OUTCROP CHARACTERISTICS OF ASPHALTIC LEWIS SANDSTONE, BLACK WARRIOR BASIN, ALABAMA: APPLICATION TO SUBSURFACE STUDIES OF RESERVOIR HETEROGENEITY

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Ernest A. Mancini
State Geologist

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By

Jack C. Pashin and Ralph L. Kugler

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Outcrop Characteristics of Asphaltic Lewis Sandstone, Black Warrior Basin, Alabama: Application to Subsurface Studies of Reservoir Heterogeneity

Jack C. Pashin and Ralph L. Kugler
Geological Survey of Alabama
Tuscaloosa, Alabama

INTRODUCTION

Much additional oil may be produced from the Black Warrior basin using improved recovery strategies, especially from fields where production is now declining. Characterizing reservoir heterogeneity may provide information regarding how improved recovery strategies, such as waterflooding, injection, strategic well placement, and infill drilling, can best be applied (Weber, 1986). Mississippian strata in the Black Warrior basin of Alabama are rich in asphalt (Wilson, 1987), and outcrops provide instructive transects of fossil oil reservoirs. Exceptional exposures of asphaltic sandstone occur in the Lewis interval of the Pride Mountain Formation (Chesterian) in Colbert County (Fig. 1), and they form the basis of this study. Lewis outcrops enable direct observation of sandstone heterogeneity and furnish sedimentologic and petrologic analogs for reservoir heterogeneity of the principal producing subsurface reservoirs in the basin (Lewis sandstone and Carter sandstone). Therefore, characterization of sandstone heterogeneity in outcrops may be advantageous in identifying specific strategies that will facilitate improved recovery of liquid hydrocarbons from Mississippian reservoirs in the Black Warrior basin.

The Lewis interval overlies the Tuscumbia Limestone disconformably and consists of three major units: (1) *Inflatia* beds, (2) Lewis sandstone, and (3) Lewis limestone (Fig. 2) (Pashin and others, 1991). The *Inflatia* beds are the basal Pride Mountain carbonate units that represent transgressive storm deposits and oolite shoals. The Lewis sandstone comprises numerous lensoid, asphaltic quartzarenite bodies that are encased in clay shale. In Colbert County, the sandstone represents regressive deposits, including storm-dominated shelf sand patches and chenier-like beach-barrier systems. Some of the beach systems evidently formed as shelf-sand bodies that were exposed and reworked in a mesotidal shore zone. The Lewis

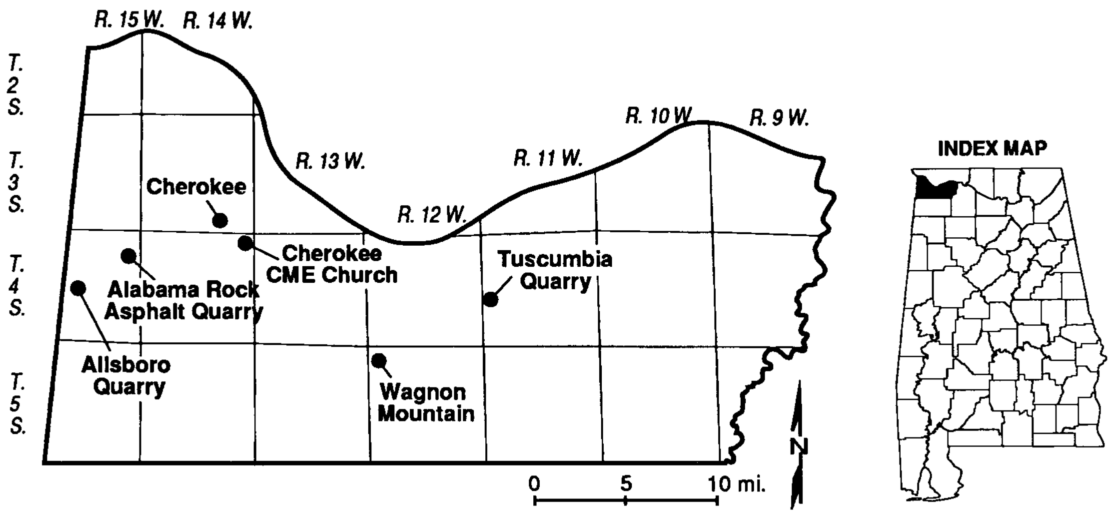

Figure 1. Map of study area showing location of outcrops of asphaltic Lewis sandstone, Colbert County, Alabama.

