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PALEOENVIRONMENTS AND HYDROCARBON POTENTIAL OF THE UPPER JURASSIC NORPHLET FORMATION OF SOUTHWESTERN AND OFFSHORE ALABAMA

Ernest A. Mancini[1], Robert M. Mink[1] and Bennett L. Bearden[1]

ABSTRACT

Upper Jurassic Norphlet sediments in southwestern and offshore Alabama accumulated under arid climatic conditions. The Appalachian Mountains of the eastern United States extended into southwestern Alabama providing a barrier for air and water circulation during Norphlet time. These mountains not only contributed to the arid climate but also affected sedimentation. Norphlet paleogeography was dominated by a broad desert plain rimmed to the north and east by the Appalachians and to the south by a developing shallow sea. The desert plain extended westward into eastern and central Mississippi.

Initiation of Norphlet sedimentation was a result of erosion of the southern Appalachians. Norphlet conglomerates were deposited in coalescing alluvial fans in proximity to an Appalachian source. The conglomeratic sandstones grade downdip into red bed lithofacies which accumulated in distal portions of alluvial fan and wadi systems. Quartzose sandstones (Denkman Member) were deposited as dune and interdune sediments on a broad desert plain. The source of the sand was the updip and adjacent alluvial fan, plain and wadi deposits. Wadi and playa lake sediments probably also accumulated in the interdune areas. A marine transgression was initiated in late Denkman time resulting in the reworking of previously deposited Norphlet sediments.

Norphlet hydrocarbon potential in southwestern and offshore Alabama is excellent with four oil and gas fields already established. Petroleum traps discovered to date are primarily structural traps involving salt anticlines, faulted salt anticlines, and extensional fault traps associated with salt movement. Reservoir rocks consist of quartzose sandstones which are principally eolian in origin. Porosity types include both intergranular and secondary dissolution. Smackover algal carbonate mudstones were probably the source for the Norphlet hydrocarbons.

INTRODUCTION

Since the discovery of oil in 1967 from the Smackover Formation at Toxey field, Choctaw County, Alabama, and of condensate in 1968 from the Norphlet Formation at Flomaton field, Escambia County, Alabama, the upper Jurassic (Figure 1) has become the primary exploration target in southwestern Alabama. In Alabama to date, a total of 40 fields have been established in Upper Jurassic rocks, but only in four of these fields has the Norphlet been productive of hydrocarbons (Figure 2). Cumulative production from these units through 1983 includes more than 76 million barrels of oil, 81 million barrels of condensate, and 881 billion cubic feet of gas; however, about 99 percent of the oil production, 75 percent of the condensate production, and 80 percent of the gas production has been from the Smackover Formation.

The discovery of productive Norphlet gas sandstones in 1979 at the Lower Mobile Bay-Mary Ann field (Figure 2) has demonstrated the potential of the Norphlet in offshore Alabama. To date, the four wells drilled to test the Norphlet in Mobile Bay have been successful gas wells and have tested 10.5 to 19.4 million cubic feet of natural gas per day. In addition, a wildcat well drilled on Alabama Tract 72 tested 21.2 million cubic feet of natural gas per day, and a wildcat well drilled on Mobile Area Block 823 less than 1 mi (1.610 km) from Alabama state coastal waters tested 26 million cubic feet of natural gas per day (Figure 2). Although drilling is to depths exceeding 20,000 ft (6096 m), the projected gas reserves for the Norphlet in the Alabama offshore region justify continued exploration.

The primary geologic factors that make a successful Norphlet petroleum prospect include the trapping mechanism, reservoir, source rock, and relationship between hydrocarbon migration and structural deformation. Regional geologic trends must be understood before a successful Norphlet exploration strategy can be formulated. This paper describes the regional stratigraphic relationships associated with Norphlet deposition in southwestern and offshore Alabama. These regional relationships were identified through a subsurface geological study utilizing several hundred well logs and more than 40 cores. Establishment of these regional relationships will help in delineating the geologic trends and processes controlling Norphlet petroleum accumulation. Emphasis has been placed on Washington, Mobile and Escambia Counties and the Mobile Bay area, Alabama, because of the petroleum discoveries already made in these areas.

