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A High Resolution Study of Petroleum Source Rock Variation, Lower Cretaceous (Hauterivian and Barremian) of Mikkelsen Bay, North Slope, Alaska

by
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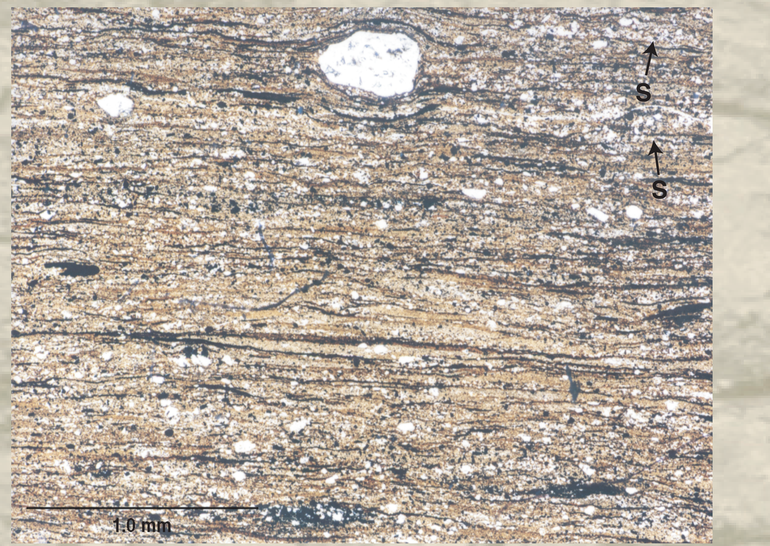
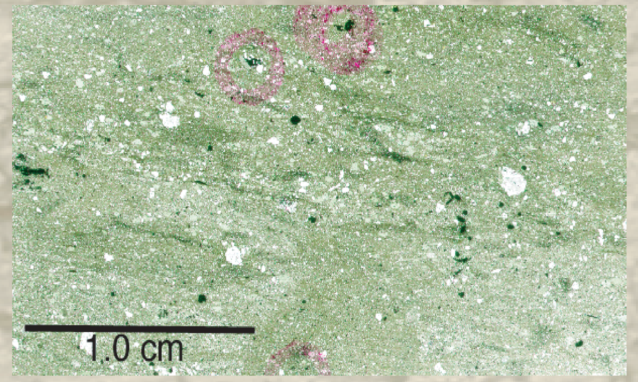
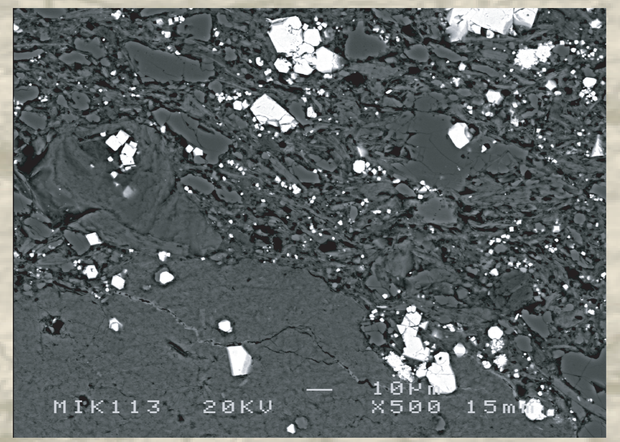
Lithofacies Continued

