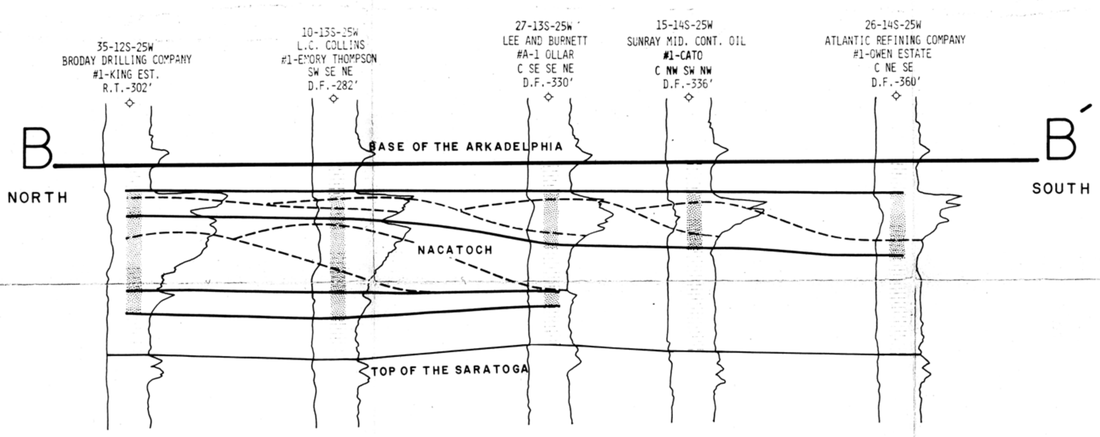
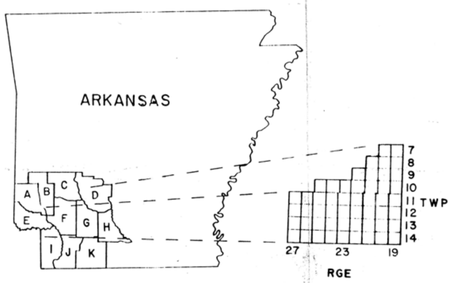
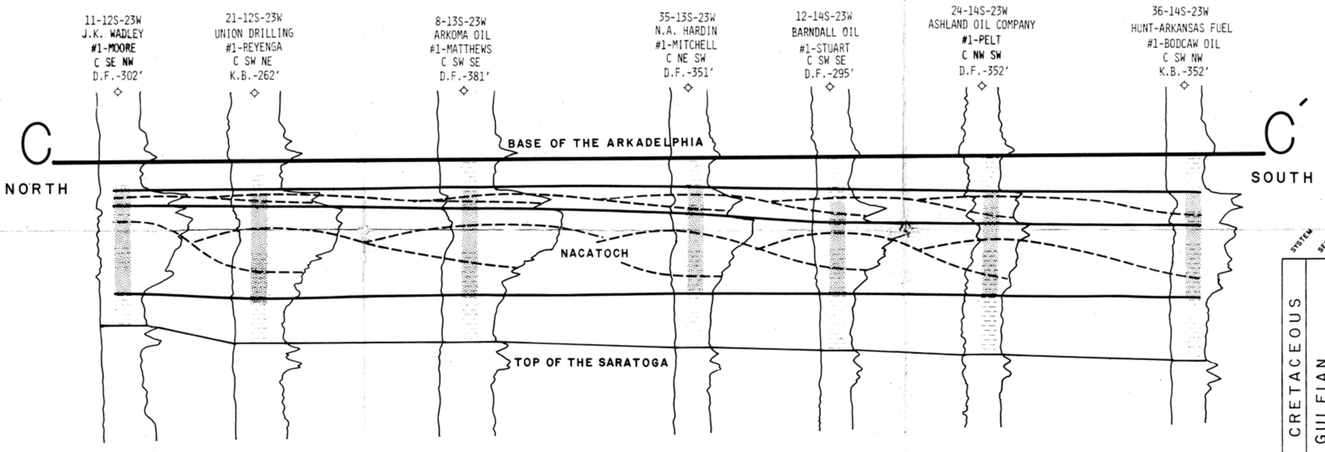
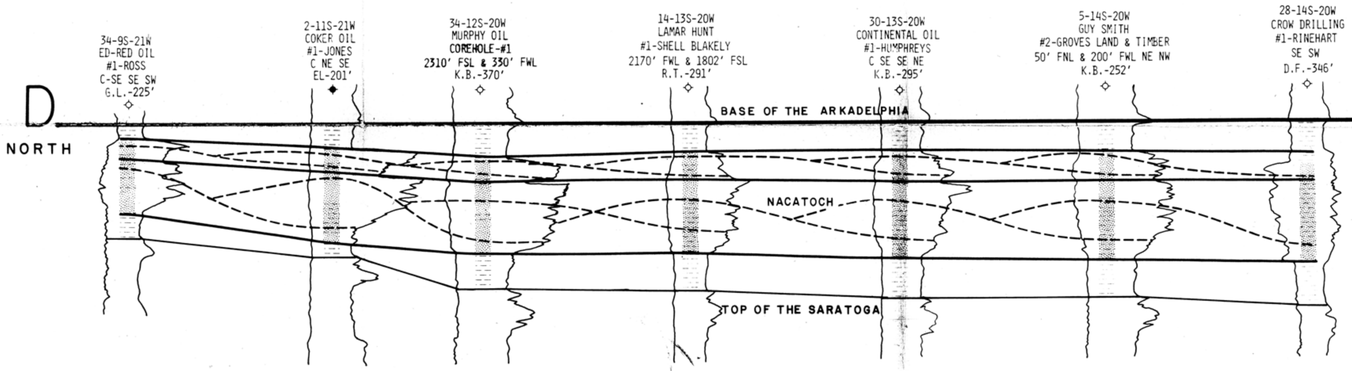




