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WEST RAYMOND FIELD

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INTRODUCTION

The West Raymond Field lies on the flank of the Oakley Salt Dome, located in T5N, R3W, of Hinds County, Mississippi, 15 miles southwest of Jackson. Oakley Dome is one of the 52 known shallow piercement domes in Mississippi. It lies near the northwestern extent of the Mississippi Interior Salt Basin (Figure 1). There are three oil fields on the flanks of the dome in this system of graben and horst fault blocks: North Oakley Dome Field is in a northern fault block; Oakley Dome Field is on the crest of the dome and in a southeastern fault block; and West Raymond Field is located in the western, southwestern, and southern fault blocks of the dome (Figure 2). West Raymond is the most developed of the three flank fields. As of January 1, 1992, the field had produced 1,694,817 bbls. of oil and 1,157,471 MCFG. Because of the field's considerable development and its available subsurface data, West Raymond can serve as an analogue of the complex structure associated with the flanks of shallow piercement domes.

STRATIGRAPHY

To date, West Raymond Field has produced from the Pine Island, Rodessa, and Mooringsport formations of the Trinity Group of the Lower Cretaceous (see Figure 3). In the northwestern Mississippi Interior Salt Basin, these rocks are part of a regional sedimentary wedge that thickens to the south-southwest. They consist of mainly clastic rocks of fluvial and deltaic origin (Reese, 1976). The beds reflect transitional transgressive/regressive sequences of sediments which are comprised of sands, shales, mudstones, and some subordinate limestones and anhydrites (Devery, 1982).

The Cotton Valley Formation is the oldest unit penetrated at West Raymond Field. The Prassel Trust 28-15 (the discovery well) was the only well to penetrate the Hosston and Cotton Valley units. These intervals are not productive in West Raymond Field; however, mudlog shows were present in both units. Permeability and porosity values were not calculated due to insufficient data.

The Sligo Formation was completely penetrated in only four wells and entered to varying depths in six other wells at West Raymond Field. The Sligo is approximately 465 feet thick in the field and consists of interbedded sands, siltstone, shales and mudstones. Though data were incomplete, analysis of available core data and porosity logs indicates a permeability range of 0 to 483 millidarcies with an average porosity of 8%. This interval has not been productive in the field.

The Pine Island Formation lies conformably between the basal sand of the Lower Rodessa and the underlying Sligo Formation. It is a transgressive sequence primarily consisting of shales with occasional fine-grained sand and siltstone stringers present. In West Raymond, the Pine Island is 100 to 150 feet thick. It is productive in one well, the No. 1 J. R. Shuff 34-6, in which 18 feet were perforated between the depth of 12,510 and 12,538 feet. As of January 1, 1992, the well had produced 66,157 bbls. of oil and 131,337 Mcf of gas.

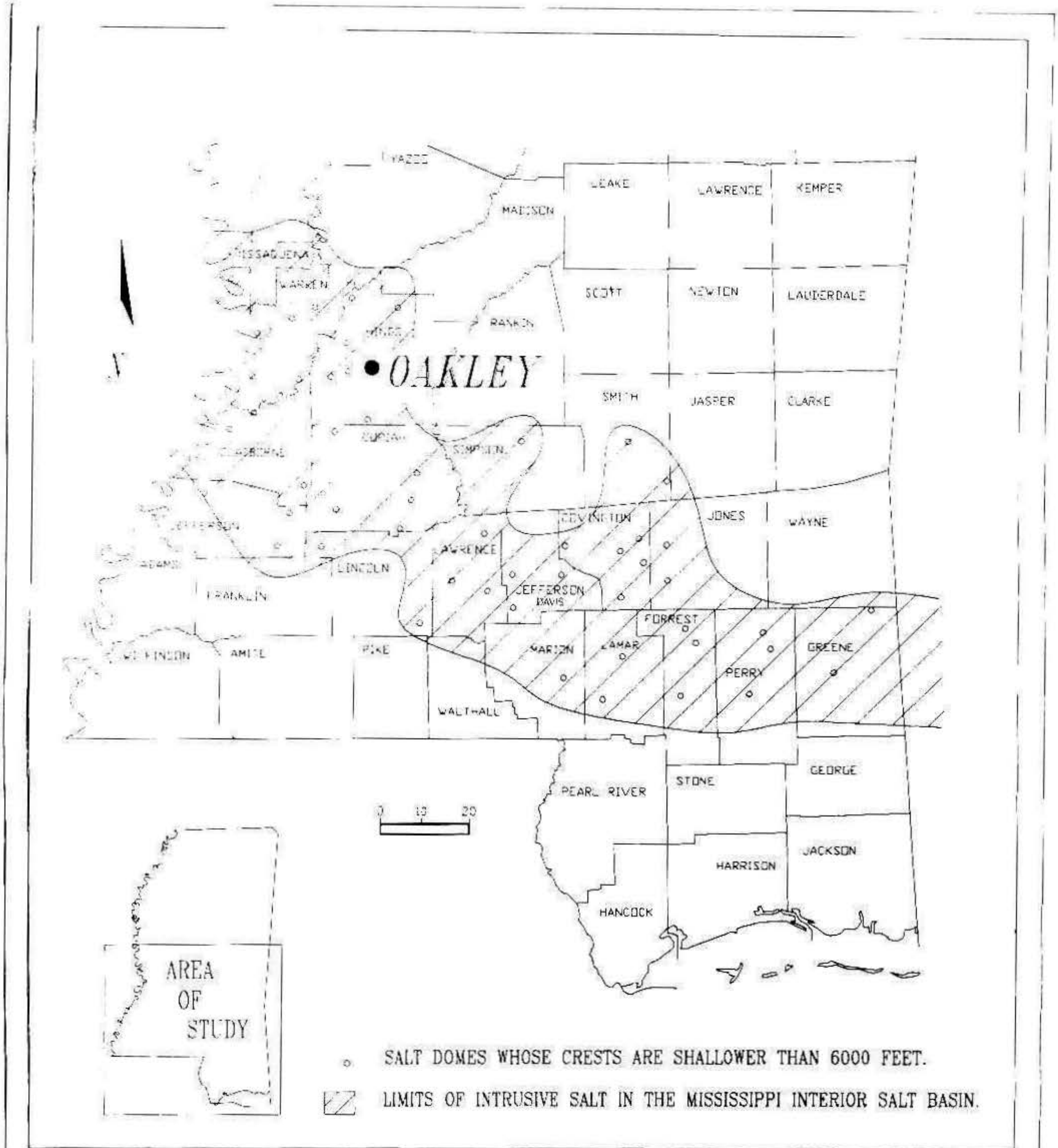

Figure 1. Index map of Mississippi Interior Salt Basin.