REGIONAL SETTING

Jurassic sedimentation in southwestern Alabama was controlled by rifted continental margin tectonics. The established plate tectonic overprint affected the accumulation of Norphlet sediments during the late Jurassic. Norphlet deposition was controlled by a combination of differential basement subsidence and the presence of pre-Jurassic paleohighs and Jurassic highs. Differential subsidence in the established rifted grabens and various basinal areas, such as the Mississippi Interior Salt basin,

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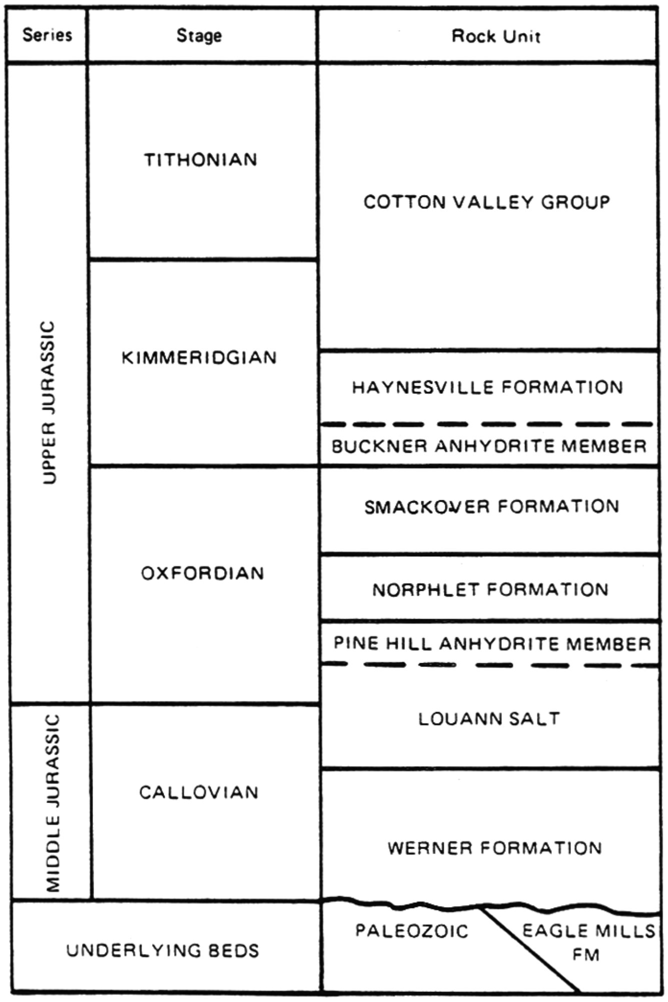

Figure 1. Generalized Jurassic stratigraphy for southwestern and offshore Alabama (modified from Imlay, 1980; Tolson and others, 1983).

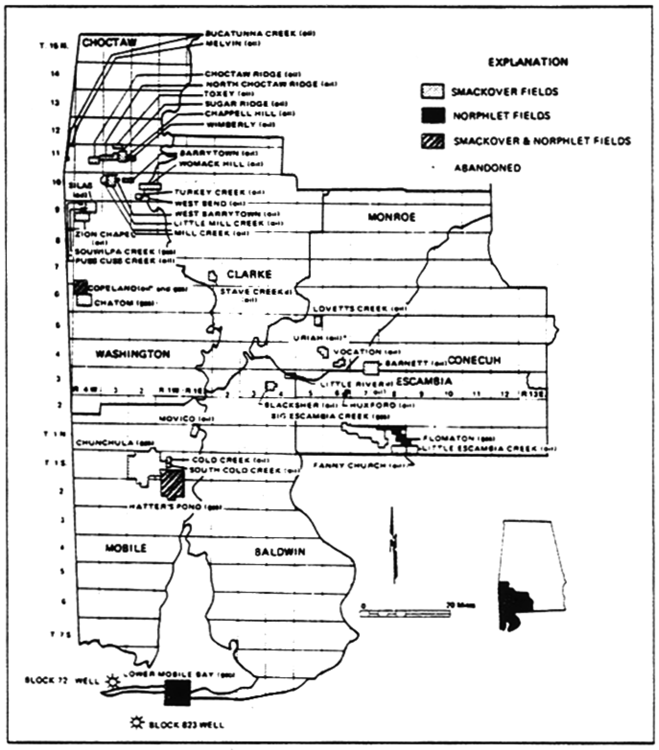

Figure 2. Jurassic fields in southwestern and offshore Alabama and new discoveries in offshore Alabama (modified from Mink, 1984).

