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GAS SHALE POTENTIAL OF ALABAMA

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ABSTRACT

Shale formations in the Black Warrior Basin and Appalachian Thrust Belt of Alabama present a diversity of opportunities for the exploration and development of natural gas. Prospective formations range in age from Cambrian through Carboniferous; they include the Middle Cambrian Conasauga Formation, a variety of Devonian shale units, and the Mississippian Neal (Floyd) Shale. Each prospective shale unit poses different challenges for development. In the Appalachian Thrust Belt, structural complexity is the principal challenge that must be met. For example, giant deformed shale masses in the Conasauga Formation contain major resources, but best practices for drilling and completion remain to be determined. A significant gas show in the Devonian section within the backlimb of a large ramp anticline are also promising, and fracturing associated with parasitic folds may enhance permeability. Organic-rich Chattanooga (Devonian) and Neal shale units in the Black Warrior Basin are enveloped by brittle carbonate formations and thus appear analogous to the prolific Barnett Shale of the Fort Worth Basin. Understanding the interplay among stratigraphic architecture, organic content, and thermal maturity are important keys to understanding the development potential of the Chattanooga Shale and the Neal shale.

INTRODUCTION

Unconventional gas production in Alabama has been dominated by coalbed methane since the 1970s, and as the coalbed methane industry approaches maturity, the vast potential for shale gas production is starting to be realized. Indeed, multiple gas shale plays are active in Alabama's Black Warrior Basin and Appalachian Thrust Belt (fig. 1). These emerging plays are extremely diverse, and while some have much in common with established shale plays in other regions, others present unique geological and engineering challenges. Meeting these challenges, importantly, will prove new exploration and development technologies that can be transferred to other regions. The purposes of this paper are to characterize the natural gas potential of shale formations in the Black Warrior Basin and Appalachian Thrust Belt of Alabama and to highlight the challenges confronting exploration and development.

The Black Warrior Basin is a late Paleozoic foreland basin that formed adjacent to the juncture of the Appalachian and Ouachita orogenic belts (Thomas, 1977, 1988). The basin can be characterized as a southwest-dipping homocline that is broken by numerous normal faults (fig. 2). Appalachian folds and thrust faults strike northeast and are superimposed along the southeast margin of the homocline. The

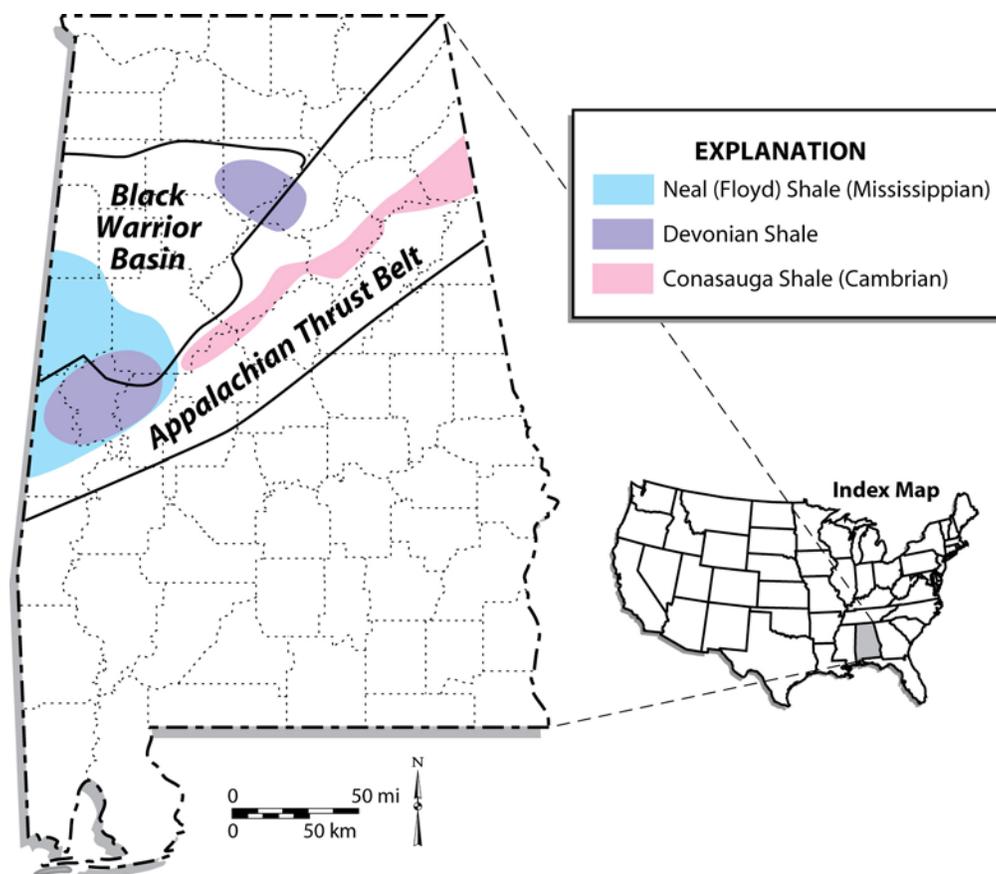


Figure 1.—Generalized map showing location of shale-gas development areas in Alabama.

basin is developed on the Alabama Promontory, which is a protuberance of the Laurentian continental platform that formed during late Precambrian-Cambrian Iapetan rifting. Ouachita orogenesis was initiated along the southwest margin of the promontory during Mississippian time (Thomas, 1977). The Black Warrior can be considered to be mainly an Ouachita foreland basin, and Appalachian thrust and sediment loads did not impinge on the southeastern part of the basin until Early Pennsylvanian time (Pashin, 2004).

The Appalachian Thrust Belt separates the gently dipping strata of the Black Warrior Basin from the crystalline internides of the Appalachian orogen. The thrust belt is composed of deformed pre-orogenic carbonates of Cambrian through Mississippian age and synorogenic siliciclastic rocks of upper Mississippian and Lower Pennsylvanian age (e.g., Thomas, 1985; Thomas and Bayona, 2005) (fig. 3). The thrust belt is detached in weak Cambrian shale, and the structural style reflects the cratonward transport of stiff pre-orogenic carbonate rocks and weak synorogenic siliciclastic rocks through frontal and lateral thrust ramps.