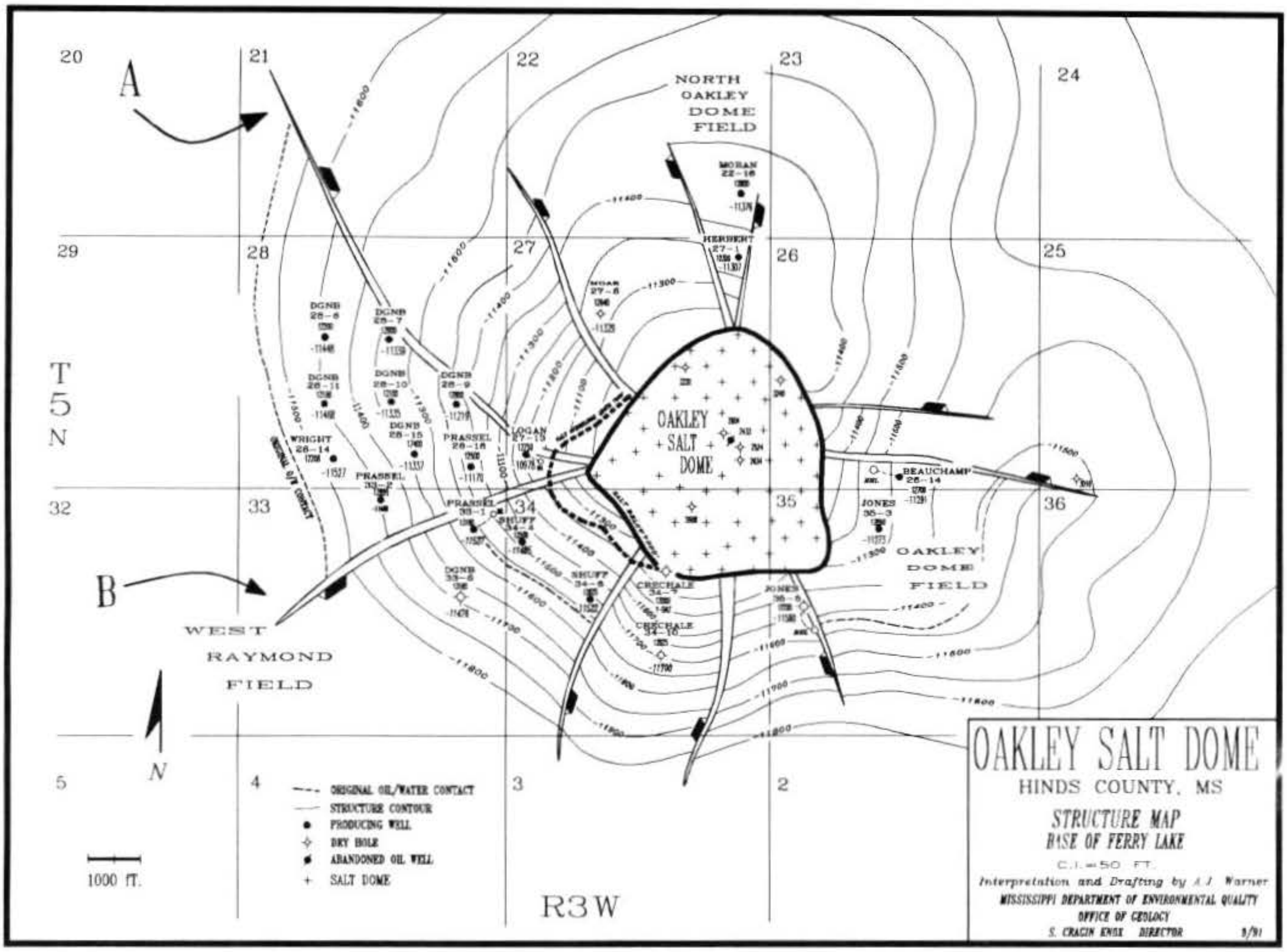

Figure 2. Structure map on the base of the Ferry Lake Anhydrite.

The Rodessa Formation consists primarily of land-derived detrital material deposited in an environment which varied from a fluvial/deltaic to a marine system (Forgotson, 1957). The Rodessa Formation includes the majority of the present producing intervals in the West Raymond Field. In the field, the Rodessa Formation is a 600- to 700-foot section that has been divided into the Rodessa Consolidated, the Middle Rodessa, and the Lower Rodessa (Figure 4). The Lower Rodessa is a 145- to 275-foot section of alternating sands and shales (Figure 4). The sands are 20 to 60 feet thick, white to gray, fine- to medium-grained, and moderately well cemented. Permeability ranges from 0 to 383 millidarcies with an average porosity of 13%. In the West Raymond Field, the Lower Rodessa has produced from two wells (the No. 1 Prassel Trust 28-16 and the No. 1 T. J. Logan Trust 27-13). As of January 1, 1992, these two wells have produced 467,015 bbls. of oil and 375,228 Mcf of gas from well depths of 11,954 to 11,965 and 11,834 to 11,864 feet, respectively.

The Middle Rodessa section (see Figure 4) is a 125- to 200-foot section of predominantly shales and mudstones with some subordinate sand and siltstone stringers. In August 1991, EP Operating Company plugged back the Lower Rodessa producing Prassel Trust 28-16 and perforated a 22-foot section in the Middle Rodessa between the depth of 11,826 to 11,848 feet. The sand in this interval had an average porosity of 7% and a permeability range of 0 to 5 millidarcies. This is the only production to date from the Middle Rodessa interval in the field.

Three distinct sands in the Rodessa Consolidated are designated as the "1st", "A", and "B" sands (Figure 5). Through the generous cooperation of EP Operating Company, the authors were able to use mudlogs, electric logs, porosity logs, sidewall cores, and conventional core data to evaluate these sands. Sand isopachs have been constructed for these three sand intervals using 6% porosity as a cutoff for calculating net sand.

The geometry of the net sand isopach of the Rodessa Consolidated sands suggests a fluvial channel origin (see Figures 6-8). Although the depositional pattern for each sand is unique, there is a common sinuous pattern of little or no

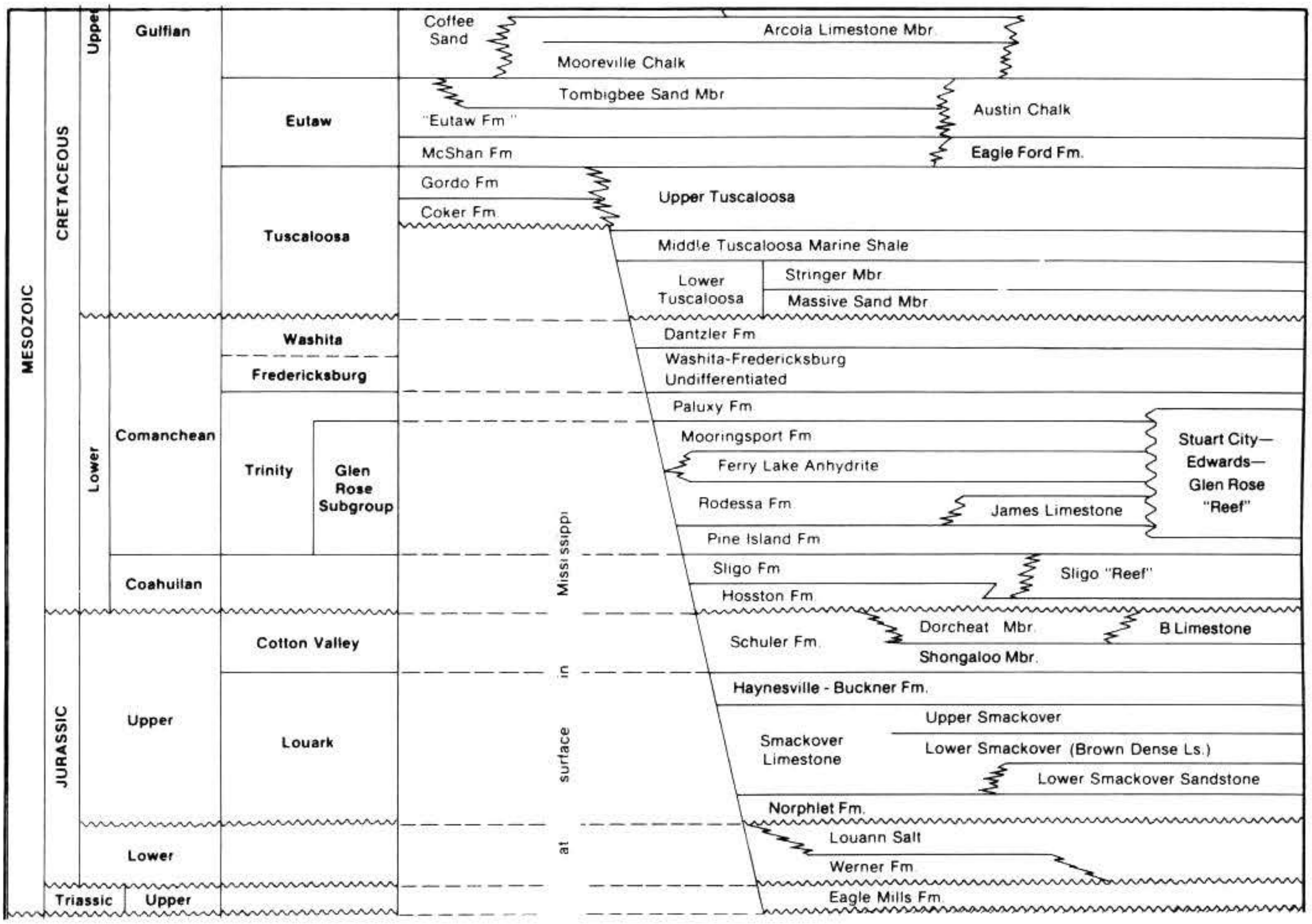

Figure 3. Mississippi stratigraphic column; from Dockery (1981).

sand present over the crest of the now present dome in each of the sand isopachs. However, there is no evidence of dome movement until Paleocene time. Therefore, this sinuous pattern of little or no sand deposition would suggest a type of natural levee being in place during deposition.

The "1st" sand interval is a 40- to 80-foot section of sand with subordinate siltstone and shale stringers. The sands are light gray to dark gray to reddish-brown, very fine- to fine-grained, silty, micaceous, and calcareous. This sand is productive in four wells in the field. Core and log analysis over the interval indicates a porosity range of 2.0 to 11.0% with a permeability range of 0 to 23.7 millidarcies. The geometry of the net sand isopach of this "1st" sand (Figure 6) suggests a mixed-load paleochannel deposit as defined by Galloway and Hobday (1983). The typical fining-upward sequence, which is indicative of a channel point bar, is recognizable in the signature of the SP curves on the electric logs in the sand interval across West Raymond Field.

The "A" sand lies stratigraphically below the "1st" sand and is productive in six wells in the field. The "A" interval consists of a 50- to 85-foot section of sand with some subordinate siltstone and shale stringers. Core and log analyses indicate a porosity range of 2.5 to 14% with a permeability range of 0 to 30.8 millidarcies across the field. The sands are clear to white to brown, very fine- to medium-grained, micaceous, argillaceous in part, and loosely cemented. The geometry of the net sand isopach of the "A" sand reflects a typical fluvial channel deposit with a subordinate pattern of deposition on the west flank of the channel deposit. The authors believe the geometry of this secondary pattern suggests a crevasse splay formed during deposition of the "A" channel sand. There is a lobate wedge of sediments originating from an apex on the western flank of the fluvial deposit. This deposit has a general westward thickening away from the source (Figure 7). The sand content and grain size are greatest near the apex and diminish toward the distal splay. This is typical of a crevasse splay deposit according to Galloway and Hobday (1983).

