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An Examination of the Arkoma Foreland Basin and its Petroleum System through Burial and Thermal History Modeling

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ABSTRACT

The Fayetteville Shale of the Arkoma Basin is an important formation in the history of unconventional natural gas resource plays. From the first well in 2003 to present day, more than 5,680 horizontal wells have been drilled and produced in the Fayetteville resulting in the tremendous growth of Southwestern Energy (SWN) during that period and an explosion in exploration for other black shale gas plays.

The Arkoma Basin is a Carboniferous arcuate foreland basin that spans across west-central Arkansas into southeastern Oklahoma along the northern side of the Ouachita orogenic belt. High levels of thermal maturity are observed in the basin; however, the existence of an extensive post-Pennsylvanian/Permian unconformity has complicated the interpretation and correlation between basin sedimentation, subsidence, and exhumation. In this study, a recently acquired and multifaceted well data set, generously provided by SWN, are used to perform a detailed basin analysis within the eastern portion of the Arkoma Basin. The dense well set from SWN covers nearly 1,400 square miles and is located in the central-western portion of Arkansas. In most cases, the available log curves available for the study include gamma ray, resistivity, density, neutron, spontaneous potential, and sonic logs. Southwestern Energy acquired and provided new thermal calibration data, such as vitrinite reflectance, rock-eval, and Apatite Fission Track Analysis (AFTA) for 23 new localities. Through the calibration with maturity data, fifty 1D models are generated in a geologically coherent basin modeling study. In each well, the synthesis of vitrinite reflectance and AFTA data are used to estimate erosion and heat-flow variations in burial and thermal history reconstructions. To aid the estimation of heat flow in areas lacking data, a regional geothermal gradient map was generated from the corrected bottom-hole temperatures of 229 wells. Structure and isochore maps demonstrating fault configurations and depocenter migration from east to west were produced from formation tops picked at tectonically significant stratigraphic levels (foreland and pre-foreland basin settings) in hundreds of wells.

Within the study area, the calibrated burial and thermal history models indicate that nearly 9,000 to 19,000 feet of section have been removed, with removed overburden thickness increasing to the south. The estimated amount of eroded overburden is in agreement with a geologically realistic framework of previously established stratigraphic thicknesses. To avoid an unrealistic amount of eroded section, the vitrinite reflectance and AFTA data from this study require that paleo-heat flow be higher than present-day heat flow. Paleo-heat-flow values range from 56 mW/m^2 in the south and increase to 78 mW/m^2 in the north of the study area. The Late Paleozoic collision event was the transitional period that changed the condition from a high heat-flow regime to the lower present-day heat flow.

A new regional picture of the thermal maturity in the central-eastern Arkoma Basin resulted from the combination of all reconstructed elements. The constrained thermal histories obtained from calibration data show that the peak source rock maturation of the Carboniferous-Ordovician sequence was between the Late Atokan (~306 Ma) and the Middle Jurassic (165 Ma) time. This corresponds to vitrinite reflectance values of ~1.9 to 3.0 (Ro%), which represents the dry gas to post-mature windows. The E.W. Moore well has been used as a type well for

numerous studies. In this well, all rocks in the stratigraphic section entered the early mature phase of oil generation around the early Permian (~285 Ma). Oil generation was short lived and the rocks reached the oil floor by the middle of the Permian (~265 Ma) as a result of continued burial. By the end of the Permian, maximum paleotemperatures had been reached and the section was within the dry gas window.

These results are consistent with those from previous authors showing that patterns of increasing thermal maturity generally reflect those of increasing depth and erosion. In addition, these authors discussed the presence of anomalous vitrinite reflectance profiles and tried to find a relationship to explain them. The increased data density in this study shows a more regional variation in heat flow and that there are no significant anomalies related to faulting. Although igneous activity existed east of the Arkoma Basin in the Mississippi Embayment during the Cretaceous, AFTA data provide evidence that the thermal history of the Arkoma Basin was not affected by these intrusives. Thus, I attribute these anomalous data points to laboratory error in the measurement of vitrinite reflectance. I conclude that most lateral variations in thermal maturity can be explained by estimates of erosion and a spatially reasonable change in heat flow.