Shale-gas exploration in Alabama is in strata ranging in age from Cambrian through Mississippian (fig. 1). Cambrian strata are being explored in the Conasauga Formation of the Appalachian thrust belt (fig. 3), which is geologically the oldest gas shale play in the world. Devonian shale has potential in both the Appalachian Thrust Belt and the Black Warrior Basin, and production has been established in the Devonian-age Chattanooga Shale (fig. 4) where the frontal Appalachian structures have deformed the homocline of the Black Warrior Basin. The Neal shale is an organic-rich facies of the Upper Mississippian-age Floyd Shale. The Neal has long been recognized as the principal source rock that charged

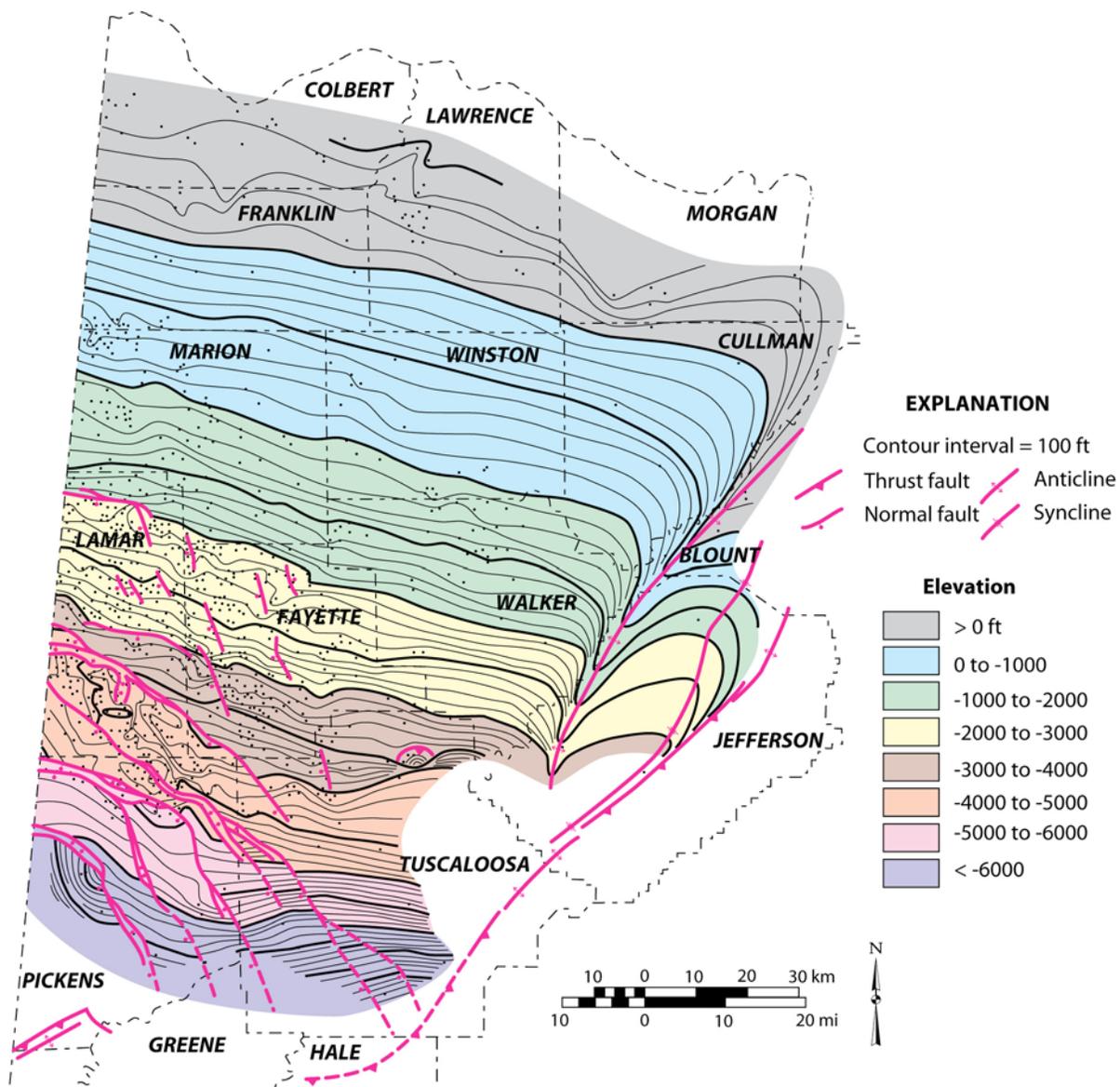


Figure 2.—Structural contour map of the top of the Tuscumbia Limestone in the Black Warrior Basin of Alabama (modified from Pashin, 1993).

conventional sandstone reservoirs in the Black Warrior Basin (e.g., Telle and others, 1987; Carroll et al., 1995) and has been the subject of intensive shale-gas exploration in recent years. The following sections summarize the basic geology of each shale gas play in Alabama, as well as some of the technological challenges that are being met to achieve economic rates of production.

CONASAUGA SHALE

The discovery of gas in the Conasauga Formation of the Appalachian thrust belt in 2005 by Dominion Exploration and Production, Incorporated, was a landmark event, not only because it represents the first commercial gas production from shale in Alabama, but because it is geologically the oldest and most

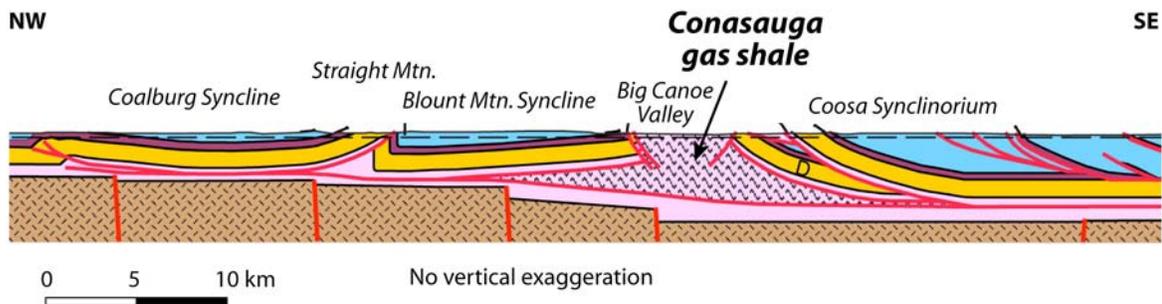


Figure 3.—Structural cross section showing tectonically thickened mass of gas shale in the Conasauga Formation of the Appalachian Thrust Belt (modified from Thomas and Bayona, 2005).

