U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

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OPEN FILE REPORT 02–189
Sheet 2 of 3

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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2002

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Lithofacies

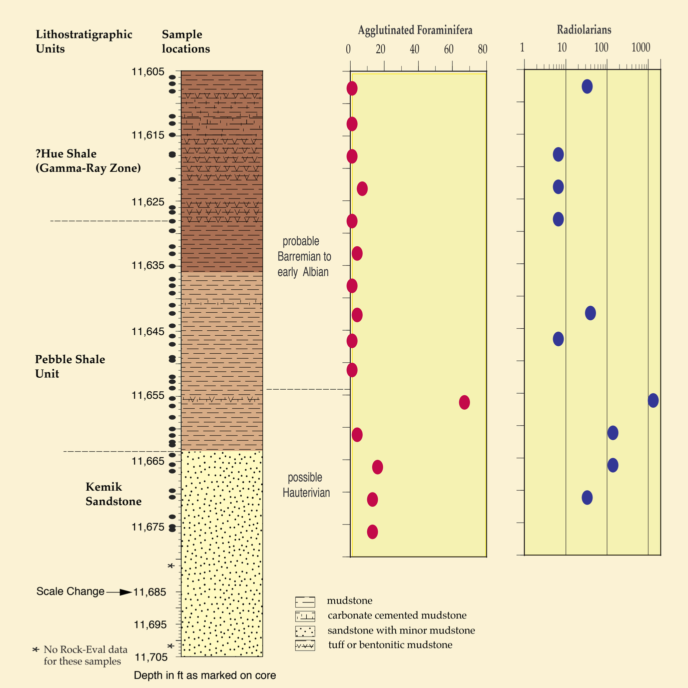
Background

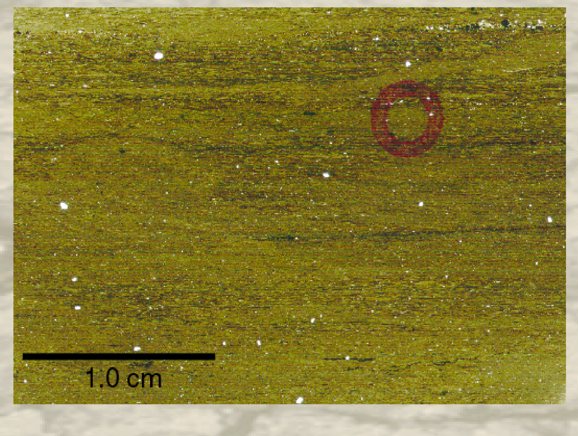
The lithofacies variability present within mudstone dominated successions is relatively poorly known in comparison with that observed in coarser clastic successions. Recent detailed studies (e.g. Macquaker and Gawthorpe, 1993) of mudstones utilizing combined optical and electron optical methods have shown startling lithofacies differences even in units that appear homogeneous at hand-specimen scale. A variety of distinct lithofacies have been identified; for example, clay-rich mudstones, silt-bearing clay-rich mudstones, nannoplankton-bearing clay-rich mudstones, nannoplankton-dominated mudstones, and carbonate cement-dominated mudstones, all of which may or may not be laminated (see Macquaker and Taylor, 1996). These lithofacies stack into larger scale packages which can be interpreted within a sequence stratigraphic framework (e.g. Macquaker and others, 1999). Terminology used for mudstones follows Macquaker and others (1998). The images shown on sheets 2 and 3 are representative examples of the lithofacies present in the Lower Cretaceous succession of the Mikkelsen Bay #1 well (see figure below). The images are organized in stratigraphic order (youngest at top left). Each set of photos comprises one or more images from the same sample showing a thin section scan (cm scale) and an optical photomicrograph (mm scale) in plane-polarized light. Several backscattered SEM images are also shown. Rock-Eval data for these samples (see sheet 1) can be compared with the textures and mineralogy present by correlating sample numbers and core depths. The red circles on many thin section scans are marks made for locating features with the SEM.