The "B" sand is the best reservoir sand of the three units of the Rodessa Consolidated. This interval is 95 to 135 feet thick and consists of white to light gray to brown, fine- to medium-grained, micaceous, moderately well cemented sands

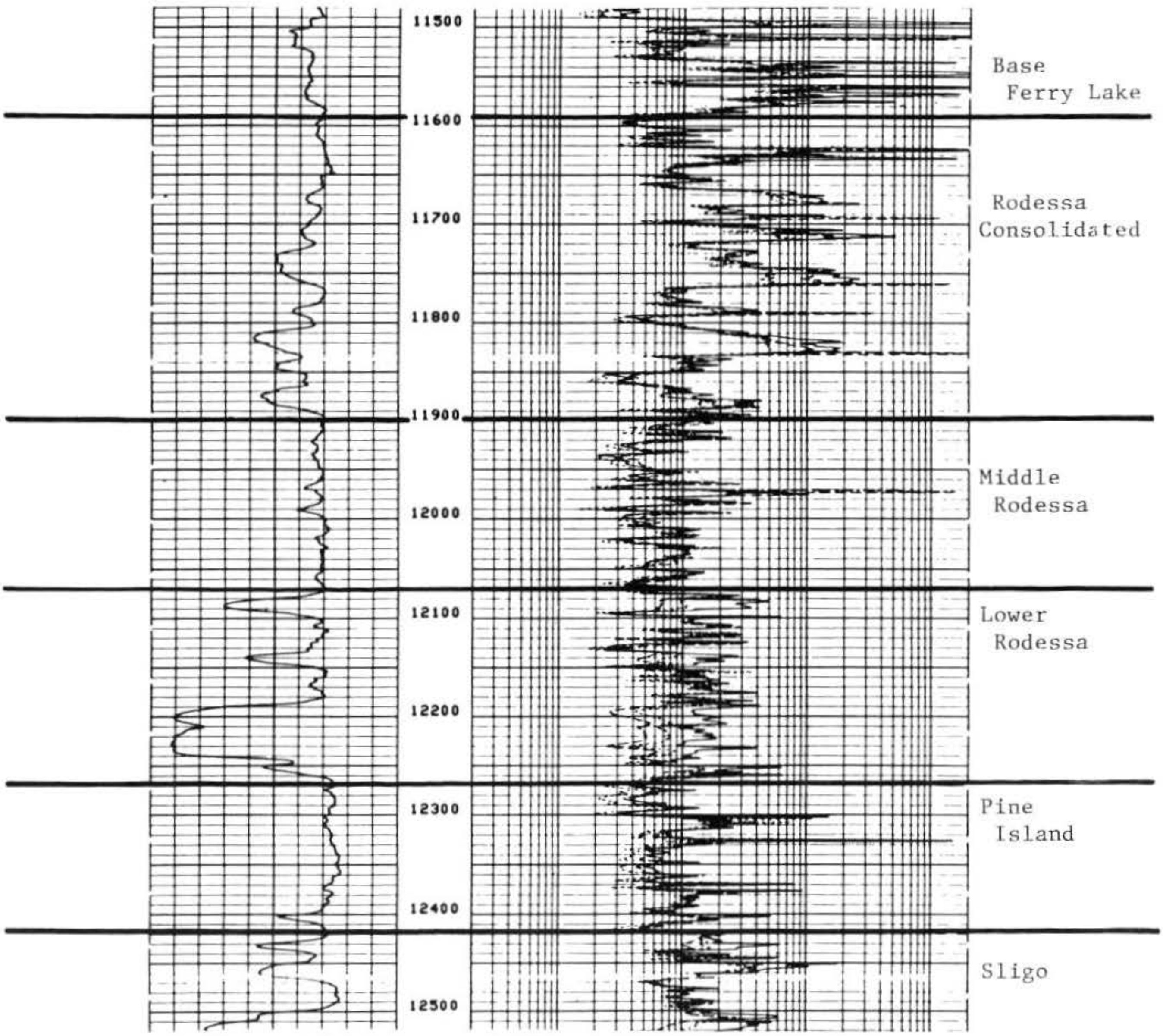

Figure 4. Type log for West Raymond Field, #1 Prassel Trust 28-15.

with interbedded siltstone and shale stringers (Figure 5). It has an average porosity of 10.5% and a permeability range of 0 to 134.5 millidarcies. It is productive in eight of the 13 producing wells in West Raymond Field. The geometry of the sand isopach reflects a depositional pattern indicative of a possible point bar accretion in a fluvial depositional system (Figure 8).

The Ferry Lake Formation is a roughly 200-foot section of off-white to gray, soft, finely crystalline anhydrite interbedded with gray shales and reddish-brown dense limestones. The massive anhydrite is a result of extensive biohermal development which gradually restricted circulation in back-reef waters, allowing deposition of the anhydrite in a restricted lagoonal environment (Forgotson, 1963). At West Raymond, the Ferry Lake Formation conformably underlies the Mooringsport Formation and is picked on the electric log at the first resistivity kick below the basal limestones or shales of the Mooringsport Formation (Devery, 1982). The base of the formation is the contact between the lowest anhydrite bed and the top of the sand-shale sequence of the Rodessa Formation. There is no production from the Ferry Lake at West Raymond Field.

The Mooringsport Formation occupies the stratigraphic interval between the lowest Paluxy sand and the top of the massive Ferry Lake Anhydrite (Nunnally and Fowler, 1954). At West Raymond, the top of the formation is at an average

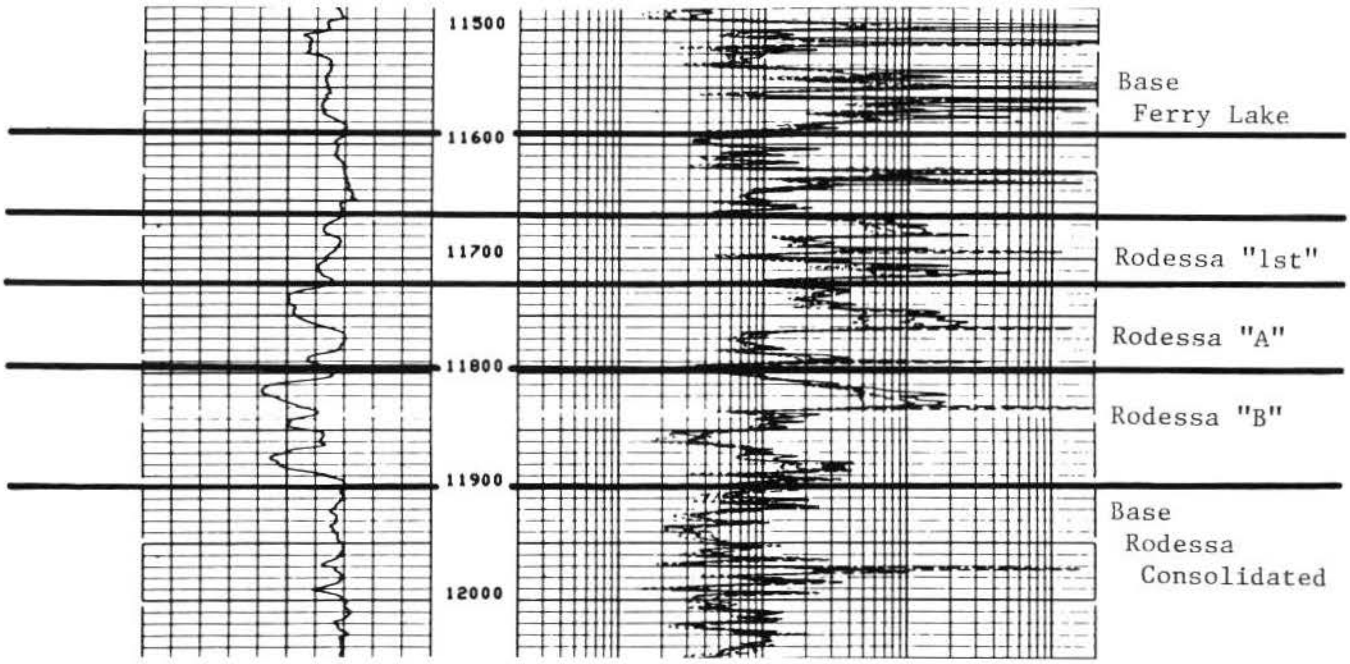

Figure 5. Type log of Rodessa Consolidated, #1 Prassel Trust 28-15.

depth of 11,050 feet. The Mooringsport Formation is 400 to 600 feet thick and is a predominantly clastic section at this locality. Deposition was in the infraneritic zone of an unstable shelf in a regressive, transitional environment as regionally the deltaic front advanced basinward and the seas became progressively more shallow (Forgotson, 1963). Mudlog, sidewall core, and electric log analyses indicate the section consists of a sequence of shales and mudstones with some subordinate limestones, sands, and siltstones. The shales are maroon, dark-red to gray, firm, and finely micaceous with greenish-gray mudstones interstratified. There are thin anhydrite stringers in the basal Mooringsport and minor amounts of nodular limestone are occasionally present throughout the unit. The sandstones are fine- to very fine-grained, silty, calcareous and micaceous and are gray-white to pink in color. At West Raymond Field, the Mooringsport currently produces from one well, the Prassel Trust 33-1, from a depth of 11,325 to 11,390. Sidewall core data indicate an average porosity of 10.0% with a permeability range of 0 to 6.0 millidarcies over the interval.