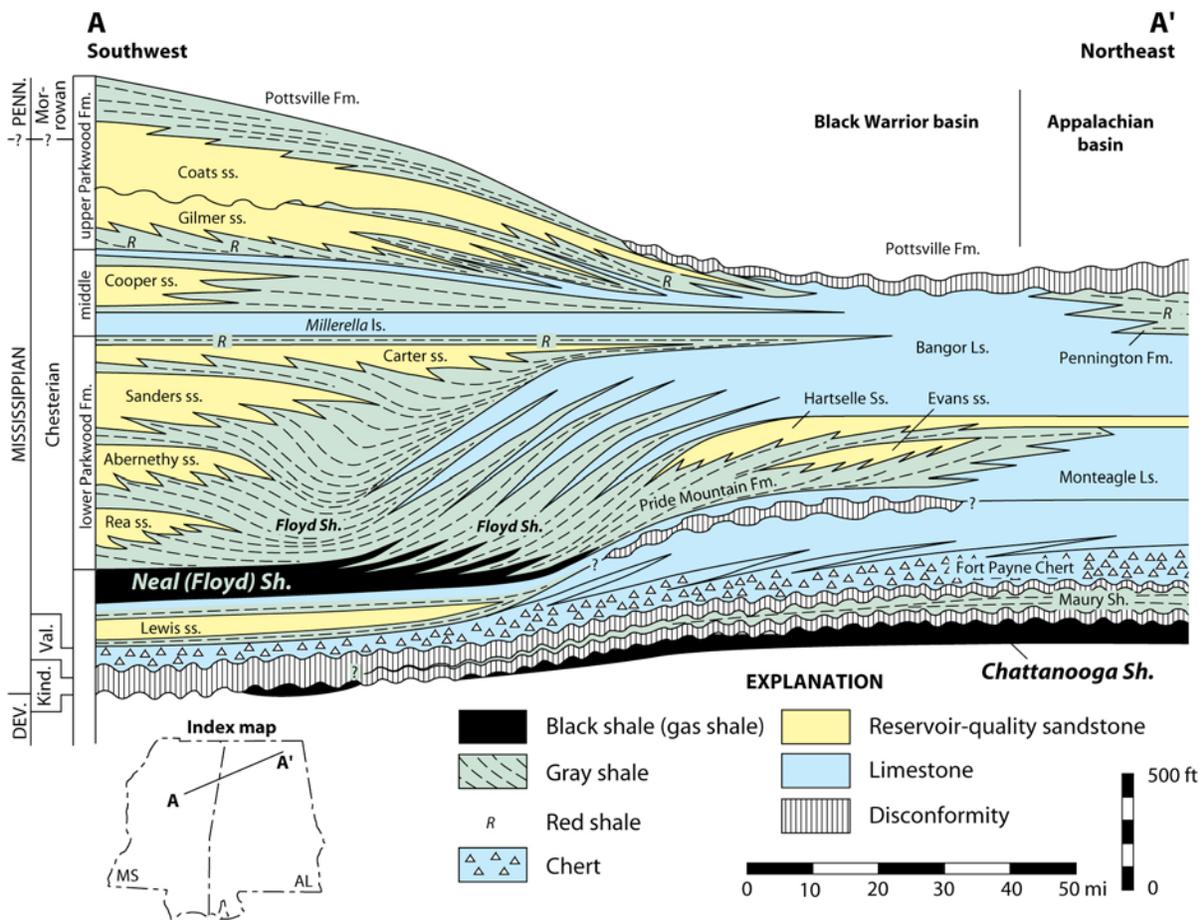


Figure 4.—Regional stratigraphic cross section of Devonian-Mississippian strata of the Black Warrior Basin showing the Chattanoga Shale and Floyd (Neal) Shale (modified from Pashin, 1994).

structurally complex shale formation from which gas production has been established. The Conasauga differs from other gas shale formations in several respects. The productive lithology is thinly interbedded shale and micritic limestone that can contain more than 3% total organic carbon.

The Conasauga is of Middle Cambrian age and can be characterized as a shoaling-upward succession in which shale passes vertically into a broad array of inner ramp carbonate facies. The shale was deposited on the outer ramp, and the shale is thickest in basement grabens that formed during late Precambrian to Cambrian Iapetan rifting (Thomas et al., 2000).

The shale facies of the Conasauga is part of the weak lithotectonic unit that hosts the basal detachment of the Appalachian Thrust Belt in Alabama (Thomas, 2001; Thomas and Bayona, 2005) (fig. 3). The shale has been thickened tectonically into antiformal stacks that have been interpreted as giant shale duplexes, or mushwads, by Thomas (2001). In places, the shale is thicker than 8,000 feet, and the shale is complexly folded and faulted at outcrop scale.

Surface mapping and seismic exploration reveal that at least three Conasauga antiforms are preserved in the Alabama Appalachians (fig. 5). Exploration has focused primarily on the southeastern portion of the Gadsden antiform, which is in St. Clair and Etowah Counties. The Palmyer and Bessemer antiforms constitute the core of the Birmingham anticlinorium. The Palmyer and Bessemer structures are overlain by a thin roof of brittle Cambrian-Ordovician carbonate rocks, and Conasauga shale facies are exposed locally. The Palmyer structure is in the heart of the Birmingham metropolitan area and thus may be difficult to develop, whereas the southwestern part of the Bessemer structure is in rural areas and may be a more attractive exploration target. Additional thick shale bodies may be concealed below the shallow Rome thrust sheet in Cherokee and northeastern Etowah Counties (Maher, 2002) and perhaps in adjacent parts of Georgia (Mittenthal and Harry, 2004).