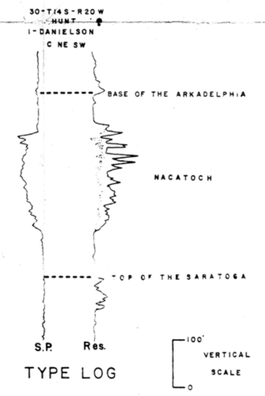


A-SEVIER Co.
B-HOWARD Co.
C-PIKE Co.
D-CLARK Co.
E-LITTLE RIVER Co.
F-HEMPSTEAD Co.
G-NEVADA Co.
H-OUACHITA Co.
I-MILLER Co.
J-LAFAYETTE Co.
K-COLUMBIA Co.





LOG SCALE 1"= approx. 220'



TYPE LOG

HYPOTHETICAL TIME EQUIVALENT LINES

0 6 12

Scale 1"= 4 miles

EXPLANATION OF
LITHOLOGICAL SYMBOLS
ON LOGS

SAND

SAND & SHALE

SHALE

PLATE II

CORRELATION SECTIONS
A-A', B-B', C-C', D-D'

GRANT E. BLACK
OKLAHOMA STATE UNIVERSITY

1980

PLATE I

STRUCTURE MAP
TOP OF THE NACATOCH SAND

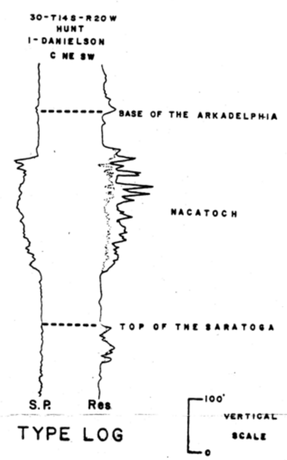
GRANT E. BLACK

OKLAHOMA STATE UNIVERSITY

1980

- DRY HOLE
- -300 TOP OF NACATOCH SAND
- OIL WELL
- GAS WELL
- JURASSIC PENETRATION

SYSTEM	SERIES	GROUP
UPPER CRETACEOUS	GULFIAN	NAVARRO
		TAYLOR



TYPE LOG

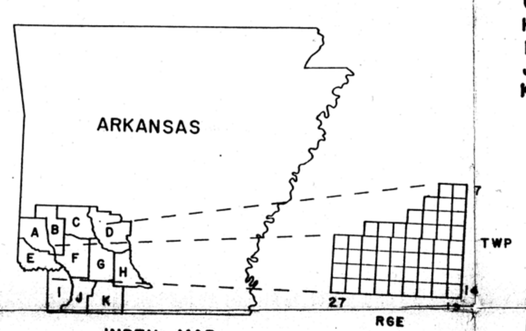
A-SEVIER Co.
B-HOWARD Co.
C-PIKE Co.
D-CLARK Co.
E-LITTLE RIVER Co.
F-HEMPSTEAD Co.
G-NEVADA Co.
H-OUACHITA Co.
I-MILLER Co.
J-LAFAYETTE Co.
K-COLUMBIA Co.

CONTOUR INTERVAL - 50'

N

0 6