Where detailed lithofacies variability is known in these rocks it is almost always interpreted in terms of changes in productivity, bottom water oxygen levels, sediment accumulation rates, relative length of the sediment transport paths, and weathering in the hinterland within an overarching climatic control. Relatively few studies have addressed the processes of deposition at high latitudes in settings where sources of detrital sediment, in addition to fluvial input, have been operating (for example, ice rafting and in some settings volcanic activity) and there are dramatic variations in seasonal productivity.

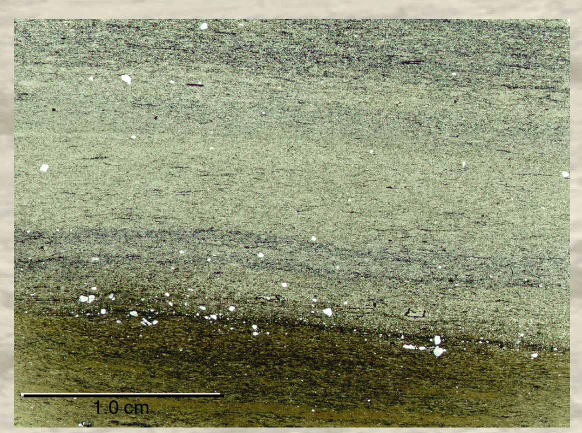
The Lower Cretaceous section described here is the upper portion of a continuous core that begins in carbonate rocks of Mississippian age (Lisburne Group) and ends in mudstones of the Lower Cretaceous Hue Shale. It is one of the few continuously cored intervals on the North Slope that includes the complete Lower Cretaceous succession. In this well the Lower Cretaceous succession overlies an unconformity, and comprises a thin basal conglomerate (approximately 1 ft thick), that is overlain by predominantly sandy strata almost 90 ft thick of the Kemik Sandstone. This sandy succession is capped by approximately 102 ft of mudstones of the pebble shale unit and lowermost part of the Hue Shale. The core we sampled and describe here includes the upper part of the Kemik Sandstone, the pebble shale unit, and possibly the lowermost part of the Hue Shale (see below).

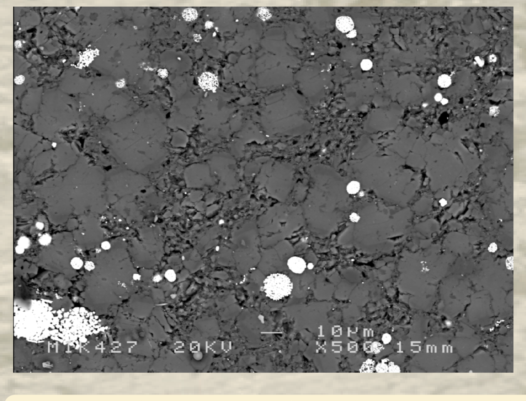
Lithofacies Log and faunal distribution (written communication from Michael Mickey and Hideyo Haga, 2000) for Lower Cretaceous Succession, Mobil-Phillips Mikkelsen Bay State #1 Well API # 50-029-20055



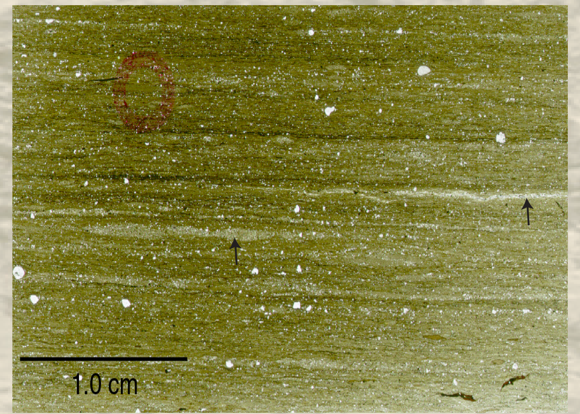



Spl 47. L. Thin section scan of ?Hue Shale at core depth 11,606.00 ft showing relict-bedded clay-rich mudstone with prominent burrows that cut across bedding, rare floating sand-sized grains, and the remnants of a sandy lamina of quartz grains and pyrite disrupted by burrowing in upper right corner. R. Photomicrograph showing area of prominent burrow ("B") and sandy lamina in upper right corner of scan. Note dispersed pyrite, silty pelleted laminae (lighter colored) which contain wispy organic material and possibly agglutinated foraminifera, and darker non-pelleted laminae which contain more clay and organic matter. Also note rounded pitted quartz grain in lower left corner.