Development of Conasauga gas resources is still in an early stage, and 18 wells have been drilled, 13 wells are active, and Big Canoe Creek Field has been established as the state's first shale gas-field. The principal challenges facing development are drilling and completion. Wells are deviated substantially toward the northwest, which reflects the predominant southeastern dip of the Conasauga Formation along the southeast margin of the Gadsden structure. Small-scale deformation contributes to the difficulty of drilling, and some fracture zones are highly pressured with gas. The thinly interbedded shale and micrite can be reactive with fluids, thus care must be exercised to avoid formation damage during drilling and completion. The production performance of the wells is highly variable, and operators are investigating methods to optimize production through hydrofracturing and other drilling and completion techniques.

DEVONIAN SHALE

Natural gas has been produced from Devonian shale since the early part of the 20th Century, yet the potential for gas production from Devonian shale in Alabama is just beginning to be realized. Two stratigraphic intervals are prospective in the Devonian section of the Black Warrior Basin and the Appalachian Thrust Belt. Operations are underway in the Chattanooga Shale, which is an extremely widespread black shale unit that is equivalent to proven gas shale formations in the Ohio Shale of the Appalachian Basin, the Antrim Shale of the Michigan Basin, and the Woodford Shale of the Arkoma Basin. Potential also exists in pre-Chattanooga Devonian strata of the Appalachian Thrust Belt in a thick section of interbedded shale, limestone, and chert.

The Chattanooga Shale (fig. 4) is widespread in the Black Warrior Basin and has been considered as a rich oil shale formation (Rheams and Neathery, 1988). The Chattanooga sits within the thermogenic gas window in much of the Black Warrior Basin (Carroll et al., 1995) and may thus contain significant prospects for natural gas. The Chattanooga disconformably overlies Ordovician through Devonian strata, and the time value of the disconformity increases northward (Kidd, 1975; Thomas, 1988). The

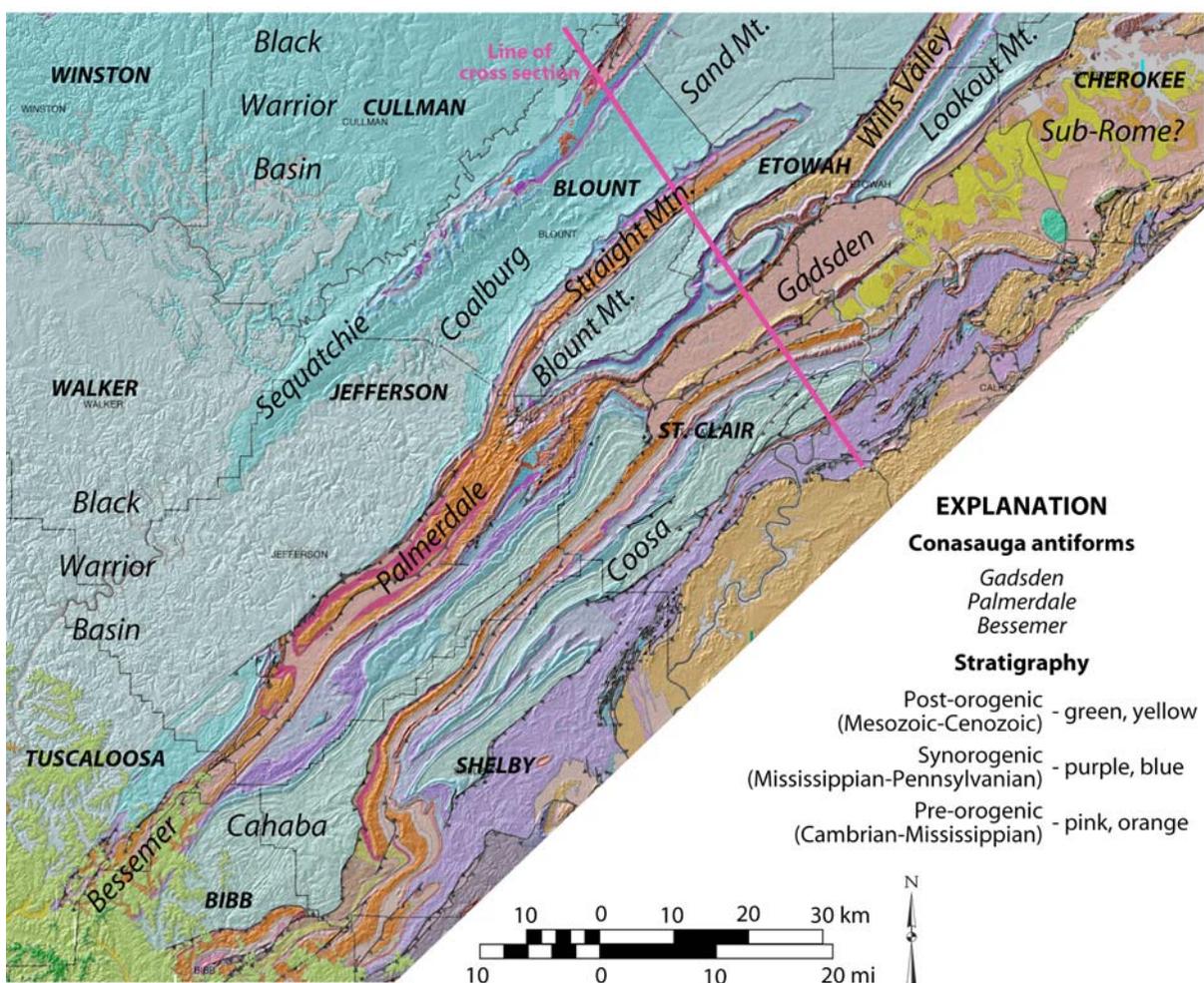


Figure 5.—Geologic map showing major structures and location of Conasauga antiforms in the Appalachian Thrust Belt of Alabama.

Chattanooga is overlain sharply by the Lower Mississippian Maury Shale, which is commonly thinner than 2 feet, and the Maury is in turn overlain by the micritic Fort Payne Chert. The Chattanooga Shale in Alabama was apparently deposited in dysoxic to anoxic subtidal environments and can be considered as a cratonic extension of the Acadian foreland basin (e.g., Etensohn, 1985).