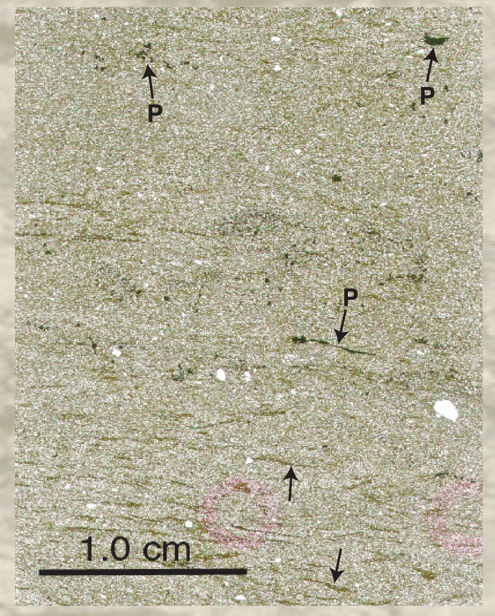


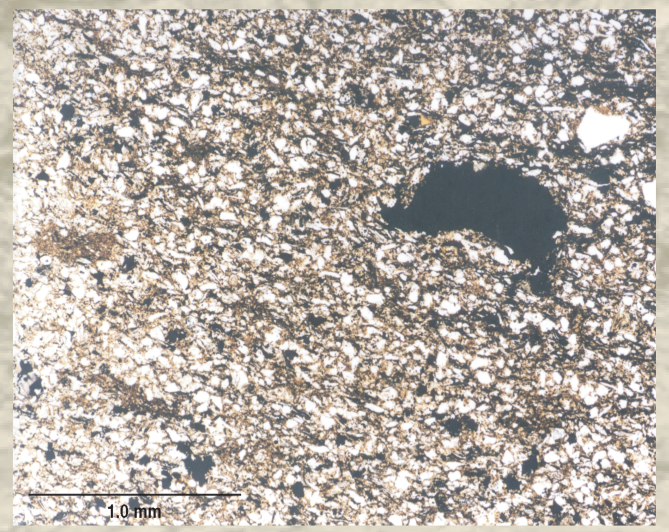
Spl 12. L. Thin section scan of pebble shale unit at core depth 11,662.50 ft showing burrow-mottled, silt and pyrite-bearing clay-rich mudstone with some pyritized flattened burrows (black, see arrows) and floating sand-sized grains. R. Photomicrograph of circled area in scan showing many disrupted laminae and rare silt-filled burrows (arrow + S). Note the prominent floating pitted quartz grain, as well as abundant disseminated pyrite and thin pyrite laminae that are commonly discontinuous.





Spl 11. L. Thin section scan of Kemik Sandstone near the top of this unit at core depth 11,664.00 ft showing bioturbated, glauconite and pyrite-bearing muddy sandstone. Note the absence of bedding features. Center. Photomicrograph showing the bioturbated fabric and wide variation in grain size and shape of both quartz and pyrite. R (above). Backscattered SEM photo showing the larger quartz grains and variation in pyrite (white) form.



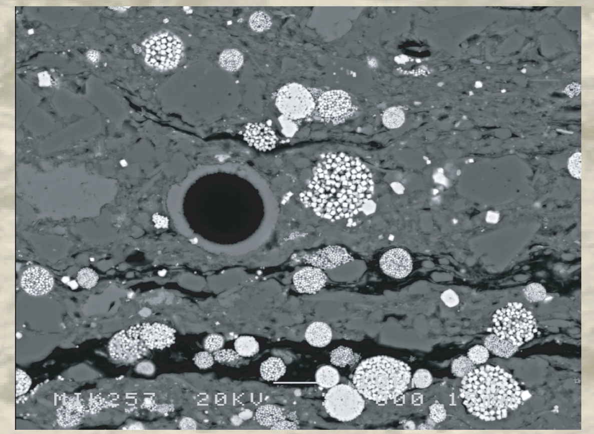


Spl 10. L. Thin section scan of Kemik Sandstone at core depth 11,665.50 ft showing bioturbated fine-grained, pyrite-bearing muddy sandstone with Phycosiphon isp burrows (arrows) and rare floating sand grains composed of quartz. Note structureless fabric and different forms of pyrite (arrow + P -- black small grains, irregular shaped mass in upper right corner, and replacing flattened burrow). R. Photomicrograph of structureless fabric and irregular pyrite grain.

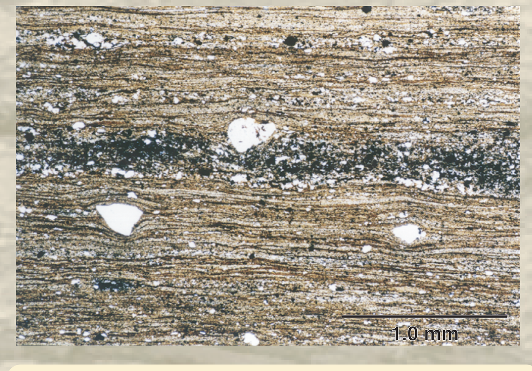
Spl 1. L. Thin section scan of Kemik Sandstone at core depth 11,701.67 ft showing sandstone composed of stacked fining-upward couplets. Each couplet comprises medium-grained sand at its base and fines-upward to muddy fine-grained sandstone. The coarser components are predominantly monocrystalline quartz with minor rock fragments. R. Photomicrograph of the coarser-grained base of a couplet showing quartz with overgrowths, abundant pyrite in the finer fraction, and a prominent rock fragment (lower right corner).