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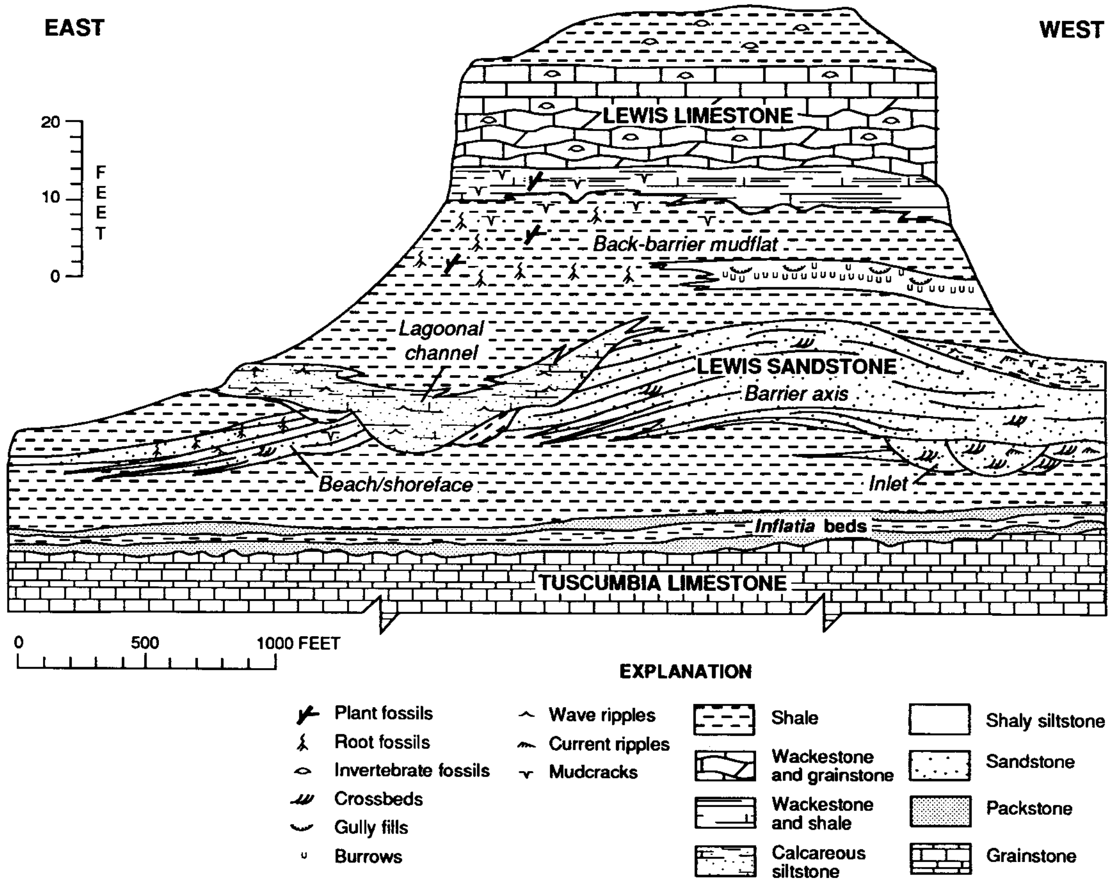

Figure 2. Outcrop diagram showing facies heterogeneity in Lewis sandstone beach-barrier deposits, Tuscumbia quarry.

limestone forms the top of the Lewis interval and represents transgressive carbonate sedimentation in a spectrum of intertidal to open-marine environments (DiGiovanni, 1984). Relict topography inherited from sea-floor and shore-zone evolution was a critical control on the facies architecture of the Lewis limestone (Pashin and others, 1991).

Reservoir heterogeneity can be classified according to scale of observation. The broadest scale of heterogeneity (level 1) is the reservoir; namely, a body of reservoir rock that is surrounded by nonreservoir rock. Level-2 heterogeneity occurs among wells, whereas level-3 heterogeneity, or interwell heterogeneity, occurs between wells. Level-4 heterogeneity occurs at the scale of a core or wellbore, and level-5 heterogeneity occurs at the scale of pores and pore throats. Lewis sandstone reservoirs are the result of an elaborate interplay of depositional and diagenetic variables that operated from microscopic to megascopic scale. This report relates sedimentologic and petrologic outcrop data to the five levels of sandstone heterogeneity.

RESULTS

Level-1 heterogeneity is a primary control on the producibility of Lewis oil, because the sandstone comprises small, isolated bodies of reservoir rock that are confined vertically and laterally by impermeable shale (Fig. 2). Bitumen-rich sandstone bodies were observed only in beach facies, but major subsurface oil production in the Lewis sandstone is from storm-dominated-shelf facies (Holmes, 1981). Improved recovery operations, such as injection, can utilize margins of reservoir sandstone bodies to confine flow and to direct the migration of oil toward desired extraction points.