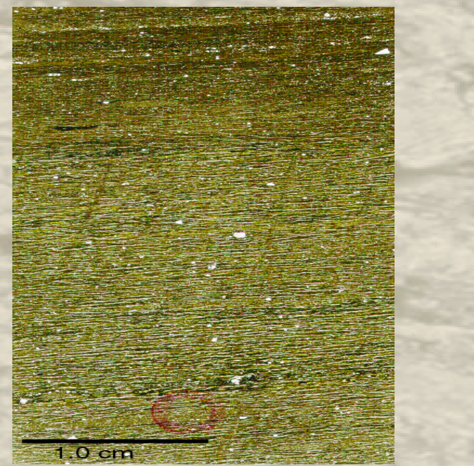
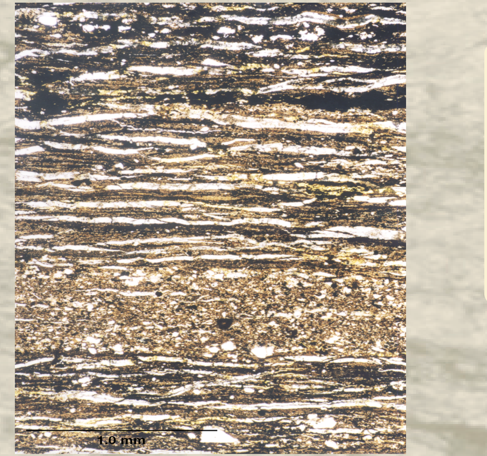




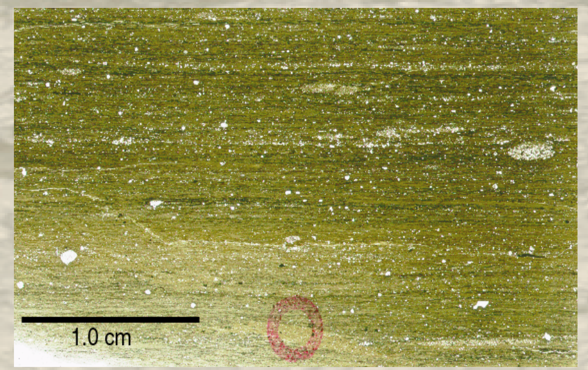
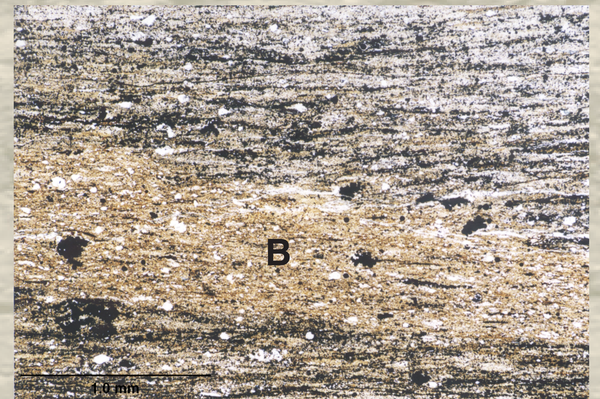
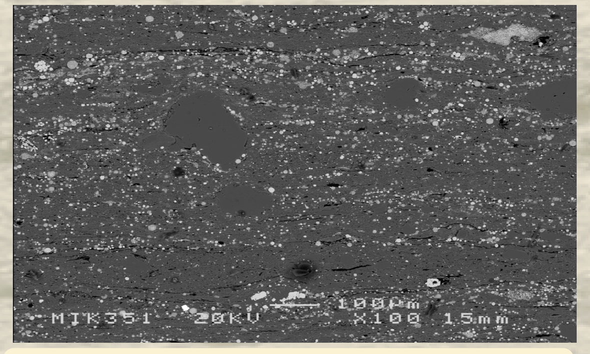
Spl 42. L. Thin section scan of ?Hue Shale at core depth 11,614.83 ft showing erosive contact between carbonate cement-dominated mudstone (lighter colored upper unit) and clay-dominated mudstone. Note that both units contain floating sand-sized grains, which are relatively common near the contact, and abundant dispersed pyrite. Center. Photomicrograph of the clay-dominated mudstone showing a prominent horizontal burrow ("B", center) and pelleted and non-pelleted laminae disrupted by bioturbation. R. Backscattered SEM photo of the carbonate cement-dominated mudstone showing zoned dolomite and calcite, common pyrite framboids (white, i.e., high backscatter coefficient), and some organic matter (dark, i.e., low backscatter coefficient). Note that many pyrite framboids are very small.



