International Journal of Coal Geology 131 (2014) 378–391

Contents lists available at ScienceDirect

International Journal of Coal Geology

journal homepage: www.elsevier.com/locate/ijcoalgeo

Organic petrology of the Aptian-age section in the downdip Mississippi Interior Salt Basin, Mississippi, USA: Observations and preliminary implications for thermal maturation history

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ARTICLE INFO

Article history:
Received 30 January 2014
Received in revised form 30 June 2014
Accepted 1 July 2014
Available online 14 July 2014

Keywords:
Solid bitumen
Organic petrology
Thermal maturity
Mississippi Interior Salt Basin
Aptian

ABSTRACT

This study identifies a thermal maturity anomaly within the downdip Mississippi Interior Salt Basin (MISB) of southern Mississippi, USA, through examination of bitumen reflectance data from Aptian-age strata (Sligo Formation, Pine Island Shale, James Limestone, and Rodessa Formation). U.S. Geological Survey (USGS) reconnaissance investigations conducted in 2011–2012 examined Aptian-age thermal maturity trends across the onshore northern Gulf of Mexico region and indicated that the section in the downdip MISB is approaching the wet gas/condensate window (R_o ~1.2%). A focused study in 2012–2013 used 6 whole core, one sidewall core, and 49 high-graded cutting samples (depth range of 13,000–16,500 ft [3962.4–5029.2 m] below surface) collected from 15 downdip MISB wells for mineralogy, fluid inclusion, organic geochemistry, and organic petrographic analysis. Based on native solid bitumen reflectance (R_o generally >0.8%; interpreted to be post-oil indigenous bitumens matured in situ), R_o values increase regionally across the MISB from the southeast to the northwest. Thermal maturity in the eastern half of the basin (R_o range 1.0 to 1.25%) appears to be related to present-day burial depth and shows a gradual increase with respect to depth. To the west, thermal maturity continues to increase even as the Aptian section shallows structurally on the Adams County High (R_o range 1.4 to >1.8%). After evaluating the possible thermal agents responsible for increasing maturity at shallower depths (i.e., igneous activity, proximity to salt, variations in regional heat flux, and uplift), we tentatively propose that either greater paleoheat flow or deeper burial coupled with uplift in the western part of the MISB could be responsible for the thermal maturity anomaly. Further research and additional data are needed to determine the cause(s) of the thermal anomaly.

1. Introduction

Production of gas from shale reservoirs is expected to supply 50% of total U.S. natural gas production by 2040 (U.S. Energy Information Administration, 2013), an increase made possible by the application of horizontal drilling and fracture stimulation technologies (Alexander et al., 2011). The U.S. Geological Survey (USGS) is tasked with the estimation of undiscovered domestic and worldwide shale gas resources and is engaged in research efforts to support this mission (U.S. Geological Survey, 2007). Determination of the geologic controls on shale gas resources requires basic rock-focused information, including the key parameters of thermal maturity, organic richness, and reservoir thickness (Curtis, 2002). However, these types of data are sparse or unavailable in many areas now being explored.

Lower Cretaceous Aptian-age strata in the Gulf of Mexico Basin are current industry targets for development as unconventional 'shale gas' reservoirs. The Aptian-age Pearsall Formation in the Maverick Basin of south Texas (Fig. 1), for example contains a USGS estimated mean undiscovered gas resource of 8.8 TCF with thermal maturity in the dry gas window (Dubiel et al., 2011; Hackley, 2012). Reconnaissance studies outside of the Maverick Basin show that thermal maturity of the Aptian-age section is lower northeast of the San Marcos Arch in Texas (Fig. 1) and eastward toward Florida with the exception of the downdip portion of the Mississippi Interior Salt Basin (MISB) (Enomoto et al., 2012). Enomoto et al. (2012) determined that the Aptian-age section in downdip areas of the MISB is approaching the wet gas condensate stage (vitrinite and solid bitumen R_o values of up to ~1.2%), suggesting that this area may have potential shale gas resources. Petroleum system modeling by Mancini et al. (2008a) indicated that the Mesozoic section in the central and eastern Gulf Coastal Plain has high potential for gas resources and recent horizontal development of the Upper Cretaceous Tuscaloosa Marine Shale as a liquids play (Barrell, 2013) in central Louisiana and southern Mississippi demonstrates potential for development of unconventional petroleum systems in the study area. The current paper evaluates thermal maturity of the Aptian-age section in

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http://dx.doi.org/10.1016/j.coal.2014.07.001
0166-5162/Published by Elsevier B.V.

