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Stratigraphic Correlation and Geochemical Analysis of Kukersite (Source Rock) Beds within the Ordovician Red River Formation, Southwestern North Dakota

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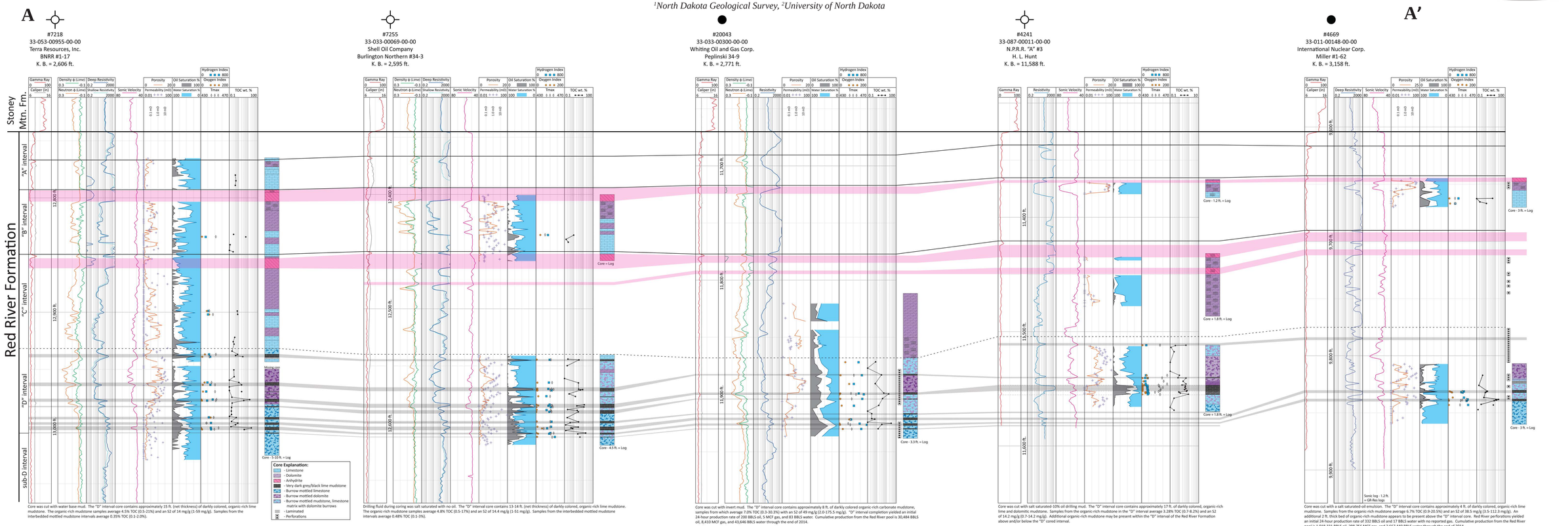

Core was cut with water base mud. The "D" interval core contains approximately 15 ft. (net thickness) of darkly colored, organic-rich lime mudstone. The organic-rich mudstone samples average 4.5% TOC (0.5-21%) and an S2 of 14 mg/g (1-59 mg/g). Samples from the interbedded mottled mudstone intervals average 0.35% TOC (0.1-2.0%).

Drilling fluid during coring was salt saturated with no oil. The "D" interval core contains 13-14 ft. (net thickness) of darkly colored, organic-rich lime mudstone. The organic-rich mudstone samples average 4.8% TOC (0.5-17%) and an S2 of 14.4 mg/g (1-51 mg/g). Samples from the interbedded mottled mudstone intervals average 0.48% TOC (0.1-3%).

Core was cut with invert mud. The "D" interval core contains approximately 8 ft. of darkly colored organic-rich carbonate mudstone, samples from which average 7.0% TOC (0.3-30.3%) with an S2 of 49 mg/g (2.0-175.5 mg/g). "D" interval completion yielded an initial 24-hour production rate of 200 BBLS oil, 5 MCF gas, and 83 BBLS water. Cumulative production from the Red River pool is 30,484 BBLS oil, 8,410 MCF gas, and 43,646 BBLS water through the end of 2014.

Core was cut with salt saturated-10% oil drilling mud. The "D" interval core contains approximately 17 ft. of darkly colored, organic-rich lime and dolomitic mudstone. Samples from the organic-rich mudstone in the "D" interval average 3.28% TOC (0.7-8.2%) and an S2 of 14.2 mg/g (0.7-14.2 mg/g). Additional organic-rich mudstone may be present within the "D" interval of the Red River Formation above and/or below the "D" cored interval.

Core was cut with a salt saturated-oil emulsion. The "D" interval core contains approximately 4 ft. of darkly colored, organic-rich lime mudstone. Samples from the organic-rich mudstone average 6.7% TOC (0.9-20.5%) and an S2 of 38.5 mg/g (3.5-112.3 mg/g). An additional 2 ft. thick bed of organic-rich mudstone appears to be present above the "D" interval core. Red River perforations yielded an initial 24-hour production rate of 332 BBLS oil and 17 BBLS water with no reported gas. Cumulative production from the Red River pool is 1,018,331 BBLS oil, 298,756 MCF gas, and 2,667,440 BBLS water through the end of 2014.

Figure 1. Stratigraphic cross-section of the Red River Formation with core analysis data and illustrated core intervals. Shaded pink intervals represent correlated anhydrite beds and grey shaded intervals represent correlated kukersite (source rock) beds.