Well spacing in Black Warrior basin oil fields is typically between 40 and 80 acres, so level-2 heterogeneity was observed only in the most extensive exposures, such as the Tuscumbia quarry (Fig. 2). In the Lewis sandstone, level-2 heterogeneity is related to cementation patterns and facies continuity. Ferroan-carbonate cement predominates at the margins and particularly at the bases of beach-sandstone bodies (Fig. 3). Therefore, oil

Figure 3. Interlaminated asphaltic (dark) and carbonate-cemented (light) sandstone, Allsboro quarry.

may be least mobile at the edges of the barrier-sandstone bodies and most mobile along the barrier axes. Subsurface studies of heterogeneity in beach-barrier sandstone indicate that porosity, permeability, and oil production are greatest along barrier axes (Sharma and others, 1990). Using infill drilling in tandem with acidizing along sandstone-body margins may optimize oil recovery from Lewis reservoirs by dissolving carbonate permeability barriers.

Level-3 heterogeneity, or interwell heterogeneity, is readily observed in Lewis outcrops. The most significant level-3 heterogeneity occurs in inlet- and lagoonal-channel facies (Fig. 2). Inlet-channel fills contain abundant asphalt, but the fills extend in cross section for only 4–25 ft and contain ferroan-carbonate cement along the margins. Therefore, inlet facies may be difficult to predict in the subsurface without the aid of stochastic models, and mobility of hydrocarbons is probably limited. However, the channel fills probably form linear to sinuous shoestrings in longitudinal section, and the asphalt deposits may thus be tubular. A tubular geometry suggests that liquid hydrocarbons can be mobilized along channel axes, thereby improving recovery. An alternative recovery method may involve a fracture design that promotes migration of hydrocarbons from the inlet facies into the beach axis. Lagoonal channels are filled with mud and silt, and are major permeability barriers that can compartmentalize reservoirs. These channels have limited width and are thus difficult to identify using well logs.

The distribution of ferroan-carbonate cement, clay laminae, and primary sedimentary structures is the dominant control on level-4 heterogeneity in the Lewis sandstone. Carbonate-cemented interlaminae occur in most asphaltic-sandstone bodies (Fig. 3) and are permeability barriers that increase tortuosity of fluid flow or may render oil immobile. Commonly, coarser laminae contain carbonate cement, whereas finer laminae contain asphalt. The coarser laminae were cemented by calcite early in the diagenetic evolution of the sandstone. This cement subsequently was replaced by ferroan calcite and ferroan dolomite/ankerite. Carbonate cementation occurred preferentially along the coarser, more permeable laminae prior to migration of oil into the sandstone. Clay laminae extend for considerable distances in the sandstone and probably restrict vertical flow rather than lateral flow; the laminae probably increase tortuosity and impound oil where they converge along wedge-shaped cross beds. Primary sedimentary structures, such as ripple cross laminae, may also increase tortuosity of flow. Burrows that pierce clay