An isopach map demonstrates that the thickness of the Chattanooga varies significantly within the Black Warrior Basin (fig. 6). The shale is thinner than 10 feet and is locally absent in much of Lamar, Fayette, and Pickens Counties, which is the principal area of conventional oil and gas production in the Black Warrior Basin. For this reason, the Chattanooga has not been considered to be the principal source rock for the conventional oil and gas reservoirs in this area. The shale is thicker than 30 feet in a belt that extends northwestward from Blount County into Franklin and Colbert Counties. A prominent depocenter is developed along the southwestern basin margin in Tuscaloosa and Greene Counties. Here, the shale is consistently thicker than 30 feet and is locally thicker than 90 feet.

Geomet, Incorporated, has begun developing natural gas resources in the Chattanooga Shale at depths between 1,600 and 2,100 feet in Blount and Cullman Counties. Initial production rates from vertical wells are as high as 160 Mcfd, which indicates that significant economic potential exists in this area. Interestingly, Geomet's operations are near where the Chattanooga is exposed along the

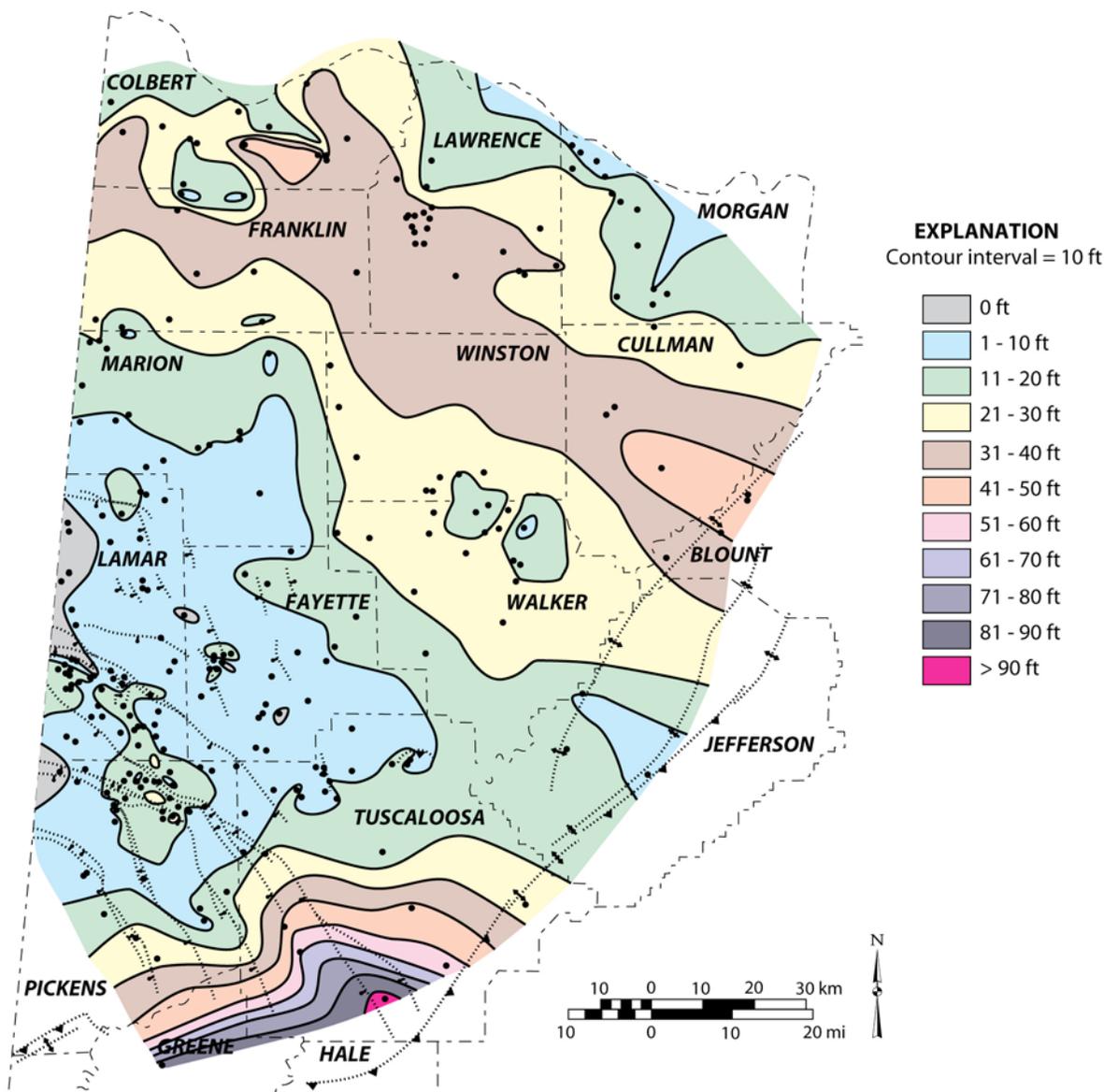


Figure 6.—Isopach map of the Chattanooga Shale in the Black Warrior Basin of Alabama.

Sequatchie anticline, which is a zone of hydrologic recharge. Hydrologic recharge has resulted in significant late-stage biogenic gas accumulations in the Antrim Shale of the Michigan Basin (Martini et al., 1998), and late-stage biogenic gas has been identified in coal along the Appalachian frontal structures in Alabama (Pashin, 2007). The Chattanooga Shale is in some respects analogous to the Barnett Shale of the Fort Worth Basin in that it is an organic-rich black shale bounded by thick, mechanically stiff limestone units that may help confine induced hydrofractures within the shale (Hill and Jarvie, 2007; Gale et al., 2007). Because the Chattanooga is relatively thin, horizontal drilling combined with controlled hydrofracturing may maximize production rates.

In Greene County, EOG Resources, Incorporated, drilled a well (Bayne-Etheridge 36-9 #1) that reached a total depth of 9,514 feet and encountered a major gas show in a thick, unnamed Devonian succession of interbedded shale, limestone, and chert that is significantly older than the Chattanooga Shale. The Devonian section was intersected in the backlimb of a large ramp anticline that had been

explored previously by Arco and Amoco in the 1980s. A dipmeter log indicates that the blacklimb of the anticline dips about 20° toward the southeast. A bimodal dip pattern indicates that parasitic folds are developed in the unnamed Devonian section, and perhaps fracturing associated with these folds contributed to the gas show. The well was hydrofractured with CO₂ foam, achieved a production rate of 120 Mcfd, and is currently shut in. Although the well may be subeconomic, it confirms that substantial oil and gas potential remains in the Appalachian Thrust Belt beyond the traditional exploration targets. Innovative drilling and completion technologies, moreover, may prove useful for unlocking the economic potential of the unnamed Devonian shale section in the thrust belt.

