Modeling the Burial and Thermal History, Organic Maturation, and Oil Expulsion of the North Louisiana Petroleum System

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EXTENDED ABSTRACT

More than 2.5 billion barrels of oil and 26 trillion cubic feet of gas have been produced from Mesozoic and Cenozoic reservoirs in north Louisiana. Zimmerman (1999) represented the first attempt to model this world-class petroleum system quantitatively, although his efforts were constrained by the paucity of kerogen data and by computer software limitations. The objectives of this present study are to apply kerogen studies and basin-modeling techniques using BasinMod® software to interpret the hydrocarbon potential and thermal maturity of prospective source rocks; to reconstruct the burial history; to constrain the depth and timing of kerogen maturation and hydrocarbon generation; to evaluate the timing of expulsion and the phase of expelled hydrocarbons; and to estimate the total volumes of hydrocarbons that were expelled, migrated, and subsequently accumulated in structural and stratigraphic traps.

Geological interpretations and petrophysical log data for lithologic determinations were provided by 140 control wells and 42 cored sample wells. Smackover (Upper Jurassic) lime mudstones are considered to be the chief source rocks. Visual analyses of Smackover samples indicate that most of the kerogen (70 to 85%) is oil-prone Type-II kerogen, consistent with previous studies (Sassen *et al*., 1987; Sassen and Moore, 1988; Sassen, 1989; 1990) and compatible with a marine origin. Kerogen maturity analyses indicate that the Smackover is mature for oil and gas. Total organic carbon contents range up to 1.5%. However, most of the sample cores are from the upper Smackover, whereas the lower Smackover is considered to have greater source rock potential. Moreover, well penetrations are confined to the updip Smackover; more distal facies that extend downdip beneath the reach of well penetrations are believed to be more prolific source rocks.

BasinMod® software was used to generate a three-dimensional basin model of the Mesozoic through Cenozoic succession in north Louisiana. The 160-m.y. succession was subdivided into 30 time slices represented by 26 depositional events and 4 unconformities. On the Monroe Uplift in north Louisiana, an angular unconformity occurs above the Lower Cretaceous strata, representing up to 4,500 ft of erosion. Burial history analysis indicates that Smackover source rocks on the Monroe Uplift attained maximum burial during the Early Cretaceous, prior to uplift and erosion. Further downdip, away from the Monroe Uplift, the Smackover underwent continuous subsidence and present-day depths represent maximum burial.

The thermal history was modeled based on basement heat flow, representing a more fundamental approach than previous efforts that assumed a constant geothermal gradient since the Late Jurassic. Present-day heat flow was determined using well bottom-

hole temperatures. Kerogen analyses were used to constrain paleoheat flow. The data are consistent with elevated heat flow during Late Triassic to Early Jurassic rifting, followed by exponential decay in heat flow to present-day values, compatible with the rift to drift evolution of this passive margin. On the Monroe Uplift, kerogen samples display higher thermal maturity than expected for the relatively shallow burial depths. Volcanic and igneous intrusive rocks associated with the Monroe Uplift (*e.g*., Kidwell, 1949, 1951; Moody, 1949) yield radiometric age dates (summarized in Byerly, 1991) that indicate Late Cretaceous igneous activity prior to 90 Ma. This is consistent with the abundant volcanic clasts observed in basal sandstones of the Upper Cretaceous Tuscaloosa Formation (Spooner, 1964), demonstrating that volcanism predated Tuscaloosa deposition. Based on this reasoning, a Late Cretaceous thermal event on the Monroe Uplift was explicitly considered in this modeling.

Kerogen data and thermal maturity modeling indicates that the updip Smackover is mature for petroleum and that thermal maturity increases basinward to the south. The downdip Smackover entered the oil window by the Early Cretaceous. Oil expulsion was modeled by assuming that the source rock expelled oil when the pore saturation exceeded the critical saturation threshold, above which the relative permeability of oil exceeds that of water. Critical saturation thresholds were modeled using values between 0.1 and 0.3, consistent with the range of values reported in the literature. This modeling indicates that peak oil expulsion occurred between 110 and 100 Ma at burial depths of 9,000 to 12,000 ft. Peak gas expulsion, both from kerogen and from thermal cracking of oil, was much later and occurred between 50 and 25 Ma, and thus postdates deposition of early Paleocene Midway shales, which form a regional seal.

Estimated expulsed oil volumes using different methodologies range from 250 billion to 2,500 billion barrels; cumulative production thus accounts for less than 1 percent of the total oil. Assuming typical reservoir recovery efficiencies of 25 to 50 percent, the original oil in place accounts for less than 4 percent of the total volumes of oil that were generated and expulsed in the north Louisiana petroleum system. Estimated total gas volumes that were generated from kerogen and from thermal cracking of oil range as high as 4,000 to 8,000 trillion cubic ft; cumulative production thus accounts for less than 1 percent of the total. These estimates indicate there is considerable deep gas (>15,000 ft depth) potential from deeply-buried reservoirs in the Cotton Valley Group and Hosston Formation.

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