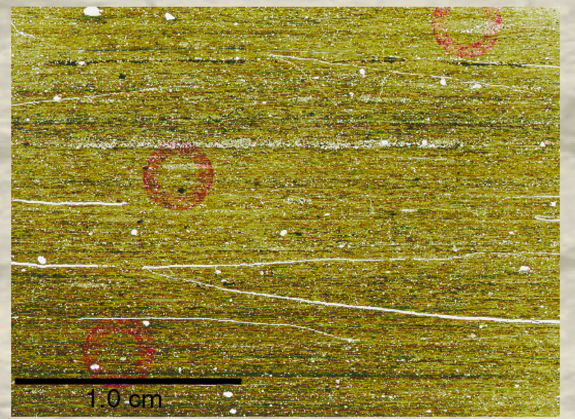
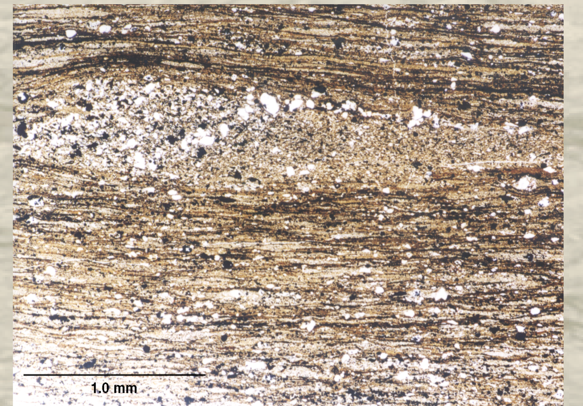

Spl 38. L. Thin section scan of ?Hue Shale at core depth 11,626.00 ft showing relict-bedded silt-bearing, clay-rich mudstone with rare floating sand-sized grains and prominent flattened silt-filled burrows (arrows). Bedding is picked out by pyrite and silt-rich laminae. R. Photomicrograph of area near middle right side of scan showing pyrite and silt-rich laminae defining relict bedding, abundant dispersed pyrite, and silt-filled burrows.

Spl 37. L. Thin section scan of ?Hue Shale at core depth 11,626.75 ft showing thin relict-bedded pyrite and silt-bearing clay-rich mudstone with some floating sand-sized grains. R. Photomicrograph of circled area of scan showing an individual bed comprised of an erosive-based, burrow-mottled silt lamina that gradually upward-fines to a clay and pyrite-rich pelleted lamina. Much of the interval is pervasively weathered, containing veins (light colored) of jarosite, alunite, and gypsum that are either sub-parallel or cross-cut the primary sedimentary fabric.