Results - Kemik Sandstone

The base of the sampled succession (11,701.67 ft) is composed of a quartz arenite with minor lithic fragments. This sandstone is thinly bedded (<0.01m). Commonly, each bed fines-upward from medium-grained sand to fine-grained sand (Sample 1). These sands are cemented by a combination of quartz and late carbonate. Overlying these medium to fine-grained sandstones is a succession of massive, bioturbated (Phycosiphon isp.) fine-grained sandstones (Sample 10) that fine-upward to muddy sandstones. The muddy sandstones in this part of the succession contain prominent pyrite nodules. The upper part of the Kemik Sandstone is a pervasively bioturbated, glauconite-rich, muddy sandstone (Sample 11).



Backscattered SEM image of a silt bearing clay-rich mudstone showing a calcisphere approximately 20 microns in diameter (from sample 25) and pyrite framboids predominantly 10 microns or less with a few up to 20 microns. Note framboids particularly associated with organic matter.



Photomicrograph of silt and pyrite-bearing clay-rich mudstone of the pebble shale unit (sample 30). Note individual sharp-based beds that upward-fine from silt-rich laminae to partially bioturbated, pellet-rich clay laminae. Also note the abundant pyrite associated with the coarse-grained part of the prominent bed in the upper part of the photomicrograph and several floating sand-sized grains.

Discussion of Lithofacies

The abrupt grain size change from sandstone to mudstone, coupled with the presence of glauconite, extensive bioturbation, and a thin lag at the contact between the Kemik Sandstone and the overlying mudstone succession (basal part of pebble shale unit) suggest a break in sedimentation associated with a significant increase in the relative length of the sediment transport path over this short interval. These changes are interpreted to have been caused by a marine transgression, with the lag deposit marking a transgressive surface as the environments and resulting facies belts shifted from upper shoreface to offshore transition depositional environments.

The thin (2 - 5 mm) units within the pebble shale unit that have erosive bases and overall fine-upward from silt-rich laminae at their bases to clay-rich pelleted laminae at their tops suggest that mud was episodically deposited subaqueously to form a stacked succession of waning flow deposits (from either storm surge or tidal events). The presence of pellets and bioturbation at the tops of these thin upward-fining units (couplets, see example above) suggests that the surficial layers of sediment were colonized prior to deposition of the next overlying unit and that significant pelletization (presumably biologically mediated) occurred either in the water column or at the sediment-water interface. In spite of their thin parting thickness (< 1 cm) the presence of bioturbation at the tops of these erosive-based, upward-fining units suggests that in genetic terms these thin units are most appropriately described as beds (e.g., Campbell, 1967) rather than laminae as they represent discrete events separated by enough time for bioturbation to occur. Moreover, the presence of bioturbation in these units suggests that the bottom waters were oxic, at least for a short interval after their depositon, rather than being anoxic as might have been inferred from the presence of apparent laminae (based on interpretations derived from hand specimen scale observations).

The preservation of relatively high proportions of organic matter in these mudstones (2 - 6 wt % TOC) coupled with the abundance of pyrite suggests that the sediment pore waters were anoxic/sulfidic below the surface layers (>5 mm). The bedded nature of the pyrite coupled with the unusually small framboid size (commonly 5 μm) might, in many settings, be interpreted as indicating that the water column was anoxic (see Wilkin and others, 1996). This interpretation, however, has to be weighed with the observation that the sediment was partially bioturbated and pelleted and this suggests that sufficient oxygen was available, at least episodically, for the bottom waters and surface sediment layers to be colonized by a macrobenthic, albeit perhaps dysoxic, community.

The majority of this mudstone succession is composed of dioctahedral micas and fine grained silt (composed of quartz and rare carbonate debris). This material was almost certainly derived from a weathered hinterland and transported to the final site of depositon by a combination of fluvial and continental shelf processes (storms and tides). In addition to this fine-grained material, however, there are also the striking rounded coarse sand-sized grains, composed of quartz and a variety of rock fragments. Given their completely different grain size range, relative to the enclosing muddy matrix, and the fact that they are mainly scattered (floating) throughout individual beds rather than concentrated at their bases or in laminae, it is reasonable to suggest that this material was transported to the site of deposition by a different process or processes than those which carried the finer grained components. Given the relatively high lattitude depositional setting of these units we support the proposition that these sand-sized grains could have been transported via ice-rafting (Bird and Molenaar, 1987). Moreover, we believe that sediment supply was not restricted to short delivery episodes but rather that there was a background detrital input, which supplied most of the fine grained material, interspersed with an irregular supply of coarse material via a separate mechanism. Blanchard and Tailleur (1983) note the abundant occurrence of very well rounded aeolian derived, floating quartz grains in Neocomian shale to the west of the Canning River, and Bird and Molenaar (1987) note that the pebble shale unit of the Sadlerochit Mountains contains minor scattered, rounded, and frosted quartz grains. We also noted the presence of these rounded, pitted quartz grains in SEM and in photomicrographs (Samples 12, 16, and 47).