The Paluxy Formation was deposited in a sand and shale facies. It characteristically consists of red to pink to white, fine- to coarse-grained, micaceous sandstones alternating with dark red, gray, and/or green shales. There are green to gray to ochre mudstones also present with some beds containing muscovite and biotite mica (Nunnally and Fowler, 1954). In Hinds County, in the northwestern part of the Mississippi Salt Basin, the Paluxy sandstones were deposited in braided streams of a fluvial system (Coyle, 1981). The top of the formation is arbitrarily placed at the base of the lowest limestone of the Washita-Fredericksburg section with the base of the Paluxy being defined as the base of the lowest sandstone above the highest limestone of the Mooringsport Formation (Nunnally and Fowler, 1954). At West Raymond, the Paluxy is between 1100 and 1450 feet thick with the top of the formation found at an average subsea elevation of -9400 feet. The section consists of alternating layers of sands, siltstones, and shales. The sands are quite abundant, with lenses 30 to 50 feet in thickness with porosities ranging from 2 to 22%. The permeability ranges from 0 to 500 millidarcies. To date, there has been no production from the Paluxy in West Raymond Field. However, it is currently producing in the Oakley Dome Field on the east flank of Oakley Salt Dome and log analysis indicates possible productive zones behind pipe in the West Raymond Field.

STRUCTURE

The trapping mechanisms for West Raymond's reservoir sands include lateral seals produced by the radial faults, the seals of the overlying Ferry Lake Anhydrite and other impervious rocks, and the updip structural closure against the salt stock of Oakley Dome. These trapping mechanisms are typical of shallow piercement dome traps. Oakley Dome is approximately one mile in diameter, roughly circular, and lies in the northwestern region of the Mississippi Interior Salt Basin. The salt stock has moved to within 2634 feet of the surface (Halbouty, 1979). Movement began in the early Tertiary and has pierced approximately 20,000 feet of Upper Jurassic, Cretaceous, and lower Eocene sediments extending up into the lower Eocene Wilcox Formation. Three hundred feet of approximately 2600 feet of the Wilcox Group remain above the caprock of Oakley Dome. As a result of the salt stock's movement and its piercement of the overlying sedi-

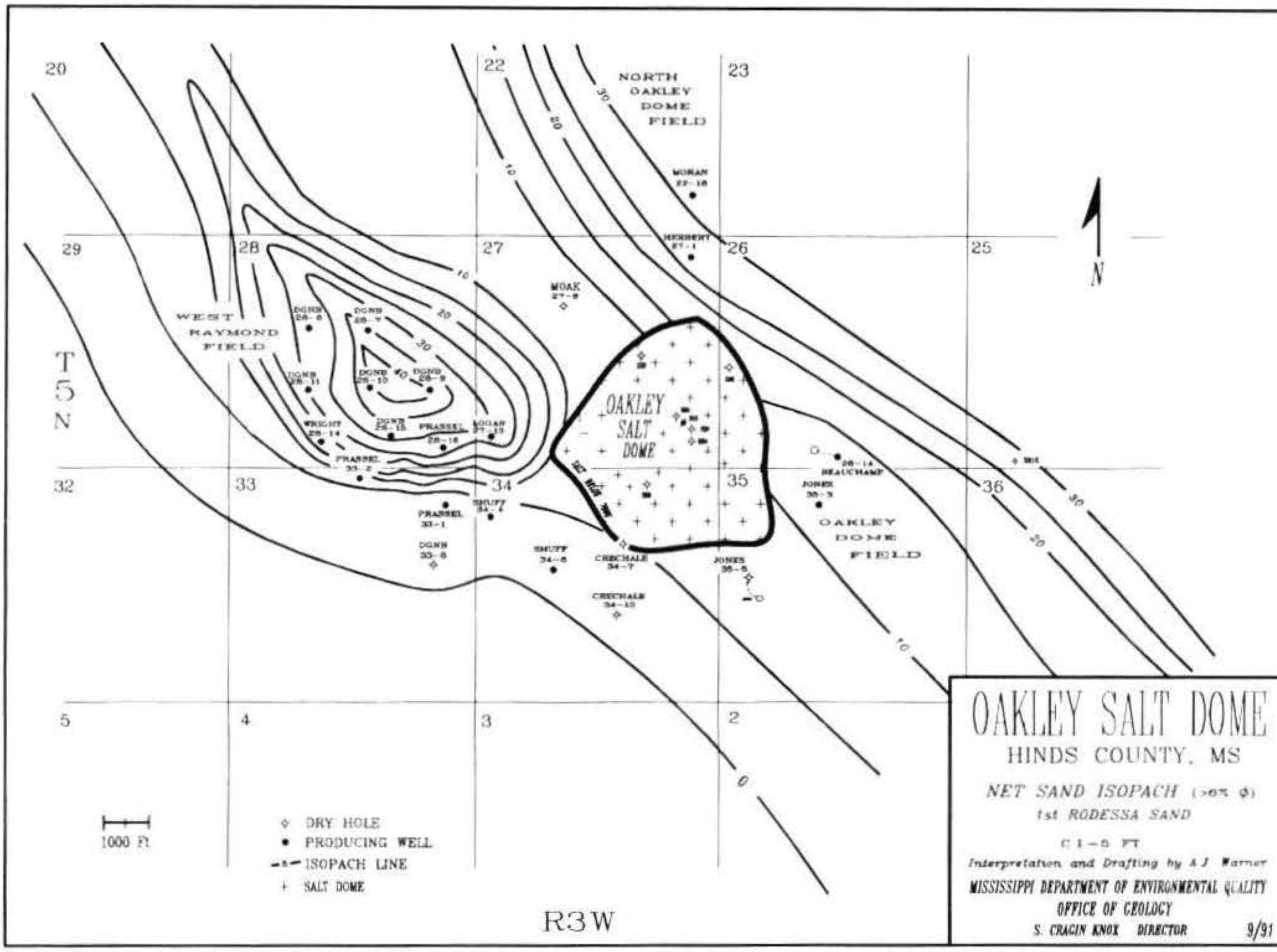

Figure 6. Net sand isopach of Rodessa Consolidated "1st" sand.

ments, a system of radial faults has developed on the flanks of the dome (Figure 2). Ten major radial faults have been discovered to date, dividing the flanks of Oakley Dome into ten separate fault blocks. The western fault block, which encompasses the majority of West Raymond Field, has an average of 7 degrees of dip to the southwest with dip increasing closer to the dome to a maximum of 12 degrees bordering the salt stock. In some cases, the radial faults have isolated reservoirs laterally, while in other cases pathways of migration have been created by positioning a porous rock against another porous rock unit, allowing the oil to move intermittently across (Evans, 1987) and/or vertically up the faults.

Fault "A" (see Figure 2), which strikes to the northwest, serves as an example of providing a lateral seal for a reservoir. The normal fault has an average of 200 feet of "down to the north" displacement with a 65 degree dip at the Rodessa depth. This displacement has juxtaposed the Rodessa Consolidated sands with the Ferry Lake Anhydrite, thus creating the northern lateral seal for these reservoir sands. This fault (Fault "A") has also placed a productive Lower Rodessa sand in contact with the shale of the Middle Rodessa, thus laterally sealing the Lower Rodessa sand and creating a reservoir at that horizon. Fault "B" (see Figure 2) is a normal fault with a strike to the southwest which separates the two producing fault blocks of West Raymond Field. This fault is an example of "plumbing" that can be created by faulting. It has a throw of 300 to 425 feet of "down to the south" displacement with a 65 degree dip at the Rodessa horizon. This repositioning has placed productive Rodessa Consolidated sands in contact with a porous and permeable Mooringsport sand in the southerly downthrown block. This repositioning has created a pathway of migration which has "charged up" the Mooringsport sand, resulting in a producing reservoir. The displacement has also provided a lateral seal for the producing Lower Rodessa sand in Prassel Trust 28-16 by placing the sand in contact with the anhydrite above the Rodessa Consolidated in the downthrown block. The displacement also provided a lateral seal for the Middle Rodessa sand, which is now producing in the Prassel Trust 28-16, by putting the sand