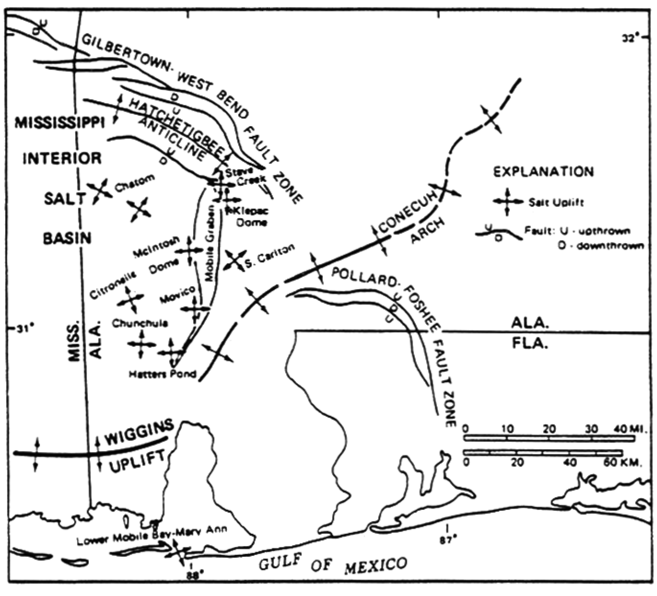

Figure 3. Major structural features of southwestern and offshore Alabama (modified from Wilson, 1975).

resulted in thick accumulations of Norphlet sandstone. Later Louann salt movement in updip areas resulted in a peripheral fault system near the updip limit of Norphlet deposition (Figure 3).

Several pre-Jurassic paleohighs and Jurassic highs are present in the southwestern Alabama area. Many of these are unnamed; however, two of the more pronounced ridges are the Conecuh and Pensacola Ridges. Another positive paleohigh in the area is the Wiggins Arch. The Wiggins, which extends eastward into Mississippi, may represent a continental block that foundered during rifting or possibly a southwestward extension of the Appalachian structural front. The radiometric age date of the metamorphic rocks recovered from the Betty Joe Anderson No. 1 well drilled in Mobile County, Alabama, on the Wiggins indicates a Mississippian age (Forest Oil Corporation, personal communication, 1982). Several of these positive features, like the Conecuh Ridge and Wiggins Arch, probably served as source areas for Norphlet sediments. The Norphlet is absent on portions of several of these features, including the Conecuh and Wiggins.

STRATIGRAPHY

In southwestern and offshore Alabama, the Norphlet Formation underlies the Smackover Formation. The contact between the Norphlet and Smackover can be gradational or abrupt. In parts of Mobile and Baldwin Counties and probably in parts of Choctaw, Clarke, Escambia and Washington Counties, the contact is conformable, grading downward from silty dolostone or limestone to dolomitic or calcitic sandstone. In much of Escambia County, the Norphlet-Smackover contact is sharp, with carbonate mudstone overlying quartzose sandstone. In updip areas (Conecuh, Monroe and Wilcox Counties), Smackover carbonates can overlie Norphlet conglomeratic sandstone. The Norphlet contact with the underlying strata is sharp. The Norphlet can overlie the Pine Hill Anhydrite Member, Louann Salt, Werner Anhydrite, Eagle Mills, Mesozoic volcanics, or Paleozoic rocks (Figure 1).

The Denkman Member of the Norphlet Formation of southwestern and offshore Alabama is lithologically distinct from the Norphlet red clastics of southern Arkansas and northern Louisiana as described by Murray (1961). The Norphlet in southwestern and offshore Alabama is dominated by a quartzose sandstone which can attain thicknesses in excess of 600 ft (183 m). This quartzose sandstone, which is referred to as the Denkman Member (Murray, 1961; Tyrrell, 1972), consists chiefly of a gray to brown, well-sorted, fine-grained subarkose having rounded quartz grains. The average composition of the Denkman is 72.5% quartz, 15.0% feldspar (plagioclase, microcline and orthoclase), 4.4% rock fragments (chert, shale, phyllite, schist and quartzite), 3.8% cement (carbonate, silica and anhydrite), 3.2% authigenic clay (illite), and 1.1% accessory minerals (Wilkerson, 1981). The Denkman typically consists of an upper massive to indistinctly horizontal, discontinuous, wavy, laminated sandstone and a lower high-angle, planar, crossbedded sandstone. The lower crossbedded sandstone comprises most of the Denkman Member. The Denkman becomes reddish-brown near its base and grades into an underlying red bed lithology.