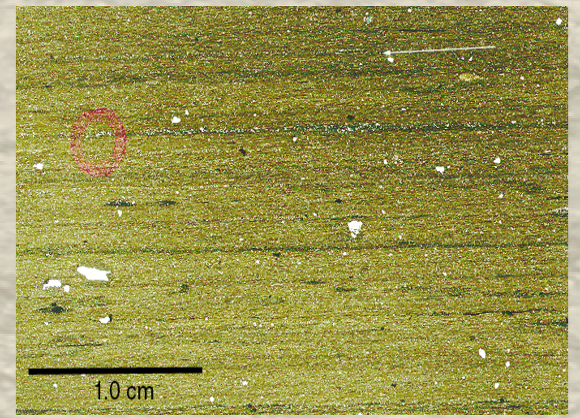
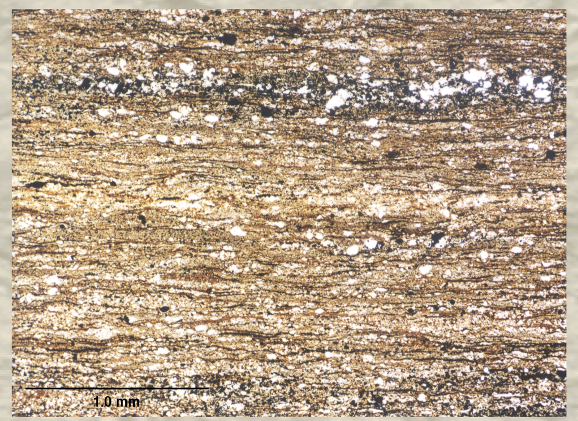
Spl 35. L. Thin section scan of pebble shale unit near top of unit at core depth 11,629.58 ft showing thin relict-bedded and bioturbated silt-bearing clay rich-mudstone with some floating sand-sized grains. Center. Photomicrograph of circled area in scan showing silt and clay-rich pelleted laminae with abundant very fine-grained disseminated pyrite and disrupted thin pyrite laminae. Note prominent burrow ("B", lighter color) that contains less pyrite and organic matter cutting across pelleted laminae. R. Backscattered SEM photo. Note rounded floating sand-sized grains.

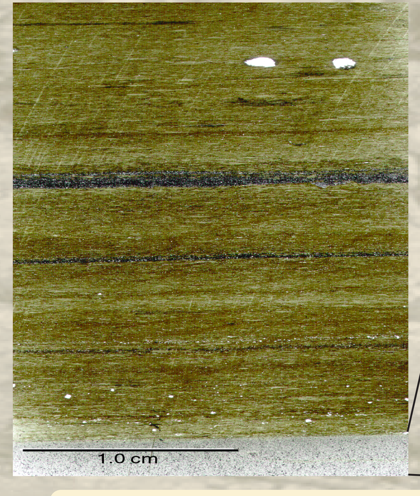
Spl 29. L. Thin section scan of pebble shale unit at core depth 11,639.17 ft showing bioturbated, thin relict-bedded silt and pyrite-bearing clay-rich mudstone. Note the prominent sharp-based bed (middle of scan) that upward-fines from silt-rich to partially bioturbated, pellet-rich clay. Also note pyrite (black) laminae disrupted by burrowing and rare floating sand-sized grains. R. Photomicrograph of middle circled area in scan showing bioturbated, silt-rich pelleted laminae and pellet-rich clay laminae. Note abundant dispersed pyrite, disrupted pyrite laminae, and prominent silt and clay-filled burrow.