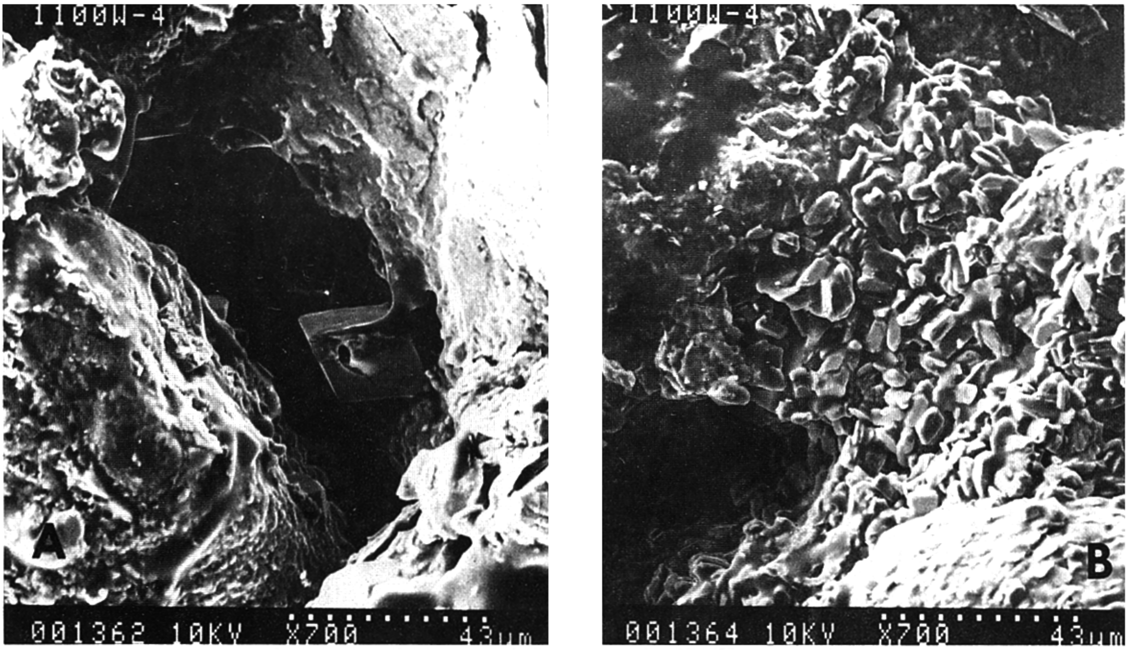

Figure 4. Scanning-electron micrographs of (*A*) macropore containing ferroan-dolomite rhomb and asphalt, Tuscumbia quarry, and (*B*) microporous kaolinite coated with asphalt, Tuscumbia quarry.

laminae may provide interlaminar-flow conduits. However, mixing of mud in sand by bioturbation generally reduces reservoir quality.

Level-5 heterogeneity is dominated by diagenetic factors (Fig. 4). Quartz overgrowths are ubiquitous but do not adversely affect the quality of the best reservoirs. Carbonate cements include early-stage siderite and calcite and late-stage ferroan dolomite/ankerite and ferroan calcite which, in contrast to quartz overgrowths, tend to occlude all pores. Fossils provided nucleation sites for pore-filling calcite which subsequently was replaced by ferroan-carbonate minerals. Pore-filling and grain-replacing kaolinite is microporous but impermeable. The presence of irreducible water in kaolinite should be considered when determining reservoir-water saturation from well logs. Asphalt coats authigenic quartz, carbonate, and kaolinite, thus confirming that oil entered the sandstone bodies late in the diagenetic evolution of the sandstone. At the time hydrocarbons entered the reservoir, the pore system consisted of interconnected, modified primary and secondary macropores between detrital framework grains and ineffective micropores within patches of kaolinite, mud fragments, and clay laminae.

CONCLUSIONS

Heterogeneity in the Lewis sandstone is controlled by depositional and diagenetic processes. The products of these processes are related in that the distribution of authigenic minerals is influenced by depositional texture. The dominant megascopic structures (levels 1–3) that control reservoir continuity and asphalt distribution, particularly the lensoid nature of the sandstone and the presence of inlet- and lagoonal-channel fills, are the result of depositional processes. Diagenetic factors, particularly occlusion of porosity by carbonate cement and authigenic kaolinite, are the dominant mesoscopic and microscopic (levels 3–5) controls on asphalt distribution within the sandstone bodies. Synthesis of outcrop data with the five-level heterogeneity classification provides insight into how lithologic variability affects fluid flow, and thus the producibility of oil from analogous subsurface reservoirs. Diverse depositional and diagenetic controls on heterogeneity in the Lewis sandstone indicate that improved-recovery strategies, such as waterflooding, injection, and strategic well placement, may be tailored to specific depositional and diagenetic reservoir settings to increase oil production from sandstone reservoirs in the Black Warrior basin.

REFERENCES CITED

DiGiovanni, Marcel, Jr., 1984, Stratigraphy and depositional environments of the lower Pride Mountain Formation (Upper Mississippian) in the Colbert County area, northwest Alabama: University of Ala-

bama, Tuscaloosa, unpublished M.S. thesis, 144 p.
Holmes, J. W., 1981, The depositional environment of the Mississippian Lewis sandstone in the Black Warrior basin of Alabama: University of Alabama, Tuscaloosa, unpublished M.S. thesis, 172 p.
Pashin, J. C.; Osborne, W. E.; and Rindsberg, A. K., 1991, Characterization of sandstone heterogeneity in Carboniferous reservoirs for increased recovery of oil and gas from foreland basins: U.S. Department of Energy Topical Report, Bartlesville, Oklahoma, contract no. DE-FG22-90BC14448, 169 p.
Sharma, Bijon; Honarpour, M. M.; Szpakiewicz, M. J.; and Schatzinger, R. A., 1990, Critical heterogeneities in a barrier island deposit and their influence on various recovery processes: Society of Petroleum Engineers Formation Evaluation, p. 103–112.
Weber, K. J., 1986, How heterogeneity affects oil recovery, *in* Lake, L. W.; and Carroll, H. B., Jr. (eds.), Reservoir characterization: Academic Press, Orlando, p. 181–222.
Wilson, G. V., 1987, Characteristics and resource evaluation of the asphalt and bitumen deposits of northern Alabama: Alabama Geological Survey Bulletin 111, 110 p.