These red bed sandstones, siltstones and shales become the dominant Norphlet lithology updip in Escambia and parts of Choctaw, Clarke, Washington, Monroe and Baldwin Counties. The red bed sandstone consists chiefly of a gray to red, poorly to moderately sorted, fine- to coarse-grained subarkose or sublitharenite having subangular quartz grains. The average composition is 59.7% quartz, 11.8% feldspar (plagioclase, microcline and orthoclase), 9.2% rock fragments (chert, phyllite, quartzite, schist, gneiss, and basic and felsic igneous), 10.7% matrix (clay), 6.0% cement (anhydrite, silica and carbonate), 2.2% accessory minerals, and 0.4% mica (Wilkerson, 1981). The red bed sandstone usually has horizontal, discontinuous to inclined, planar laminae.

The Denkman and red bed lithologies are replaced further updip in Wilcox, Monroe, Conecuh and Escambia Counties by Norphlet conglomeratic sandstone. The sandstone is gray or red, poorly sorted, fine- to coarse-grained having angular to subangular quartz. Typically, the sandstone contains granule to cobble-sized clasts of chert, shale, quartzite, granite and rhyolite.

Shale occurs at the base of the Norphlet sequence in parts of Escambia and Choctaw Counties and most likely is present elsewhere in Alabama, particularly in the offshore area. The shale is typically black, structureless to wavy laminated and illitic. It is essentially barren of any organic remains. The shale may be Norphlet or Louann lithofacies.

ENVIRONMENT OF DEPOSITION

The accumulation of thick Jurassic salt deposits, anhydrites and red beds in association with Norphlet sandstones indicates that arid climatic conditions were prevalent during Norphlet deposition. The Appalachian Mountain system of the eastern United States extended into southwestern Alabama and provided a barrier both for air and water circulation during the Jurassic. This mountain system not only contributed to the arid climate of southwestern Alabama during the Jurassic but also affected sediment accumulation. Paleogeography in southwestern Alabama during the Jurassic was probably dominated by a broad desert plain rimmed to the north and east by the Appalachian Mountains and to the south by a developing shallow sea (Figure 4). The desert plain extended westward into eastern and central Mississippi.

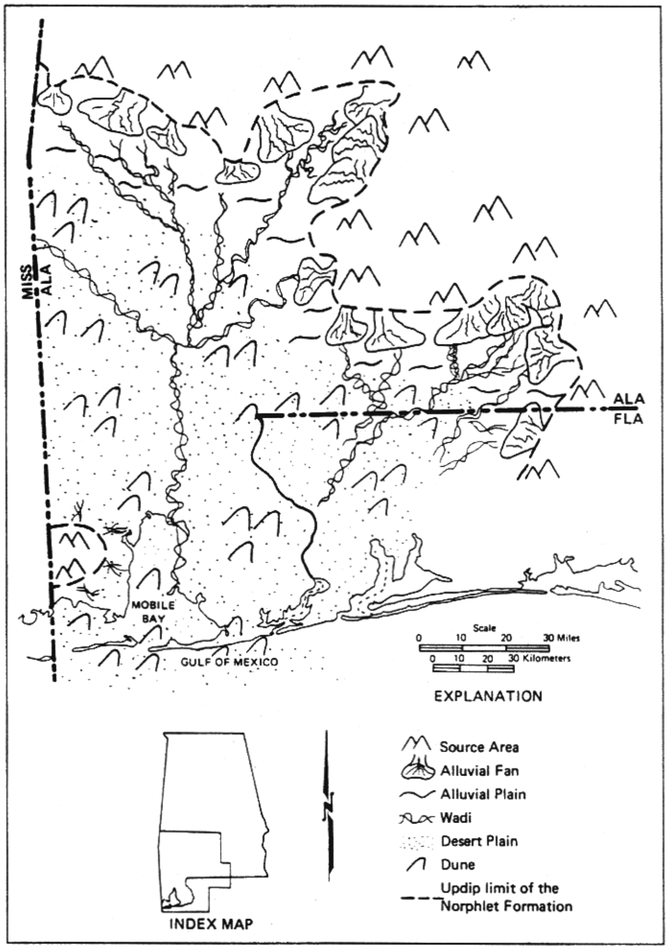

Figure 4. Generalized Norphlet regional setting and paleoenvironments for southwestern and offshore Alabama.