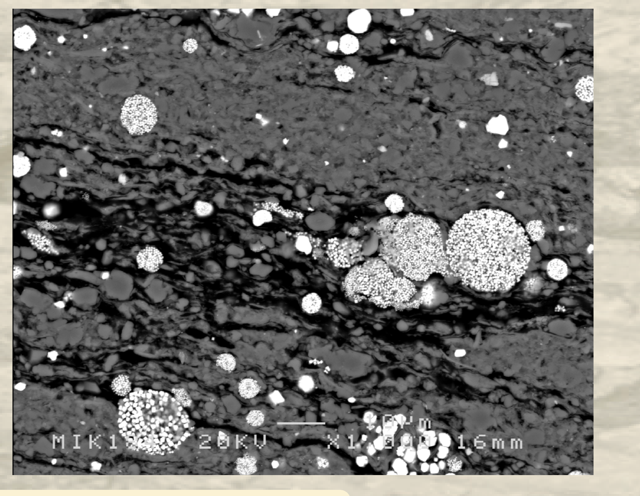


Spl 24. L. Thin section scan of pebble shale unit at core depth 11,647.00 ft showing thin relict-bedded silt and pyrite-bearing, clay-rich mudstone. Note the pervasive burrow-mottled fabric and rare floating sand-sized grains. Center. Photomicrograph showing abundant dispersed pyrite and disrupted pyrite laminae, pelleted silt, and clay. Note lozenge shaped burrow, clast, or nodule (arrow) composed of middle circled area in scan showing bioturbated, silt-rich fine-grained dolomite and quartz. R. Photomicrograph showing a silt-filled burrow (arrow).

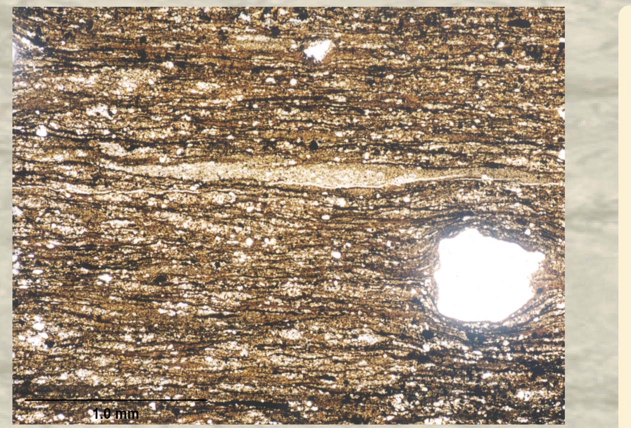



Spl 20. L. Thin section scan of pebble shale unit at core depth 11,652.90 ft showing thin relict-bedded silt and pyrite-bearing clay-rich mudstone. Many of the beds have silt-rich lamina at their bases which upward-fine to burrow-mottled clay- dominated laminae. R. Photomicrograph showing euhedral pyrite associated with the silt lamina and pyrite framboids dispersed throughout the matrix.





Spl 18. L. Thin section scan of pebble shale unit at core depth 11,655.33 ft showing thin-bedded silt-bearing clay-rich mudstone with relict laminae. Individual beds comprise couplets of thick pelleted laminae and thinner clay and amorphous organic matter-rich laminae. Disseminated pyrite is common in the matrix and very abundant in several laterally continuous, prominent beds. Euhedral pyrite is particularly concentrated in the silt-rich laminae, although not visible at this scale. A lapilli tuff is present at the base of the scan. This sample contains a few floating sand-sized grains in the several mm above the tuff. Center. Photomicrograph showing lapilli tuff at base of scan and overlying burrowed and pelleted clay-dominated mudstone. Note the sharp contact. R. Backscattered SEM photo of clay-dominated mudstone showing abundant pyrite framboids (white, i.e., high backscatter coefficient) and woody material (dark, i.e., low backscatter coefficient). Note that many pyrite framboids are less than 5 μm.

Spl 16. L. Thin section scan of pebble shale unit at core depth 11,658.25 ft showing thin relict-bedded silt and pyrite-bearing clay-rich mudstone. Note rare floating sand-sized quartz grains and pyrite (black) in multiple forms including disseminated, in thin discontinuous laminae, and replacing burrows. R. Photomicrograph of circled area in scan showing extensively burrowed fabric of residual clay laminae separated by pelleted, more silt-rich laminae. Note prominent floating pitted sand-sized quartz grain.


Spl 14. L. Thin section scan of pebble shale unit at core depth 11,661.00 ft showing thin relict-bedded silt-bearing clay-rich mudstone. Note the presence of partially flattened, silt-filled burrows (arrows), rare floating sand-sized quartz grains (up to 350 μm), and pyrite (black) in multiple forms including disseminated, in thin laminae that are commonly discontinuous, replacing possible phosphatic debris (arrow + P), and in a prominent bed associated with silt and fine sand grains. R. Photomicrograph of fecal pellet-rich laminae both above and below laterally prominent bed (in lower part of scan) containing pyrite (black) associated with silt and fine sand grains. Note that disseminated pyrite is abundant in some laminae.