Scale 1" = 2 miles



INDEX MAP

R 20 W R 19 W

T 7 S
T 8 S
T 9 S
T 10 S
T 11 S
T 12 S
T 13 S
T 14 S

R 27 W R 26 W R 25 W R 24 W R 23 W R 22 W R 21 W R 20 W R 19 W

NOTE: DATUM DATA SOUTH OF THE DASHED LINE IS NOT ON THIS MAP BUT WAS USED IN CONTOURING.

PLATE III

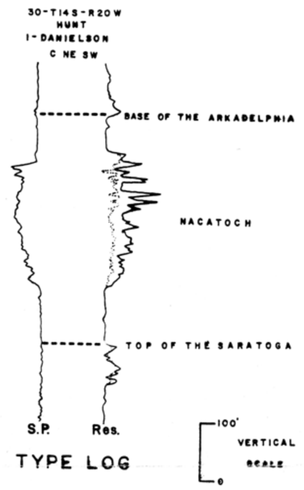
LOG MAP

NACATOCH SAND

GRANT E. BLACK

OKLAHOMA STATE UNIVERSITY

1980



TYPE LOG

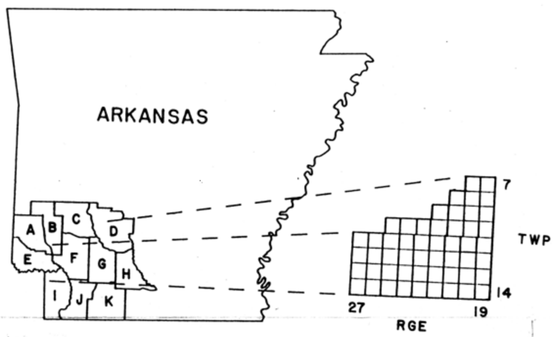
A-SEVIER Co.
B-HOWARD Co.
C-PIKE Co
D-CLARK Co.
E-LITTLE RIVER Co.
F-HEMPSTEAD Co.
G-NEVADA Co.
H-OUACHITA Co.
I-MILLER Co.
J-LAFAYETTE Co.
K-COLUMBIA Co.

Log scale 1"= approx. 430'

N

0 6

Scale 1"= 2 miles



T 7 S
T 8 S
T 9 S
T 10 S
T 11 S
T 12 S
T 13 S
T 14 S

R 27 W
R 26 W
R 25 W
R 24 W
R 23 W
R 22 W
R 21 W
R 20 W
R 19 W

BLEVINS
GURDON
POSSIBLE CHANNEL ?
WASHINGTON
PRESCOTT
WAVE DOMINATED DELTA
REGRESSIVE NEARSHORE BARRIER-BAR & BEACH FACIES
(250-400' of sand)
CHIDESTER
HOPE
McNAB
FULTON
THIN (<75') PROGRADED
REGRESSIVE SAND FACIES
OFFSHORE INTERBEDDED
SANDS & SHALES