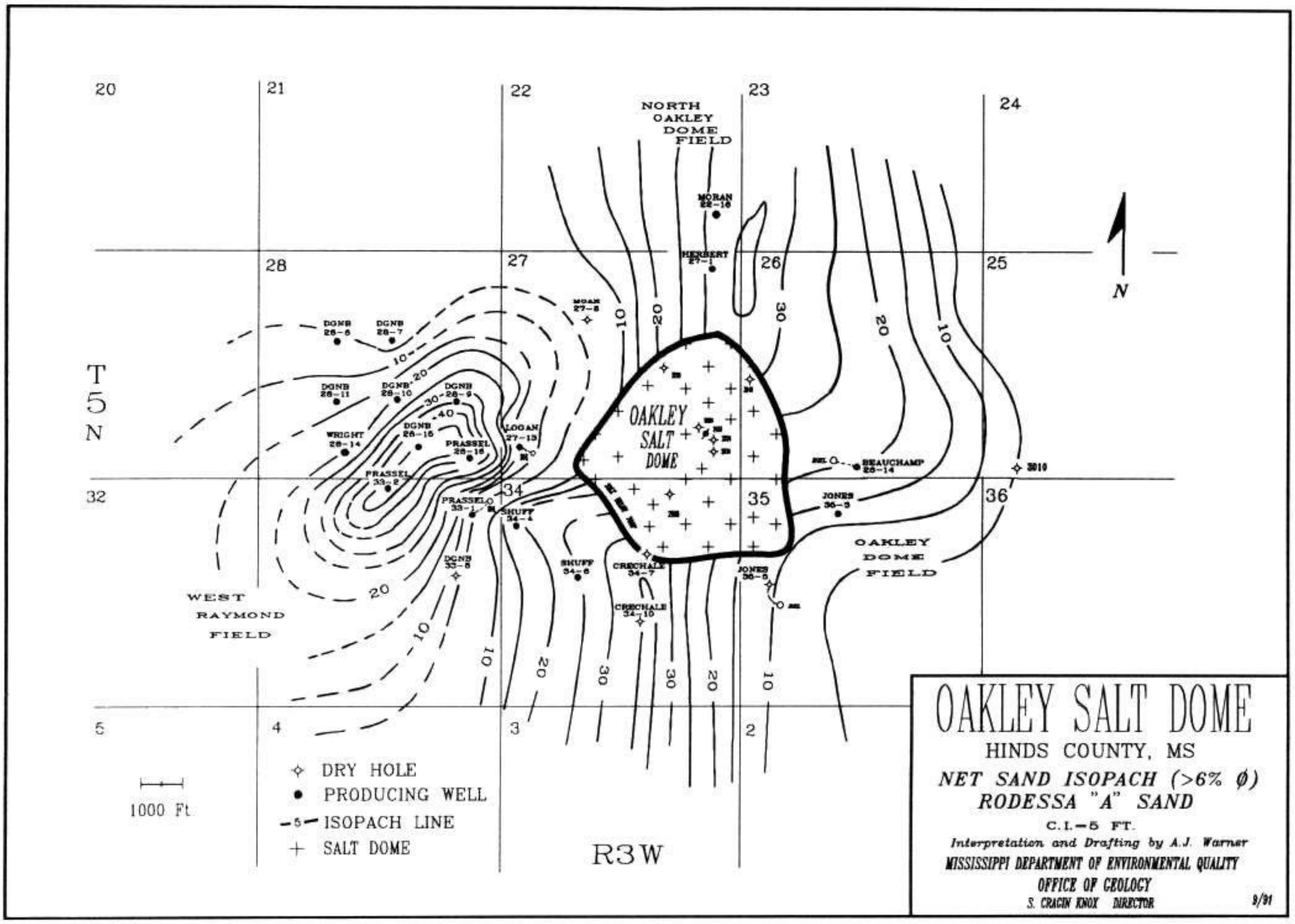

Figure 7. Net sand isopach of Rodessa Consolidated "A" sand.

in contact with the Ferry Lake Anhydrite in the downthrown block.

PRODUCTION

Enserch has drilled 14 wells in West Raymond Field (see Figure 2) since its discovery in 1985. One well drilled in the southwestern fault block tested wet. The remaining 13 wells in the two fault blocks of the field are producing from sands in the Lower Cretaceous Rodessa Consolidated, the Middle Rodessa, the Lower Rodessa, the Mooringsport, and the Pine Island formations. Production is from a well depth ranging from 11,625 to 12,550 feet. West Raymond Field has yielded 1,694,817 bbls. of oil and 1,157,471 Mcf of gas as of January 1, 1992. Well logs and core data analysis indicate other zones, yet to be completed, to have production potential. An example of production behind pipe is the #1 Prassel Trust 28-16 which was originally completed in August 1986 in the Lower Rodessa (11,954 to 11,965 feet). The well flowed 529 bbls. of 39.6 gravity oil per day, with one bbl. of water per day and 116 Mcf of gas per day on a 16/64 choke with 1300 # formation tubing pressure. As of January 1, 1992, the well had produced 258,243 bbls. of oil and 181,654 MCFG from the Lower Rodessa. In August 1991, the well was plugged back and perforated in a Middle Rodessa sand (11,826 to 11,848 feet). The well flowed at 148 bbls. of 41.3 gravity oil per day, with no water reported and 74 Mcf gas per day on a 16/64 choke with 130 # formation tubing pressure.

CONCLUSION

West Raymond Field illustrates the complex structures which are associated with shallow piercement domes and provides a suitable example for future flank piercement dome exploration. The consequence of the piercing of the overlying sediments by the salt stocks often results in favorable conditions for the formation of hydrocarbon traps. Structural highs, lateral seals, and a conduit for migration of hydrocarbons from deeper source rocks, as well as the necessary updip structural closure provided by the salt stock, are examples of essential reservoir components which are characteristically found on the flanks of piercement domes.

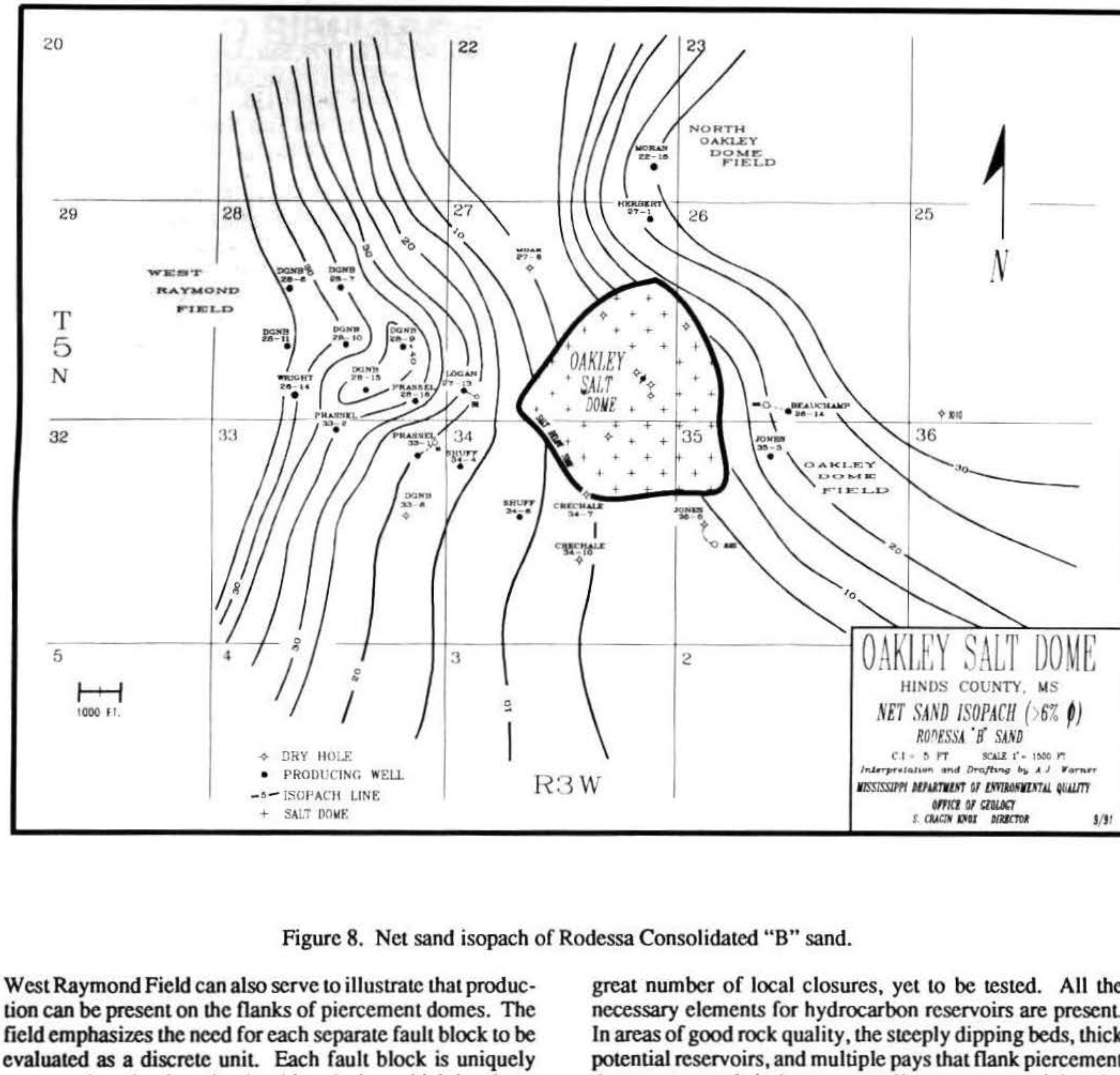

Figure 8. Net sand isopach of Rodessa Consolidated "B" sand.