Results - mudstone succession

Lithofacies identified in the pebble shale unit and possible basal part of the Hue Shale include silt and pyrite-bearing clay-rich mudstones, carbonate cement-dominated mudstones, clay-dominated mudstones, clay-bearing pyrite-rich mudstones, and lapilli tuff. In spite of burrowing (attributed to Planolites isp.) and burrow mottled textures (Samples 12, 16, and 24) present in much of the section, many of the units exhibit relict bedding textures. The individual beds are most commonly 2 to 5 mm thick, with their enclosing bedding planes delineated by either silt or pyrite-rich laminae (Samples 14, and 18). These beds commonly have erosional bases and fine-upward from silt-rich laminae at their bases to clay-rich pelleted laminae towards their tops (Samples 14, 29, and 37). In some intervals larger burrows, of indeterminate origin, cross-cut the smaller scale burrows and disrupt some of the bedding planes (Samples 35, 42, and 47).

The clay component in these mudstones is composed of indeterminate dioctahedral micas that comprise an intimate mixture of illite and mixed layer illite/smectite. The silt component is mainly composed of quartz, detrital carbonate, minor lithic fragments, and feldspar. In addition, the detrital component of these mudstones includes significant amounts of organic matter (2 - 6 wt%) composed of both higher plant and amorphous material, some calcispheres, and varying numbers of radiolaria and foraminifera (see strat column, this sheet). Rounded to sub-rounded, floating sand-sized grains are present through the majority of the studied succession and are scattered throughout individual beds (Samples 12, 35, 38, and 42).

Pyrite of varied size and habit is present throughout the succession (Samples 12, 14, 18, 35,37, and 42) and is particularly abundant towards the upper part of the section. Very small (5 μm) disseminated pyrite framboids are common in most units (e.g., Spl 18). Euhedral pyrite, observed in SEM, is particularly concentrated in the coarser-grained laminae. Pyrite also replaces burrows and possibly phosphatic debris (Spl 14); is associated with some foraminifera and calcispheres (See sheet 3); and replaces some radiolaria (Michael Mickey and Hideyo Haga, written communication, 2000).

A lapilli tuff composed predominantly of Na-rich clay and quartz is present at the base of sample 18 as well as higher in the section above 11,628 ft. Sample 18 also contains abundant pyrite, the highest total organic carbon content of our samples, and rare floating sand-sized grains. Additionally, the greatest number of both agglutinated foraminifera and radiolaria are reported from a composite core sample (11,654-11,659 ft) that spans the depth interval including our sample 18 (Michael Mickey and Hideyo Haga, written communication, 2000).

Finely crystalline carbonate-cement dominated mudstones are abundant towards the top of the sampled succession (Spl 42), but also are present below there. Like the other units in this succession, these mudstones contain abundant dispersed framboidal pyrite, are pelleted, bioturbated, and contain floating sand-sized grains. These carbonate cemented units are quite distinct from the other samples as their intergranular porosity is infilled by pre-compaction zoned, non-ferroan and ferroan dolomite and calcite (Spl 42).

Some units within the upper part of the mudstone succession are intensely weathered, in spite of this material being derived from core, as a result of reaction with the atmosphere --possibly humid-- during storage of the core. SEM and EDS reveal that the primary fabric of these units has been disrupted by the secondary growth of gypsum, jarosite, and alunite that together form pervasive sub-parallel to cross-cutting secondary (i.e., post drilling) mineral veins (Spl 37). Detailed textural analyses of the less weathered parts of these units suggest that their unweathered mineralogies are clay-bearing (bentonitic) pyrite-rich mudstones, with the pyrite being predominantly framboidal. This weathering, which is especially developed towards the top of the sampled interval (11,606 ft), and even more so above that level, has also caused the core to crumble and split along bedding planes.