The presence of lapilli tuffs indicates the contribution of some airfall volcanic material to the sediment. The tuff at a core depth of 11,655.33 ft also may be significant because the greatest numbers of both agglutinated foraminifera and radiolaria are found in core samples that include this interval in the well. In addition, the mudstone above the tuff contains the highest total organic carbon, unusually abundant and laterally continuous pyrite bands, 2 thin carbonate-cemented mudstones, and very few floating sand-sized grains. These faunal and organic data suggest that tuff emplacement may have had a significant environmental impact by supplying otherwise limiting nutrients which caused the productivity to increase. The notable lack of floating sand-sized grains in these beds may be a result of dilution of the ice-rafted debris by unusually large amounts of fine-grained detrital sediment delivered to the sediment water interface; or alternatively, it may result from other processes related to the volcanism that in some way inhibited or interrupted ice formation or ice-rafting.

Conclusions

In the Mikkelsen Bay # 1 well, the Kemik Sandstone is predominantly comprised of bioturbated quartz arenites with quartz and late carbonate cements. The overlying mudstone succession of the pebble shale unit and possibly the Hue Shale comprises a variety of mudstone lithofacies including: silt and pyrite-bearing, clay-rich mudstones; clay-rich mudstones; carbonate cement-dominated mudstones; clay-bearing, pyrite-rich mudstones; and lapilli tuff.

The fabric and composition of the mudstones suggests that during their deposition the environment was episodically anoxic/sulfidic. The fundamental controls on this variability may have been linked to variable sediment input (associated with combined fluvial and ice-rafted input), and perhaps short periods of enhanced productivity associated with the relatively high latitude depositional setting of these rocks. Overall, these mudstones are very organic-rich (2 to 6 wt % total organic carbon) in spite of pelleting and partial to thorough bioturbation.

The carbonate-dominated mudstones probably precipitated in the sediment in response to microbially mediated diagenetic processes (sulfate reduction and methanogenesis). The intervals where these cements occur are probably related to breaks in sediment accumulation. The abundance of radiolaria, agglutinated foraminifera, pyrite and organic matter in association with the lapilli tuff suggests that the volcanic material may have been supplying otherwise limiting nutrients to the paleoecosystem.

Rock-Eval data and calculated parameters for the sampled succession in the Mikkelsen Bay State #1 well suggest 3 units that are fairly well stratigraphically confined. These 3 units also have characteristics that are consistent with borehole geophysical log signatures and lithofacies. For the upper part of the Kemik Sandstone, Rock-Eval data indicate that it is a non-source unit that contains migrated hydrocarbons. In the overlying mudstone succession, Rock-Eval data indicate that there are 2 distinct units. The lower part of the pebble shale unit is a type II, oil-prone source rock that is just entering the oil window and hasn't reached peak hydrocarbon generation, whereas the mudstones above it have generated hydrocarbons. These upper mudstones, equivalent to the upper part of the pebble shale unit and possibly the lower part of the Hue Shale, are also probably type II, oil-prone source rocks, but they have already generated hydrocarbons thereby lowering S2, TOC, and HI and relatively increasing S1 values. The original S2 and TOC values for this upper unit were probably closer to or greater than present values for the lower part of the pebble shale unit, suggesting that the kinetics of hydrocarbon generation in the upper unit are faster.

In the North Slope area of this well near Mikkelsen Bay, Rock-Eval data indicate that the Lower Cretaceous mudstone succession, including the pebble shale unit, investigated in this study is oil prone. The one sample that might be interpreted as gas prone is from a weathered sample of the core. Furthermore, the data from this high resolution study show that the lithofacies and organic facies in the pebble shale unit and their behavior in pyrolysis experiments are more variable and complex than previously demonstrated. High resolution studies of this kind are rare, but more are clearly needed to describe and explain the variability that exists in mudstone successions.

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