West Raymond Field can also serve to illustrate that production can be present on the flanks of piercement domes. The field emphasizes the need for each separate fault block to be evaluated as a discrete unit. Each fault block is uniquely connected to the dome's plumbing design which has been created by the radial faulting. As illustrated, the faulting may allow one horizon to be charged, making it productive, or may breach the seals of a previously productive sand, leaving it nonproductive or only marginally productive. Thus, every sand encountered may be productive. This is evident from the presence of multiple reservoirs found on the flanks of the West Raymond Field. To date, West Raymond Field is only a marginally commercial success. However, the rocks of the Trinity are of relatively lesser reservoir quality in this northwestern portion of the Interior Salt Basin as compared to the equivalent rocks in the southeastern Salt Basin. Still there has been significant production at West Raymond and the field continues to produce.

The shallow piercement domes in Mississippi contain a great number of local closures, yet to be tested. All the necessary elements for hydrocarbon reservoirs are present. In areas of good rock quality, the steeply dipping beds, thick potential reservoirs, and multiple pays that flank piercement domes can result in large per well reserve potential under relatively small acreage.

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JACKSON READY MIX MISS-LITE PLANT AND CLAY PIT TO CLOSE AFTER 34 YEARS OF OPERATION

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Mississippi Office of Geology

The Jackson Ready Mix Miss-Lite Aggregate Division is closing after 34 years of manufacturing lightweight aggregate. This was Mississippi's only lightweight aggregate plant. Raw material for the aggregate was mined at Cynthia, Mississippi, in a pit adjacent to the plant. This pit is in the Yazoo Clay, a fossiliferous, montmorillonitic clay of Late Eocene age. At present, it provides the best outcrop of this formation in the state with over 130 feet of section exposed in the pit walls.

Yazoo Clay exposures at the Cynthia clay pit have been cited in numerous publications. They are referenced by Priddy (1960, Bulletin 88) and Moore (1965, Bulletin 105) respectively in the Madison and Hinds county geological bulletins of the Mississippi Geological Survey. The Cynthia clay pit is the subject of seven articles in *Mississippi Geology* covering such subjects as calcareous nannoplankton and geologic age (1984, v. 5, no. 1), tar deposits (1985, v. 5, no. 4), pteropods (1986, v. 6, no. 4), depositional environment and gravity flows (1987, v. 8, no. 2), microspherules from a postulated impact event (1988, v. 8, no. 4), clay chemistry (1989, v. 9, no. 4), and test and core hole correlation (1991, v. 12, no. 3, 4). It is also listed as a stop in Field Trip Guidebook T372 of the 28th International Geological Congress (1989, p. 48-51).

The Cynthia clay pit has long been a convenient field trip stop for viewing fresh exposures of Yazoo Clay and for collecting both vertebrate and invertebrate fossils. It is particularly well known for the frequent occurrence of vertebrae and other remains of Mississippi's State fossil, the archaeocete whale. The sixty-foot long archaeocete whale (and the state fossil of Alabama), *Basilosaurus cetoides* (Owen), is most common. A smaller, sixteen-foot long archaeocete whale, *Zygorhiza kochii* (Reichenbach), has also been found in the pit as have vertebrae of the eighteen-foot long sea snake *Pterosphenus schucherti* Lucas. While the pit will continue to exist as a topographic feature, its lower levels will fill with water (which was regularly pumped out during operation) and its upper levels will completely grass over within a year.

The writer takes this opportunity to thank Jackson Ready Mix and, in particular, Miss-Lite Plant Superintendent Tollie Waldrup and Shipping Clerk Rickey Watkins for their cooperation over the years. They have been helpful to the numerous scientists and field trip groups that have come their way. Mr. Waldrup, now with the Liv-Lite Corporation in Livingston, Alabama, worked at the Miss-Lite Plant for 34 years and was hired on the opening day of operation, January 22, 1958.

SELECTED BIBLIOGRAPHY ON THE OCCURRENCES OF HYDROCARBON IN IGNEOUS AND METAMORPHIC ROCKS

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ABSTRACT

A detailed review of available geologic literature has produced to date some 139 references describing occurrences of hydrocarbon in igneous and metamorphic rocks. Earliest published reports include work by Caddell (1902), Arschinow (1914), and DeGolyer (1915). Gulf Coast examples include the "Serpentine fields" described by Udden (1915), Udden and Bybee (1916), and the Jackson Dome described by Monroe (1932). Among the earliest oil fields of the Gulf Coast, the Serpentine Fields produced over 6.6 million barrels of oil from an altered basalt (serpentinite). The Jackson Dome, first drilled in 1917, produced over 125 BCF of natural gas from the Jackson Gas Rock, an Upper Cretaceous age reef sitting atop an extinct volcano.

Examined as case studies, these references can be interpreted to conclude a biogenic origin for hydrocarbons, but hydrocarbon production can occur from igneous and metamorphic rocks when: (1) weathered igneous and metamorphic reservoir rocks are topographically higher than the source rocks (e.g., the Wiggins Anticline), and (2) igneous and metamorphic rocks exert structural and/or stratigraphic control on the reservoir or source rocks (e.g., the Jackson Dome and the Sharkey Platform).

In the 1980's abiogenic theories for hydrocarbons were revived by proposing degassing from lower crust/upper mantle sources (Gold, 1985; Coveney et al., 1987; and Komor et al., 1988) or igneous activity associated with subduction zones, rift zones, spreading centers (e.g., black smokers), or hot spots. Several super-deep stratigraphic tests have been drilled in an attempt to verify these theories. Most notable of these tests are U.S.S.R.'s Kola SG-3, the world's deepest boring at 39,586 feet, and Sweden's Siljan Ring, Gravberg No. 1. Preliminary results from both tests do not indicate degassing, but in theory the mechanism for such production has been observed in nature (Welhan and Lupton, 1987; Coveney et al., 1987). Further, if abiogenic theories are confirmed, areas outside sedimentary basins could prove to be the plays of the twenty-first century.

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A TURRITELLINE GASTROPOD-DOMINATED BED IN THE BYRAM FORMATION (OLIGOCENE) OF MISSISSIPPI

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ABSTRACT

A turritelline gastropod-dominated assemblage in the Lower Oligocene Byram Formation of Smith County, Mississippi, appears to have lived and been deposited in a shallow, near-shore environment characterized by oscillatory currents and perhaps fluctuating salinities. The assemblage represents an exceptional occurrence of abundant turritellines during the Early Oligocene on the Gulf Coastal Plain, and may have been a result of locally favorable temperature conditions.

INTRODUCTION

Turritelline gastropods (Family Turritellidae, Subfamilies Turritellinae and Protominae) are common members of benthic marine assemblages of Cretaceous to Recent age worldwide, and they are frequently the dominant component of the macrofauna in such assemblages. In North America, turritelline-dominated assemblages have been reported in clastic sediments from throughout the Cenozoic (e.g., Paleocene of Maryland and Virginia [Beauchamp, 1984]; Eocene of California [Merriam, 1941, p. 17]; Miocene of Maryland [McCartan et al., 1985]; Miocene of California [Cooley, 1985]; Pliocene of Florida [DuBar, 1958, p. 94; Spizuco and Allmon, 1992]).

Turritelline-dominated limestones (sometimes referred to as "turritella limestone" or "turritella rock") have been described from the Paleocene of Mississippi (Lowe, 1933, p. 6), Alabama (Smith et al., 1894, p. 193; LaMoreaux and Toulmin, 1959; Toulmin, 1977, p. 96), and Texas (Gardner, 1935) and the Oligocene of North Carolina (Rossbach and Carter, 1991). Turritellines are less abundant, but nevertheless common, in Oligocene limestones in Florida (Mansfield, 1937) and Mississippi (Mansfield, 1940; May, 1974, p. 95-96).