The initiation of Norphlet sedimentation was the result of basin subsidence accompanied by erosion of the southern Appalachian Mountain chain. Norphlet conglomeratic sandstones were deposited in proximity to their Appalachian source. This Norphlet lithofacies is most prevalent in Choctaw, Marengo, Clarke, Wilcox, Dallas, Monroe, Conecuh, Escambia and Covington Counties, Alabama, or in areas that would be considered updip with respect to Norphlet deposition. The paleogeographic setting and arid climate of Norphlet sediment accumulation in addition to the sedimentary characteristics of the conglomeratic sandstones suggest that this lithofacies was deposited as coalescing alluvial fans (Wilkerson, 1981; Pepper, 1982). The restricted updip distribution of these deposits in association with apparent pre-Jurassic paleohighs and Jurassic highs, the presence of granule to cobble-sized clasts of chert, shale, quartzite, granite and rhyolite, the red coloration, the immature texture of the sandstones (poorly sorted and having angular to subangular quartz) and apparent lack of stratification support a transport mechanism similar to a braided-stream pattern characterized by intermittently high volumes of flow.

Downdip and into Choctaw, Clarke, Washington, Monroe, Baldwin and Escambia Counties, Alabama, the conglomeratic lithofacies of the Norphlet grades to a red bed lithofacies. The red bed lithofacies probably represents distal portions of the alluvial fan systems (Wilkerson, 1981; Pepper, 1982). Braided streams (wadi) intermittently flowed across these systems, dissecting the alluvial plain. The immature to submature texture (poorly to moderately sorted having subangular quartz grains and high clay matrix content), sandstone composition (rich in feldspar and rock fragments and low in quartz), the red coloration, and the primary sedimentary structure sequence indicate a fluvial dominated transport mechanism having sporadic high-flow volumes.

The Denkman Member or quartzose lithofacies of the Norphlet accumulated as dune and interdune sands (Wilkerson, 1981; Pepper, 1982) on a broad desert plain which was bordered on the north and east by the Appalachians and to the south by a developing shallow sea. The desert plain extended westward into eastern and central Mississippi where the upper Norphlet has been interpreted to be eolian (Hartman, 1968; Badon, 1975; McBride, 1981). The principal source of the sand was the updip alluvial fan, plain and wadi deposits. The sand was for the most part transported by the wind into the desert plain area. Wadi deposits and desert lake deposits were probably also present in the interdune areas.

The most distinguishing features of the Denkman are thick sets of low- to high-angle (up to 30°), bimodal, well-sorted, planar crossbeds and several types of penecontemporaneous, soft sediment deformation structures, including slump features, pillar structures, and small-scale faults. This lithofacies is dominated by quartzose sand which is texturally mature (well-sorted having rounded quartz) and has a composition consisting of a significant percent of feldspar. The low- to high-angle crossbedded sands are probably dune facies, while low-angle to horizontally laminated sands either may represent dune crests or interdune areas. Wavy discontinuous laminae are associated with the low- and high-angle crossbeds. Such structures may be adhesion ripples which commonly occur in wadi or desert lake deposits. The presence of a significant percent of feldspar in the Denkman is attributed to the proximity and nature of the eroding source terrain and the arid climate evident during Norphlet deposition.

The upper part of the Denkman is usually massively bedded; however, wavy, horizontal laminations are apparent on occasion. The massive Denkman is inferred to be intertidal in origin (Sigsby, 1976; Wilkerson, 1981; Pepper, 1982) and probably reflects reworking of the underlying sediments by a rise in sea level which was initiated in late Norphlet time and continued into Smackover time.

In summary, the sequence of deposition of the various Norphlet lithofacies would first include accumulation of shale in isolated lagoons or bays along an emerging shoreline. Norphlet sand accumulation was then initiated with the uplift and erosion of the Appalachian Mountains. Conglomeratic sandstones were deposited in proximal alluvial fans and red bed lithologies accumulated in distal alluvial fan and wadi environments. Sand from these environments was transported toward the coast across a desert plain. This sand was reworked into the dune and interdune Denkman lithofacies. A marine transgression was initiated in late Denkman time resulting in the reworking of the underlying sediments. The marine transgression continued into Smackover time.