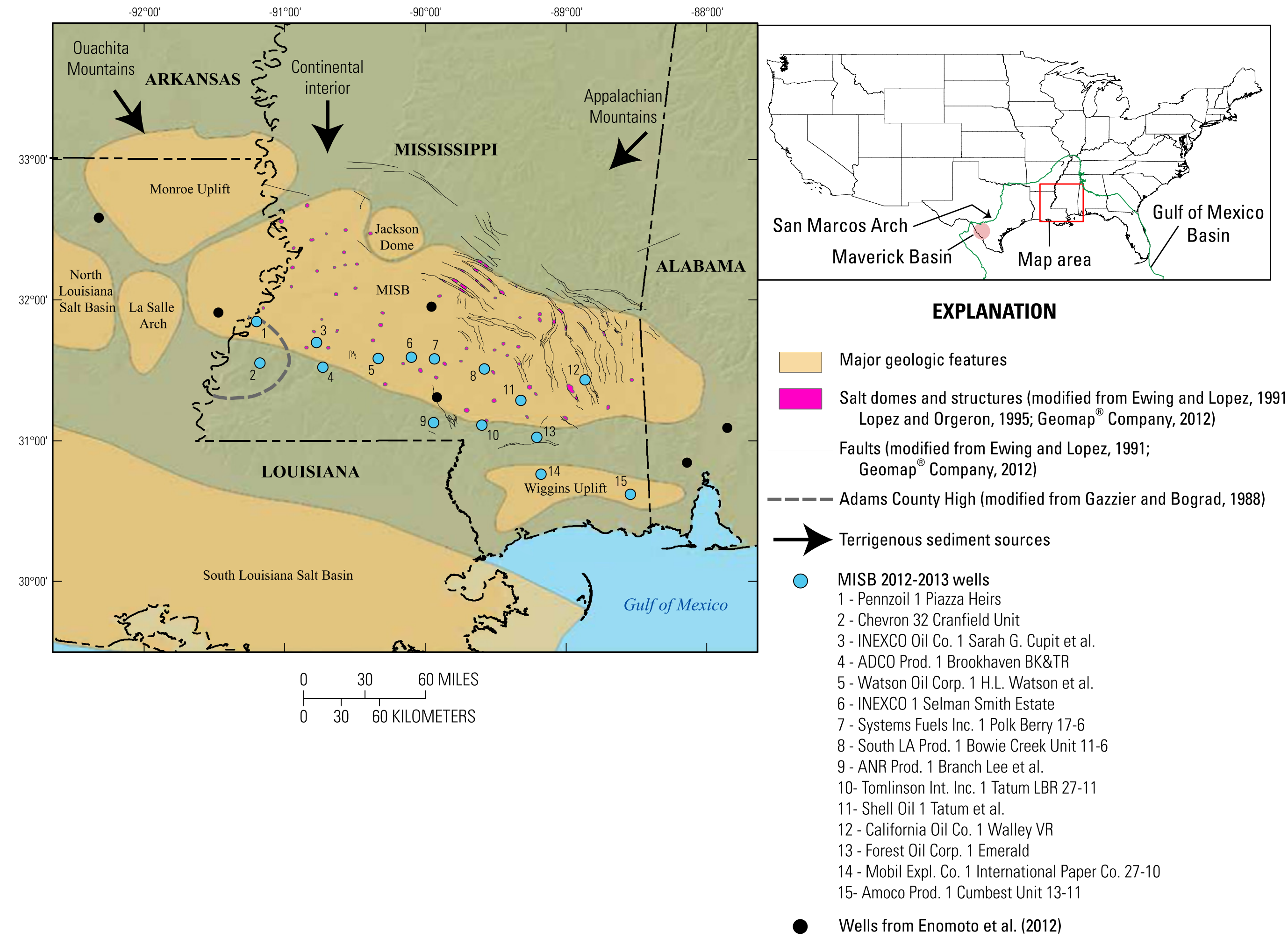

Fig. 1. Map of the Mississippi Interior Salt Basin (MISB) showing 2012–2013 well sample locations, well sample locations from Enomoto et al. (2012), salt domes and structures (modified from Ewing and Lopez, 1991; Geomap® Company, 2012; Lopez and Orgeron, 1995), faults (modified from Ewing and Lopez, 1991; Geomap® Company, 2012), terrigenous sediment sources, Adams County High (modified from Gazzier and Bograd, 1988) and major geologic structures within the region.

the downdip MISB in the context of shale gas potential through focused organic petrographic analyses.

2. Geologic setting and stratigraphy

The MISB extends from southwestern Alabama to northeastern Louisiana and contains numerous salt diapir and pillow structures formed from the underlying Jurassic Louann Salt (Fig. 1). Major geologic structures bounding the MISB include the Monroe Uplift and the Jackson Dome to the north, and the La Salle Arch to the west. The Wiggins Uplift, a relict mass of continental crust of Paleozoic age left behind during Late-Triassic–Jurassic rifting of Pangaea, occurs south of the basin from the southeast to northwest (Dallmeyer, 1989; Ewing, 1991; Mancini and Puckett, 2002). In the southwestern corner and extending downdip of the MISB is a region known as the Adams County High. An area that is relatively void of faulting except where a few relatively high relief anticlinal structures occur (Meylan, 1997).

The Lower Cretaceous Aptian-age section evaluated in this study includes the Sligo Formation (Hauterivian-age at base), Pine Island Shale, James Limestone, and the Rodessa Formation (Albian-age at top) (Fig. 2). In the Early Cretaceous, the northern Gulf of Mexico experienced relative tectonic quiescence (Yurewicz et al., 1993) and a stable rimmed carbonate platform extending from south Texas to