Despite the commonness of their occurrence, the paleoenvironmental conditions that contributed to the formation of turritelline-dominated assemblages have seldom been investigated in the fossil record. Recent

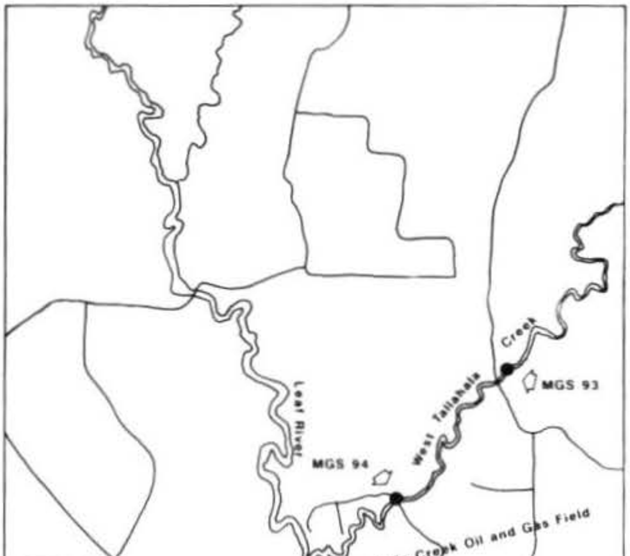

Figure 1. Map showing location of MGS locality 94.

turritellines are most abundant in shallow depths, on soft substrates, in relatively cool, nutrient-rich waters, often associated with upwelling zones (Allmon, 1988a). Whether this was true throughout the history of the group, however, remains unclear (Allmon, 1992; Allmon and Knight, 1992). There is thus a great need to reconstruct the paleoenvironments of individual turritelline-dominated fossil

Figure 2. Concentration of *Turritella mississippiensis* Conrad exposed at MGS locality 94.

assemblages.

In this paper we describe an assemblage from the Oligocene Byram Formation in Smith County, Mississippi, dominated by *Turritella mississippiensis* Conrad, 1848, and attempt to reconstruct the environment in which this assemblage was deposited. This represents the first published record of a turritelline-dominated assemblage from the Oligocene of the Gulf Coast, and the first such assemblage of any age in clastic sediments in Mississippi.

LOCATION AND DESCRIPTION OF THE BED

The bed is exposed in the clay bank of West Tallahala Creek (MGS locality 94; Figure 1). The turritellines are present as a layer no more than 5 cm (or no more than two or three shells) thick in otherwise only sparsely fossiliferous dark gray sandy clay (Figure 2). Laterally, the concentration of shells appears to be very localized, covering an area of no more than a few square meters. The entire bedding plane is not visible in the stream bed, however, and it is possible that the concentration is more extensive.

The turritelline shells are mostly unbroken; their surfaces are largely unabraded and some are even slightly glossy. They show very little variation is size (Figure 3). Analysis of compass orientation of the shells shows a markedly bimodal pattern (Figure 4). Such patterns have been produced experimentally by placing turritelline shells in oscillating (i.e., swash zone) waves (Toots, 1965; Nagle, 1967); shells align perpendicular to the oncoming waves, with roughly an equal number of apices pointing in each direction (Nagle, 1967). Although behavior of Recent turritellines is still too poorly understood to attribute particular orientation patterns of fossil shells to "life position" (Allmon, 1988a, 1989), such strongly bimodal patterns as shown in Figure 4 would appear to be good evidence of an oscillatory wave environment. At the Tallahala Creek locality, the orientation of such waves seems to have been approximately northwest-southeast.

Associated macrofauna at this locality is very sparse. Only a single individual of the large gastropod *Turbinella wilsoni* Conrad and fragmentary small bivalves were found in situ on the same bedding plane.

MICROFAUNA AND PALEOENVIRONMENT

The microfauna at MGS 94 was studied by picking a sample (761 Foraminifera, 283 ostracode valves) from the 1.25 phi size fraction of a wet-sieved sediment sample.

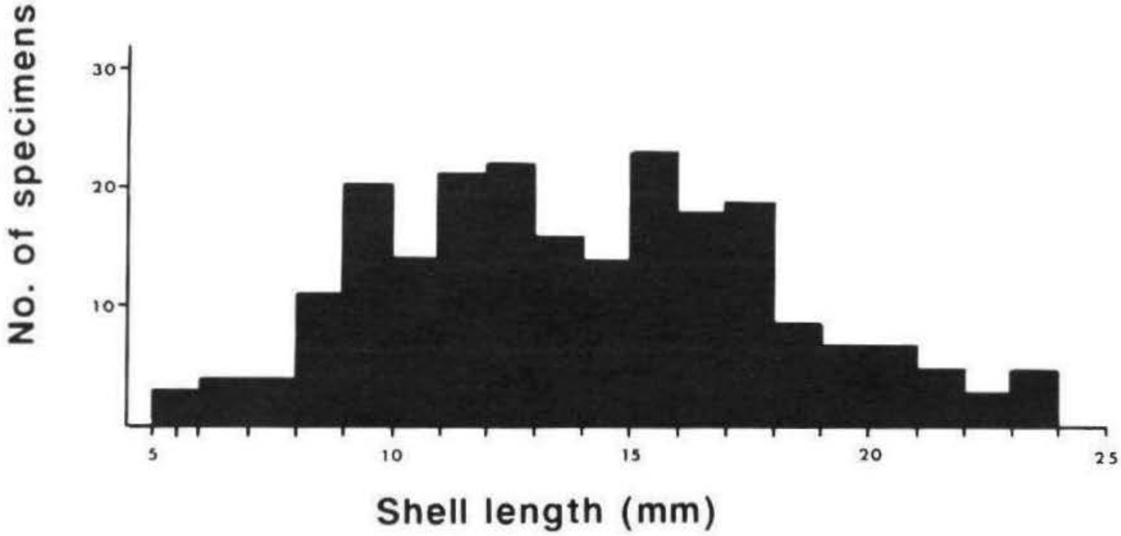

Figure 3. Size distribution histogram for 324 of the individuals of *Turritella mississippiensis* shown in Figure 2.

Results are given in Table 1.

The benthic foraminiferal sample is dominated by rotaliines, especially individuals of one or (probably) more species of the genus *Nonionella*. Dominance of Rotaliina was noted in the uppermost Byram to the west of MGS 94 in Warren County, Mississippi, by Fisher and Ward (1984), who interpreted it as indicating a very nearshore environment, probably a "shallow (<3 meters), low energy, hyposaline lagoon." On the other hand, Murray (1973) lists *Nonionella* as characteristic of normal marine shelf environments 10-1000 m in depth. Walton (1964) recognized a *Nonionella*-dominated fauna inhabiting water 10-30 fathoms (20-60 m) deep in an arcuate zone of the shelf to the northeast of the mouth of the modern Mississippi delta. Murray (1973, p. 104) discusses the Recent occurrence of benthic Foraminifera around sewer outfalls on the California coast. While *Nonionella* spp. are common on unpolluted areas of the shelf at 20-120 m depth, Murray emphasizes that *Nonionella* is "adversely affected by the sewage."

The ostracode sample is dominated by genera of the family Cytherideidae, especially *Cocoaia* and *Heterocyprideis*. Hazel et al. (1980) note that members of this family are typical of inner sublittoral to brackish-water environments.

Based on the information summarized by Murray (1973), the foraminiferal sample (especially the genera *Nonionella* and *Eponides*, which together comprise 85.5% of the total) is indicative of temperate to subtropical temperatures. Hazel et al. (1980) suggest that the Vicksburg ostracode fauna was relatively unaffected by, and therefore unreflective of, Early Oligocene temperature changes.

GEOLOGIC SETTING

The Early Oligocene marine sequence of the Vicksburg Group in Mississippi contains the best preserved and most diverse Oligocene molluscan faunas known from North America. Despite this diversity, however, turritelline gastropods are generally not common in the formations that comprise this group. This is in contrast to earlier Eocene and Paleocene units in which turritellines are common. In at least one mollusk fauna in the latest Late Eocene Yazoo Clay, which underlies the Vicksburg Group in central Mississippi, turritellines are the most common large gastropod (Dockery and Siesser, 1984).

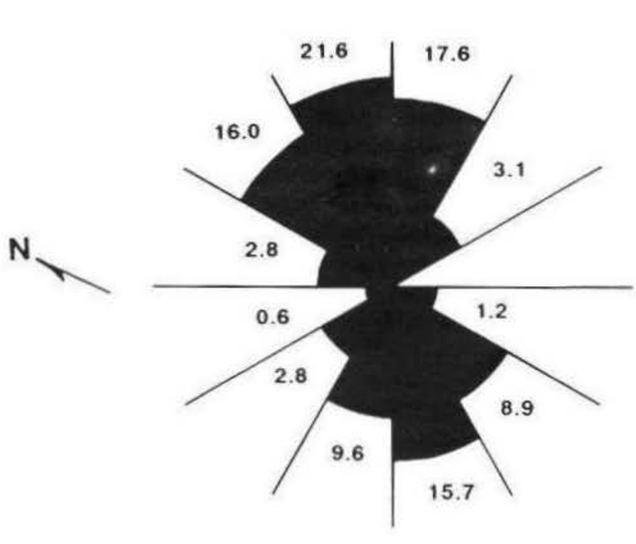

Figure 4. Rose diagram showing the compass orientation of apices of the 324 individuals of *Turritella mississippiensis* whose sizes are plotted in Figure 3. Diagram drawn using the techniques described by Nemec (1988)