PETROLEUM GEOLOGY

Petroleum traps in southwestern and offshore Alabama are principally structural traps involving salt anticlines, faulted salt anticlines, and extensional fault traps associated with salt movement. Stratigraphy plays an integral part in the formation of Norphlet petroleum traps, as can be evidenced by the existing fields and recent Norphlet discoveries.

The Flomaton field in Escambia County, Alabama, which was discovered in 1968 with the drilling of the Humble Oil and Refining Company, Bernice S. Wessner No. 1 well, consists of a low-relief, faulted, salt anticline associated with the Pollard-Foshee fault system. The primary trapping mechanism is the large down-to-the-north fault which truncates an anticlinal nosing trend. Structural closure is evident in the northwestern and southeastern portions of the field. Currently, 14 wells are producing in Flomaton with cumulative production to date exceeding 8.5 million barrels of condensate and 121 billion cubic feet of natural gas. The Norphlet reservoir in the field is primarily the Denkman lithofacies. Porosity averages 13.5 percent, and permeability averages 10 md.

The Norphlet petroleum trap in Copeland field, Washington County, is a salt anticline. The field was discovered in 1974 with the drilling of the Amoco Production Company, W.M. Curlee No. 1 well. The Curlee well produced over 95,000 barrels of oil and 59 million cubic feet of gas between 1974 and 1979. Presently, no oil is being produced from the Norphlet in Copeland. The Norphlet reservoir in this field is in the quartzose lithofacies, which has an average porosity of 18 percent and an average permeability of 197 md.

The Hatter's Pond field, Mobile County, which was discovered in 1974 with the drilling of the Getty Oil Company Peter Klein No. 1 well, produces from both the Smackover and the Norphlet Formations. The petroleum trap involves salt movement along the west side of the Mobile fault system that has resulted in a faulted salt anticline. To date, over 16.4 million barrels of condensate and 64 billion cubic feet of natural gas have been produced from 14 wells located in this field. The Norphlet reservoir in Hatter's Pond field is the quartzose lithofacies. The porosity of the eolian Denkman lithofacies at Hatter's Pond field has been interpreted as secondary dissolution by Honda and McBride (1981). They believe that this secondary porosity is a result of decementation of anhydrite or calcite and by grain dissolution. Porosity averages 10.4 percent, and permeability averages 0.5 md in the Hatter's Pond field.

The Norphlet petroleum trap in the Lower Mobile Bay-Mary Ann field, Mobile Bay, Alabama, is a low-relief, faulted, salt anticline. Mobil Oil Exploration and Producing Southeast, Inc. discovered this natural gas field in 1979 with the drilling of the State Lease 347 No. 1 well. To date, the four wells drilled to test the Norphlet in the field have tested 10.5 to 19.4 million cubic feet of natural gas per day. The quartzose lithofacies of the Norphlet is the reservoir in this field. Porosity averages 10.9 percent and is principally developed as secondary dissolution in the Denkman Member. Permeability of these sandstones averages 1.1 md.

Smackover algal carbonate mudstones were probably the source for the Norphlet hydrocarbons. These mudstones are locally rich in algal and amorphous kerogen (Mancini and

Benson, 1980). The thermal alteration indices for these rocks indicate that the thermal history for much of southwestern and offshore Alabama was highly favorable for the generation and preservation of hydrocarbons. To date, analyses of samples from the black shares associated with the Norphlet in Escambia County have indicated these shales are essentially barren of any significant organic matter.

CONCLUSIONS

1. Upper Jurassic Norphlet paleogeography in southwestern and offshore Alabama was dominated by a broad desert plain rimmed to the north and east by the Appalachians and to the southwest by a developing shallow sea. The desert plain extended westward into eastern and central Mississippi.
2. Norphlet conglomerates were deposited in coalescing alluvial fans in proximity to an Appalachian source, and red beds accumulated in distal portions of alluvial fan and wadi systems. Quartzose sandstones were deposited as dune and interdune sediments on a broad desert plain. A marine transgression was initiated in late Norphlet time resulting in the reworking of previously deposited Norphlet sediments.
3. Norphlet hydrocarbon potential in southwestern and offshore Alabama is excellent with petroleum traps being primarily structural traps involving salt anticlines, faulted salt anticlines, and extensional fault traps associated with salt movement. Reservoir rocks consist of quartzose sandstones having intergranular and secondary dissolution porosity. Smackover algal carbonate mudstones were probably the source for the Norphlet hydrocarbons.

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