NEAL (FLOYD) SHALE

The Mississippian Floyd Shale is an equivalent of the prolific Barnett Shale of the Fort Worth Basin and the Fayetteville Shale of the Arkoma Basin and has thus been the subject of intense interest. The Floyd is a broadly defined formation that is dominated by shale and limestone and extends from the Appalachian Thrust Belt of Georgia to the Black Warrior Basin of Mississippi.

Usage of the term, Floyd, can be confusing. In Georgia, the type Floyd Shale includes strata equivalent to the Tuscumbia Limestone, and in Alabama and Mississippi, complex facies relationships place the Floyd above the Tuscumbia Limestone, Pride Mountain Formation, or Hartselle Sandstone and below the first sandstone in the Parkwood Formation (fig. 4). Importantly, not all Floyd facies are prospective as gas reservoirs. Drillers have long recognized a resistive, organic-rich shale interval in the lower part of the Floyd Shale that is called informally the Neal shale (Cleaves and Broussard, 1980; Pashin, 1994). In addition to being the probable source rock for conventional oil and gas in the Black Warrior Basin, the Neal has the greatest potential as a shale-gas reservoir in the Mississippian section of Alabama and Mississippi. Accordingly, usage of the term, Neal, helps specify the facies of the Floyd that contains prospective hydrocarbon source rocks and shale-gas reservoirs.

The Neal shale is developed mainly in the southwestern part of the Black Warrior Basin and is in facies relationship with strata of the Pride Mountain Formation, Hartselle Sandstone, the Bangor Limestone, and the lower Parkwood Formation (fig. 4). The Pride Mountain-Bangor interval in the northeastern part of the basin constitutes a progradational parasequence set in which numerous stratigraphic markers can be traced southwestward into the Neal shale (Pashin, 1993). Individual parasequences tend to thin southwestward and define a clinoformal stratal geometry in which nearshore facies of the Pride Mountain-Bangor interval pass into condensed, starved-basin facies of the Neal shale. Interestingly, the Neal maintains the resistivity pattern of the Pride Mountain-Bangor interval, which facilitates regional correlation and assessment of reservoir quality at the parasequence level.

The Neal shale and equivalent strata were subdivided into three major intervals, and isopach maps were made to define the depositional framework and to illustrate the stratigraphic evolution of the Black Warrior Basin in Alabama (Pashin, 1993). The first interval includes strata equivalent to the Pride Mountain Formation and the Hartselle Sandstone and thus shows the early configuration of the Neal basin (fig. 7). The Pride Mountain-Hartselle interval contains barrier-strandplain deposits (Cleaves and Broussard, 1980; Thomas and Mack, 1982). Isopach contours define the area of the barrier-strandplain system in the northeastern part of the basin, and closely spaced contours where the interval is between 25 and 225 feet thick define a southwestward slope that turns sharply and faces southeastward in western Marion County. The Neal starved basin is in the southwestern part of the map area, where this interval is thinner than 25 feet.

The second interval includes strata equivalent to the bulk of the Bangor Limestone (fig. 8). A generalized area of inner ramp carbonate sedimentation is defined in the northeastern part of the map area where the interval is thicker than 300 feet. Muddy, outer-ramp facies are concentrated where this interval thins from 300 to 100 feet, and the northeastern margin of the Neal starved basin is marked by

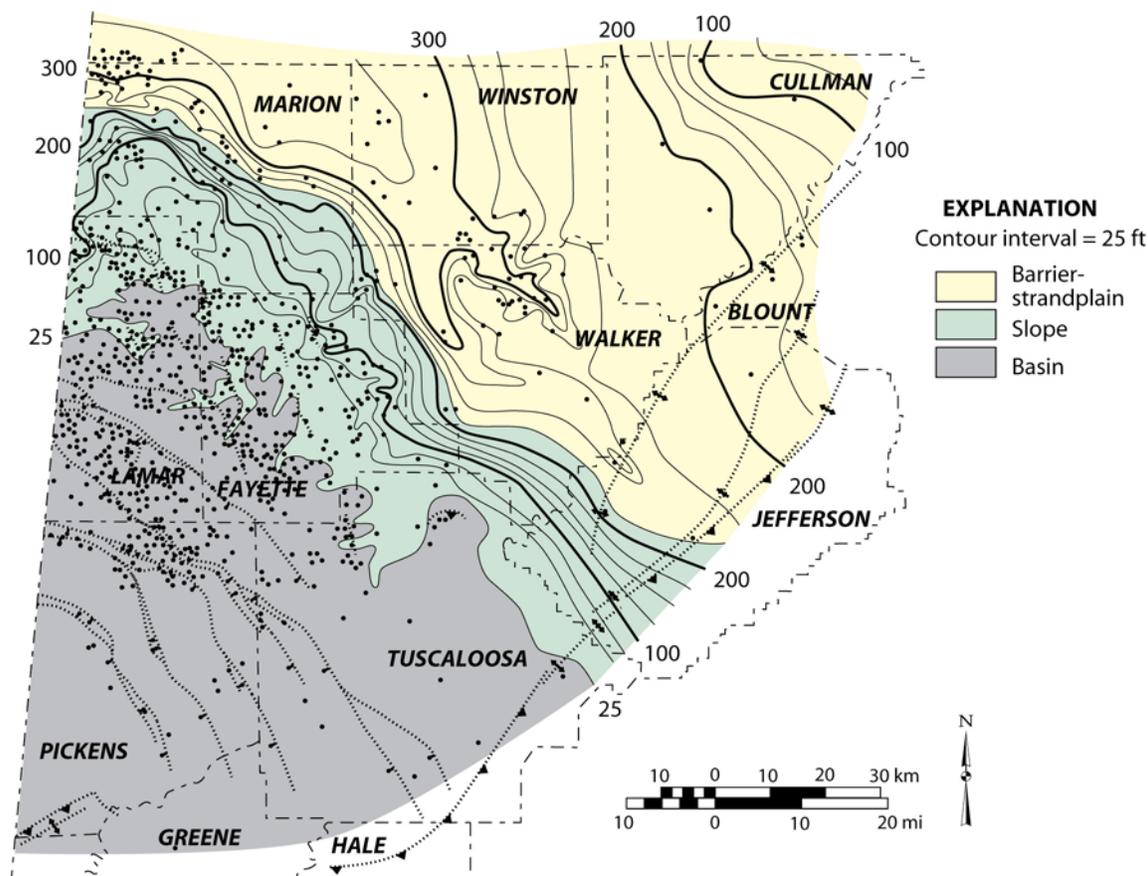


Figure 7.—Isopach map of the Pride Mountain Formation, Hartselle Sandstone, and equivalent strata in the Neal shale in the Black Warrior basin of Alabama (modified from Pashin, 1993).