Table 1

A. Foraminifera		
Taxon	Number of Individuals	% of Total
Rotaliina		
Bolivina	10	1.3
Cibicides	12	1.6
Eponides	30	3.9
Asterigerina	9	1.2
Globigerina	1	0.1
Guttulina	12	1.6
Nonionella	621	81.6
Polymorphina	5	0.6
Pulvinulina	16	2.1
Rotalia	17	2.2
Uvigerina	5	0.6
Miliolina		
Quinqueloculina	10	1.3
Textulariina		
Textularia	13	1.7

B. Ostracoda		
Genus	Number of Valves	% of Total
Cytherelloidea	9	3.2
Paracytheridea	5	1.8
Cocoaia	122	43.1
Heterocyprideis	141	49.8
Loxoconcha	6	2.1

Seven formations comprise the Vicksburg Group in Mississippi including in ascending order the Red Bluff, Forest Hill, Mint Spring, Marianna, Glendon, Byram, and Bucatunna. The Red Bluff Formation is a glauconitic, fossiliferous clay with a well-preserved and diverse molluscan fauna that is present in eastern Mississippi and western Alabama. It grades westward into the basal fluvial/deltaic sands of the Forest Hill Formation. Forest Hill sediments overlap the Red Bluff clays in eastern Mississippi where they contain marine mollusks in their upper part just below the contact with the overlying Mint Spring Formation. Baum and Vail (1988) incorrectly identified the Red Bluff and Forest Hill formations as the regressive phase of their Late Eocene coastal onlap cycle TE3.3 and considered the Eocene-Oligocene boundary to be a condensed section. This boundary is at the Yazoo - Red Bluff contact and clearly represents a sea level lowstand rather than a surface of maximum flooding (Dockery, 1990). Therefore, the overlying basal Vicksburg units should be placed as coastal onlap cycle TO1.1. Turritellines are present in the Red Bluff Formation but are not especially common.

The Mint Spring Formation is a transgressive, sandy limestone in eastern Mississippi and a fossiliferous, glauconitic sand in central and western Mississippi. Baum and Vail (1988) placed this unit along with the overlying Marianna Limestone in their coastal onlap cycle T01.1. However, if the Red Bluff - Forest Hill sequence is placed as cycle TO1.1, then the Mint Spring - Marianna interval would be cycle TO1.2. There are numerous fossiliferous outcrops of the Mint Spring Formation in Mississippi, but turritellines are common only at MGS locality 110, just north of Vicksburg. Even here they are by no means the dominant taxon.

The Marianna Limestone is the carbonate equivalent of the Mint Spring Formation. Carbonates of this unit lack well-preserved aragonitic shells; thus much of its molluscan fauna, including turritellines, is unknown.

Baum and Vail (1988) placed the Glendon, Byram, and Bucatunna formations in their coastal onlap cycle TO1.2 (TO1.3 if the Mint Spring - Marianna sequence is placed as TO1.2). They placed the surface of maximum flooding for this cycle at the top of the Glendon Limestone and considered the fossiliferous Byram sands and sparsely to nonfossiliferous Bucatunna clays to be a regressive phase of the cycle. Just as in the Marianna Limestone, the Glendon Limestone lacks aragonitic shells. Calcitic pectinid shells and molds of aragonitic taxa, however, indicate that the Glendon molluscan fauna is similar to that in the Byram Formation.

For the most part the Byram Formation is a glauconitic, very fossiliferous, clayey sand with a well preserved molluscan fauna. The Byram differs from the underlying Mint Spring in being less homogeneous; the aggrading Byram shelf received alternating deposits of sand and clay while on the destructional Mint Spring shelf clays were winnowed out, leaving a thin, moderately clean, bioturbated, homogeneous sand. At MGS locality 106 near Edwards, Mississippi, the remains of large land mammals, including a well preserved *Metamynodon* skull (Manning et al., 1985) and a well preserved *Subhyracodon* jaw (Dockery and Manning, 1990), were found in marine beds of the Byram Formation associated with a diverse molluscan and coral fauna. Turritellines are present in almost all outcrops of the Byram Formation (including, rarely, MGS 106), but are common only at MGS 94.

The sparsely to nonfossiliferous clays of the overlying Bucatunna Formation comprise the final part of the TO1.3 (TO1.2 of Baum and Vail) regressive phase in which brackish water environments were dominant.

The sediments exposed at MGS locality 94 appear to be near the top of the Byram Formation. As measured in a straight northeast-southwest line, it is one mile downstream from and southwest of MGS 93, which is a more typical Byram outcrop in having a much more diverse macrofauna.

According to a structure map of Luper (1972, pl. 2) for the top of the Glendon Limestone in Smith County, regional dip below MGS localities 94 and 93 is about 45 feet per mile to the southwest. This map indicates the top of the Glendon to be about 217 feet above sea level at locality 94 and 262 feet above sea level at locality 93, while the Center Ridge 7 1/2 minute quadrangle topographic map shows both localities to be at 270 feet above sea level. The elevation of these outcrops above the top of the Glendon Limestone according to the previous figures is 53 feet for locality 94 and 8 feet for locality 94. Luper (1972, p. 42) noted the Byram Formation to range between 5 and 22 feet in thickness in Smith County. The overlying Bucatunna Formation was noted to vary between 24 and 88 feet in thickness (Luper, 1972, p. 44). Based on these thicknesses, it would seem that locality 94 is a fossiliferous lens within the Bucatunna. Fossils at locality 94, however, are certainly of Byram age (e.g. *Turritella mississippiensis*; see Dockery, 1982, and MacNeil and Dockery, 1984), and Luper (1972, p. 42) gives locality 94 as his only reference locality for the Byram Formation in Smith County. Whether at the top of the Byram Formation or a lens within the Bucatunna Formation, locality 94 contains one of the latest marine faunas within the Vicksburg section.

PALEOENVIRONMENTAL CONDITIONS

Microfaunal and regional stratigraphic information suggest that the sediments exposed at MGS 94 were deposited in a shallow (~10 m), low-energy embayment, fairly close to shore, with normal salinity and relatively high turbidity. The apparent dominance of the foraminiferal fauna by one genus is consistent with the dominance of the molluscan fauna by turritellines, and may indicate, if not non-normal salinity, then frequently and/or rapidly fluctuating salinities. Similar mixed salinity conditions were discussed by Puri and Vanstrum (1971) for a turritelline-dominated bed in the Plio-Pleistocene of Florida. The orientation of the turritelline shells may indicate the activity of oscillatory (tidal?) currents. If the negative relationship between sewage and *Nonionella* noted by Murray (1973) is due to a negative relationship with higher nutrient levels, and if this intolerance for high nutrient levels applied also to Oligocene species of this foraminiferal genus, it may indicate that nutrient levels in the Byram at MGS 94 were relatively low.

SEQUENCE STRATIGRAPHY AND DISRUPTIONS OF MOLLUSCAN FAUNAS

Dockery (1984, 1986) showed that prominent molluscan faunal turnovers occurred across group/stage boundaries within the Paleogene section of the Gulf Coastal Plain and argued that these turnovers were the result of falling sea level. Gaskell (1991) noted similar extinction patterns for Gulf Coast Paleogene benthic foraminiferal faunas. She failed to recognize the Jackson-Vicksburg Group contact as a sequence boundary, however, and correlated faunal turnovers with sequence boundaries only at the base of the Midway, Wilcox, and Claiborne groups. Hansen (1987) argued that climatic cooling associated with possible bolide impact events and not sea level fluctuations was responsible for Paleogene molluscan turnovers. This point was contested between Dockery and Hansen (1987, 1988).

Whatever the cause of the major Paleogene molluscan faunal turnovers, these events coincide with sequence boundaries at the base of the Gulf Coast Groups/Stages. The most significant of these faunal turnovers is at the Jackson-Vicksburg boundary, which is equivalent with the Eocene-Oligocene boundary. Here falling sea level and climatic cooling may have doubly stressed shallow benthic marine communities. Large planicostate venericard bivalves, which characterize earlier Paleocene and Eocene molluscan faunas, became extinct at this boundary. A large group of stromboid gastropods, prominently including *Calyptraphorus*, also became extinct at this time.

Turritellines continued across the Eocene-Oligocene boundary, but with a diminished prominence in the northern Gulf Coast region (Allmon, 1988b, 1992). Rather than the widespread abundance they had attained during Paleocene and Eocene times, their occurrence was more restricted and discontinuous during the Early Oligocene.

The turritelline-dominated fauna in the upper Byram at MGS 94 appears to represent a very localized occurrence of optimal conditions for the group during a time of generally low abundance. What exactly these conditions were, however, remains unclear. The preliminary foraminiferal data suggest that is was not higher nutrients, so it may have been local water temperatures. A global cooling episode beginning in the latest Eocene proceeded irregularly, and culminated in the Early Oligocene (Keller, 1983; Shackleton, 1986; Hansen, 1987). The exceptional occurrence of a turritelline-dominated assemblage in the upper Byram may have been due to locally warmer (or, more likely based on the foraminiferal fauna, still cooler) waters at this locality.

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