Florida developed. This platform was the site for >10,000 ft (>3000 m) of Lower Cretaceous carbonate and evaporite deposition (McFarlan, 1977; McFarlan and Menes, 1991). In Mississippi, sediment influx diluted the carbonate system and proximal clastic rocks grade downdip basinward into carbonates on the outer shelf (Yurewicz et al., 1993). The lowermost unit in the studied section, the Sligo Formation, consists of fine to medium grained shallow marine sandstones with red and gray shales deposited in shoreface and proximal shelf environments (Devery, 1982). Fine-grained terrigenous sediment, draining from the Appalachian and Ouachita mountains, the U.S. continental interior, and adjacent coastal plain sediments during the mid-Aptian-age, put an end to the carbonate dominated system forming the dark gray and black shales interbedded with minor limestone that comprise the Pine Island Shale (Goddard, 2001; Salvador, 1991). Dinkins (1969) placed the Sligo Formation-Pine Island Shale contact at the first occurrence of limestone or interbedded limestone and sandstone in the basal Pine Island. The James Limestone, a fossiliferous limestone (shelf) and dense micrite (deeper waters) formed during recommencement of carbonate deposition over the Pine Island Shale (Forgotson, 1963). Increased rates of subsidence and a supply of fine-grained clastic sediments returned during the Upper Aptian-age, resulting in the deposition of the overlying Rodessa Formation, primarily in semi-restricted lagoonal environments (Forgotson, 1963). The Rodessa Formation is comprised of interbedded clastics and limestone with some anhydrite (Dinkins, 1969; Nunnally and Fowler, 1954). The James Limestone and Pine Island Shale are not continuously present in Mississippi and in some locations the Rodessa Formation directly overlies the Sligo Formation (Dockery, 1996).