the 100-foot contour. Importantly, this interval contains the vast majority of the prospective Neal reservoir facies, and the isopach pattern indicates that the slope had prograded more than 25 miles southwestward during Bangor deposition.

The final interval includes strata equivalent to the lower Parkwood Formation (fig. 9). The lower Parkwood separates the Neal shale and the main part of the Bangor Limestone from carbonate-dominated strata of the middle Parkwood Formation, which includes a tongue of the Bangor that is called the *Millerella* limestone (fig. 4). The Lower Parkwood is a succession of siliciclastic deltaic sediment that prograded onto the Bangor ramp in the northeastern part of the study area and into the Neal basin in the southern part and contains the most prolific conventional reservoirs in the Black Warrior Basin (Cleaves, 1983; Pashin and Kugler, 1992; Mars and Thomas, 1999). The lower Parkwood is thinner than 25 feet above the inner Bangor ramp and includes a variegated shale interval containing abundant slickensides and calcareous nodules, which are suggestive of exposure and vertic soil formation. The area of deltaic sedimentation is where the lower Parkwood is thicker than 50 feet and includes constructive deltaic facies in the Neal basin and destructive, shoal-water deltaic facies along the margin of the Bangor ramp. In the southern part of the study area, the 25-foot contour defines a remnant of the Neal basin that persisted through lower Parkwood deposition. In this area, condensation of lower Parkwood sediment brings middle Parkwood carbonate rocks within 25 feet of the resistive Neal shale.

Several wells have been drilled in search of natural gas in the Neal Shale of Alabama, but to date, these wells have achieved limited success. All wells have been drilled where the Neal sits within the

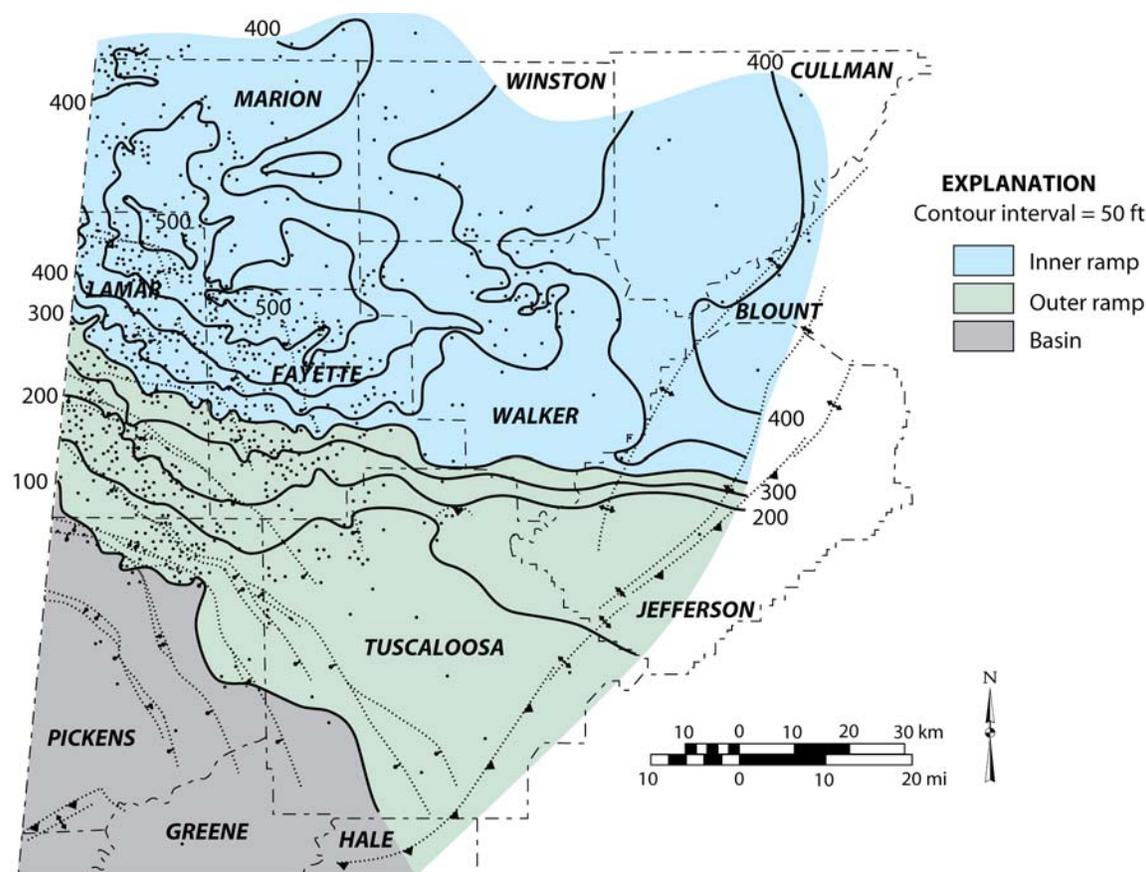


Figure 8.—Isopach map of the Bangor Limestone and equivalent strata in the Neal shale of the Black Warrior Basin in Alabama (modified from Pashin, 1993).

thermogenic gas window, and isolation from fresh-water recharge suggests that only thermogenic gas is present. Thus far, only vertical wells have been drilled, and horizontal wells may be required because of limited reservoir thickness. Some Floyd wells have not penetrated the Neal starved basin facies, whereas others have been drilled in proximity to normal faults, which has been an unsuccessful strategy in the Barnett Shale (Hill and Jarvie, 2007). It is unclear whether the organic-poor gray shale above the Neal is an effective barrier to hydrofractures. One strategy that has not been attempted yet is to develop the shale where middle Parkwood carbonate rocks are within 25 feet of the Neal Shale and may form an effective hydrofracture barrier. Condensation of the lower Parkwood section in this area further helps maximize the stratigraphic range of potential reservoir facies in the Neal basin.