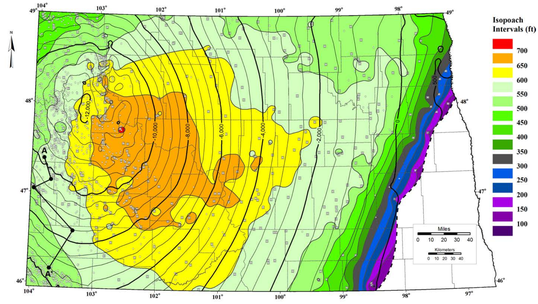

Figure 2. Isopach (color fill) and structure contour (black lines) map of the Red River Formation within North Dakota displaying the Figure 1 cross-section wells (large black circles). Light grey circles and squares represent control wells for the Red River Formation's structure and isopach contours.

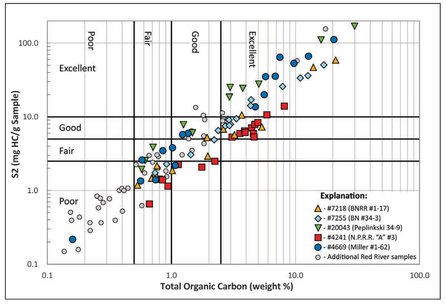

Figure 3. Organic-richness plot of analyzed Red River core samples from North Dakota.

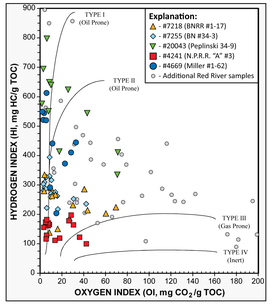

Figure 4. Modified Van Krevelen diagram of analyzed Red River core samples from North Dakota.

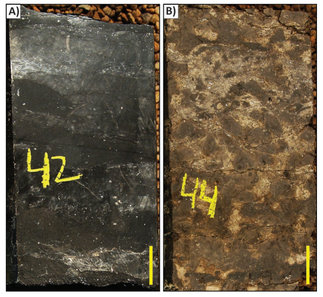

Figure 5. Red River Formation core photographs from International Nuclear Corp's Miller #1-62 (NDIC: 4669, API: 33-011-00148-00-00). A) Organic-rich, kukersite source bed from core depth 9,842 ft., and B) burrow mottled lime mudstone from core depth 9,844 ft. The yellow bar in the bottom right hand corner of each photograph represents 1 inch.

Discussion

Laminations and thin beds of organic-rich mudstone referred to as kerogenites or kukersites have been previously described within the "D" interval (also referred to as the "C" burrowed member) of the Red River Formation (Kendall, 1976; Carroll, 1979; Longman et al., 1983; Stasiuk and Osadetz, 1990; Nordeng, 2014). Longman et al (1983) described 2-6 inch thick, organic-rich marker beds within the "C" burrowed member which he referred to as kerogenites and commented that they can be correlated across much of the basin. Stasiuk and Osadetz (1990) interpreted that the kukersite (kerogonite) beds formed as benthic mats composed of G. Prisca within a subtidal marine water setting. Nordeng (2014) noted that kukersite beds display a negligible gamma ray signature in comparison to adjacent, surrounding organic-lean carbonate beds, which makes identifying these source beds in wireline logs difficult. Therefore, core examination and sampling is necessary to identify and evaluate kukersite source beds within the Red River Formation.

Five Red River Formation cores that extend through the "D" interval from west-central to southwestern North Dakota were examined and sampled for geochemical analysis (Figs. 1-4). Samples were collected preferentially from darker colored, presumably more organic-rich portions of each core (e.g. Fig. 5a) along with a few samples from the lighter colored, presumably organic-lean portions as well (e.g. Fig. 5b). All collected samples were analyzed using LECO TOC, and samples that yielded equal or greater than 0.5 wt. % TOC were analyzed using RockEval 6 pyrolysis.

The majority of samples that contained higher TOC values (>1%) were collected from relatively thin beds of darkly colored, faintly laminated to bioturbated lime mudstone that appear to represent kukersite beds as previously described. The kukersite beds examined, sampled, and correlated during this study typically range from several inches to 2–3 ft. in thickness and are laterally continuous across the "D" interval (Fig. 1). While kukersite beds do not display any notable gamma-ray log response, they display elevated resistivity signatures which are likely the result of higher oil saturations and/or lower porosity than the surrounding burrow mottled carbonate mudstone. The thicker (≥1.5 ft. thick), more organic-rich (<5% TOC) kukersite beds also display elevated wireline log porosity (density and neutron) and sonic travel time signatures when surrounded by low porosity (<2%), organic-lean limestone. The increased organic content lowers the rock density and artificially increases the wireline log porosity signature relative to the surrounding organic-lean limestone (Passey et al., 1990).

Combining the kukersite beds together, the Red River "D" interval contains approximately 6-7 ft. net thickness of source rock within vicinity of the Miller #1-62 well. Further north, towards the deeper portions of the Williston Basin, the "D" interval contains 13-17 ft. net thickness of source rock with overall TOC averages of 3-5%. Tmax values varied within each core sample set, but generally range from 440° to 455° for each of the five cores sampled, indicating all five sampled cores have experienced oil generation at depth.

References

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