Illite/Smectite Geothermometry of the Proterozoic Oronto Group, Midcontinent Rift System

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Abstract: Characterization of the Nonesuch Formation, middle unit of the Proterozoic Oronto Group, as a potential hydrocarbon source for the Lake Superior basin portion of the Midcontinent Rift system requires an understanding of the thermal maturity of the region and its relationship to the thermal history. Illite/smectite (I/S) expandability data were collected from the Nonesuch Formation and the overlying Freda Sandstone and compared with organic thermal maturity data; both data sets coupled with a thermal and burial history for the White Pine area of Michigan allow regional interpretation of maximum formation temperatures of the Nonesuch Formation and the Freda Sandstone with respect to time. Samples collected from drill holes in northeastern Wisconsin display nearly pure smectite within the lower Freda Sandstone trending abruptly to ordered I/S within the Nonesuch Formation. Regular trends of decreasing expandability with depth occur in four other drill holes to the northeast. Comparison of I/S expandability between similar stratigraphic intervals reveals a significant trend of increasing thermal maturity to the northeast, with the lowest thermal maturities observed in the Iron River Syncline area just west of White Pine, Michigan.

I/S geothermometry suggests maximum temperatures in the Nonesuch Formation of 140 ° C in Wisconsin, 115 ° C in the Iron River Syncline area, 160 ° C at White Pine, and 190 ° C near the southern portions of the Keweenaw Copper District. The geographic pattern of temperatures determined from I/S geothermometry is identical to that determined from organic thermal maturity indicators in the Nonesuch Formation (Imbus *et al.* 1988, 1990; Hieshima and Pratt, 1991; Pratt *et al.*, 1991; Mauk and Hieshima, 1992).

Regular variations in I/S expandability with depth occur in the Freda Sandstone and the Nonesuch Formation near the southern limits of the Keweenaw Copper District. These variations suggest a fossil geothermal gradient of 55 ° C/km and limit the thickness of sediment above the Nonesuch Formation to approximately 3 km. In comparison, 3.6 km of Freda Sandstone are presently exposed near the Wisconsin border, and numerical modeling suggests a range of 4 – 6 km of sediment overlying the Nonesuch Formation. None of the data indicate the presence of the Bayfield Group sediments above the Nonesuch Formation at the time of clay diagenesis. Samples from White Pine suggest a two-stage burial history: 1) clay reaction, possible hydrocarbon maturation, and copper-sulfide mineralization at maximum temperatures above 100 ° C during the main rifting and burial event, followed by 2) fracturing, reverse faulting, and fluid circulation during a rift-terminating compressional event that may have allowed petroleum migration and native copper mineralization at temperatures below 100 ° C Abrupt changes in I/S expandability with depth and the presence of poorly crystalline I/S (greater than 80% expandable) and kaolinite in the Freda Sandstone in Wisconsin appear to represent later overprinting of the diagenetic assemblage by fluids that were probably cooler and of differing composition than earlier diagenetic fluids. However, the authigenic assemblage from the vicinity of White Pine, Michigan, which includes up to 25% expandable I/S, appears to represent a diagenetic profile formed during the main rifting and burial event. Therefore, these expandable I/S-type clays are essentially 1.0 billion years old.

Key Words: Diagenesis • Illite/Smectite • Mineralization • Proterozoic • Retrograde • Thermal history

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