SUMMARY AND CONCLUSIONS

Multiple gas shale plays are emerging in the Black Warrior Basin and Appalachian thrust belt of Alabama and present diverse opportunities for exploration and development. Prospective formations include the Middle Cambrian Conasauga Formation, Devonian shale units that include the Chattanooga Shale, and the Upper Mississippian Floyd Shale.

In the Conasauga Formation, gas is being produced from thinly interbedded shale and limestone that was deposited in outer ramp environments and was deformed into a giant antiformal stack during Appalachian thrusting. Similar antiformal stacks are developed in other parts of the Appalachian Thrust

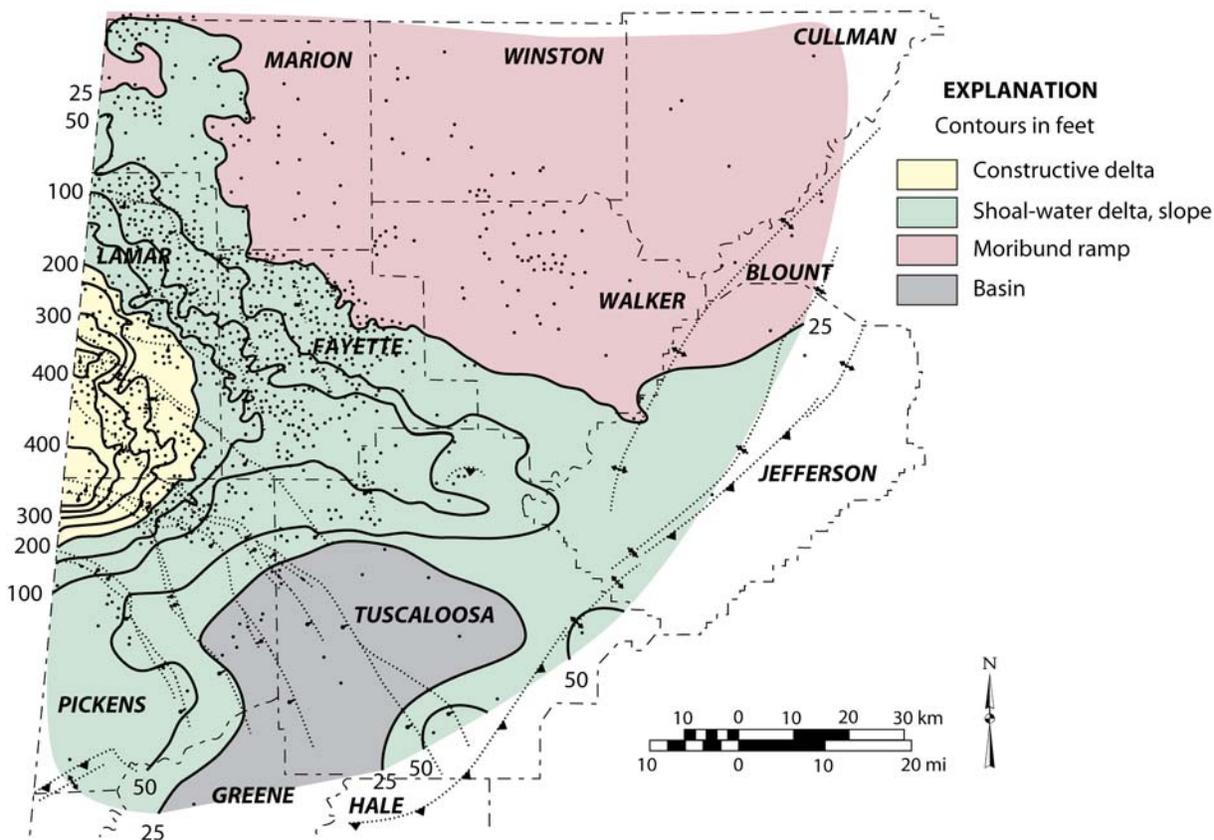


Figure 9.—Isopach map of the lower Parkwood Formation and equivalent strata in the Neal shale of the Black Warrior Basin in Alabama (after Pashin, 1993).

Belt and may be prospective for development. The Chattanooga Shale was deposited in a large euxinic basin during Devonian time and is being developed in the northeastern Black Warrior Basin where it is more than 30 feet thick. A depocenter where thickness of the shale exceeds 90 feet is developed in the southeastern part of the basin and has yet to be explored. In the thrust belt, a major gas show has been discovered in a pre-Chattanooga Devonian section containing interbedded shale, limestone and chert. The Neal shale is an Upper Mississippian starved-basin deposit that is considered to be the principal source rock for conventional hydrocarbons in the Black Warrior Basin and is being explored as a gas reservoir in the area containing most of the basin's conventional reserves.

Critical challenges that face Alabama's fledgling shale-gas industry are understanding basic reservoir properties, working with structural complexity, and optimizing production from formations with variable reservoir thickness and heterogeneity. In the Conasauga Formation, a major resource base has been identified, and keys to commercialization are understanding the interplay between pressurized fracture zones and gas storage in rock matrix, as well as the determination of best practices for drilling and completion. Similar challenges face development of the pre-Chattanooga Devonian section in the thrust belt, where dipping structural panels with parasitic folds offer potential. Limited reservoir thickness is a major challenge in the Black Warrior Basin, and vertical wells in the Chattanooga Shale are quite promising. Understanding the geomechanical properties of Chattanooga and Neal shale and their bounding units will aid in well design. For example, horizontal drilling and completion techniques like those that have been successful in the Barnett Shale may be transferable to the Chattanooga and Neal plays but have yet to be attempted in the Black Warrior Basin of Alabama. Indeed, Alabama's shale-gas

industry is in its infancy, and innovative approaches to reservoir characterization and development are required to unlock the full potential that lies in such a geologically varied array of prospects.

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