Preliminary Sedimentology of Milk River Equivalent in the New Abbey/Lacadena Gas Fields, Saskatchewan*

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Abstract

The main purpose of this report is to document aspects of the sedimentology of the Milk River equivalent (Myhr and Meijer-Drees, 1976) in the new Abbey and Lacadena gas fields in southwest Saskatchewan. The study focuses on 54m of continuous core cut by Husky at 11-24-21-19W3M, an early development well drilled in late 2001 near the center of the reservoir. This core was logged for basic attributes followed by preparation of 61 thin sections to investigate mineralogy, texture and various reservoir quality issues. Results are presented along with brief discussions of, and comparisons with Hatton area Milk River equivalent (MRE). A secondary purpose of the report is to discuss implications of the documented sedimentology to historic and modern models of MRE deposition.

This report does not discuss trapping mechanisms in the Abbey/Lacadena fields. Pedersen (2003) indicates that the reservoir, as currently delineated, sits on a large, low relief structural high, but that stratigraphic controls may be important. Well logs cannot be used to make estimates of net pay due to extremely high shale content (Meijer-Drees, 1972). The fields have pushed MRE production 75km northeast of pre-discovery limits. Over 440 wells are currently producing at Abbey/Lacadena at rates of ~$1x10^3m^3$/d to over $29x10^3m^3$/d (~35mcf/d to over 1mmcf/d). By the end of the third quarter of 2003, almost $764x10^6m^3$ (27bcf) of gas had been produced from the fields.

Regional Setting of Abbey/Lacadena Fields

The Milk River equivalent in Saskatchewan is the shelfal component of an early Campanian clastic wedge. Figure 1 and Figure 2 summarize the regional stratigraphic relationships and paleogeography of the unit. Abbey/Lacadena Milk River equivalent (MRE) is more than 200 km basinward of known coeval shoreface deposits. The traditional view of depositional processes on the MRE shelf is illustrated in Figure 3 (modified from Swift and Rice, 1984). According to this view, coarse silt and fine sand are moved across the muddy shelf by storm-driven currents, resulting in thick shale punctuated by sharp-based storm beds. At certain stratigraphic levels, in specific areas, sand beds thicken and coalesce into “sand bodies” far removed from shoreface time equivalents (Berg, 1975).

More recently, the MRE has been re-interpreted to include one or more lowstand surfaces of erosion. O'Connell et al. (1999) proposes one major unconformity, which cuts down to near the base of the MRE across the Alberta gas pool. Ridgely (2000) reports the presence of transgressive shoreface and even fluvial sediments in the same area, also above a lowstand surface of erosion near the base of the MRE. Pederson (2003) identifies two lowstand systems tracts (his Figure 3) with related sandier intervals in the Abbey area. Regional correlations and depositional analysis are not specific goals of this report. However, the sedimentological observations contained herein are relevant to a regional understanding of the MRE and their implications will be discussed.

Description of Abbey/Lacadena Area MRE Core

Figure 4 is a map of the Hatton-Abbey/Lacadena area, indicating the locations of cores examined. Figure 5 is a log section from Hatton to Abbey showing the stratigraphic position of cores referenced in this report. Husky cut 54m of continuous core in mid-MRE in 11-24-21-19W3M. After slabbing, the core was logged in detail using a binocular microscope. In spite of problems with clay swelling, it was possible to identify the following key lithofacies (see Figure 6):

A) very silty/sandy burrow-homogenized shale to very shaly very fine (vf) sand; burrows generally indistinct *Chondrites*-like forms with occasional larger sub-vertical types visible.
B) moderately silty/sandy burrow-homogenized shale; more or less as above.
C) slightly silty/sandy, un-burrowed to weakly burrowed shale.

The preceding lithofacies occasionally show increased bentonite clay content. Figure 7(a) is a photograph of lithofacies A and B as they appear on slabbed surfaces.

D) moderately-burrowed to un-burrowed, very thin beds (average 0.5cm) of coarse silt/vf sand; these typically have sharp bases and tops and commonly include laminations of coarser claystone rip-up clasts. Where lightly-burrowed, fine horizontal to very low angle cross-lamination is evident; the silt/sands are friable to unconsolidated with good porosity where undisturbed, to poor porosity where burrowed (dispersed clay matrix); Figure 7(b) is a core photograph of a burrowed sandy shale with common thin silt/vf sand beds.
E) mudstone intraformational conglomerates (commonly sideritic, with sandy shale or shaly vf sand matrix).
F) calcite and siderite cemented intervals.

As shown in Figure 6, the cored interval can be divided into two subtle coarsening- or shoaling-upward members. The top of the lower member is at ~323m, near the base of core 4. This member consists of intercalated, very thin silt/vf sand beds (lithofacies D) and variably silty/sandy burrowed shale. The "sandiness" of the burrowed shale component increases upward and there is noteworthy intra-formational conglomerates near the top. This lower member contains the majority of intact silt/vf sand thin beds (approximately 9 per meter in cores 5 and 6) and is considered by Husky to be the prime contributor of gas production.

The remainder of the cored interval is part of another subtle coarsening- or shoaling-upward member. The lower portion (307m to 323m) consists of interbedded, relatively clean bentonitic shales and slightly sandy burrowed shales with a few preserved thin silt/vf sand beds. The section from 307m to the top of core 1 consists of moderately to very sandy shale (lithofacies A and B) with interbeds of very shaly burrow-homogenized very fine sand. This interval will flow small gas rates only. Very little original bedding is preserved in this uppermost portion of the upper member.

Observations suggest that the entire cored section was originally deposited as interbedded very fine sand, silt, and shale. Intensity of burrowing is the key determinant of the ultimate lithofacies. From a gas reservoir perspective, the very thin, but mainly un-burrowed, coarse silt/vf sand beds provide good quality, if volumetrically limited, reservoir. Figure 6 tabulates the thin silt/vf sand bed count by core (92.5cm in 184 beds in all). Only about 1m of the fully homogenized lithofacies in cores 1 and 2 appears to potentially constitute low permeability gas reservoir.

Following macroscopic examination of the core, 61 large format (5cm by 3cm) thin sections were prepared to image the internal structure of the very thin, coarse silt/vf sand beds, and to further investigate reservoir potential of the homogenized lithofacies. Thin section petrography led to a more refined and process-oriented lithofacies scheme (Figure 8). The basic element is coarse silt/vf sand to shale cycle. In the MRE at Abbey, the full cycle is comprised of three lithologies resting on a scour surface. From the base upward, these are:

1. thin (0.2 to 2cm) micro-hummocky cross-stratified (micro-HCS) coarse silt or very fine sand; rare current ripples; common sideritic claystone and claystone rip-up clasts; generally sharp but concordant contact with:
2. thin (0.2 to 1cm) parallel laminated silt and shale; rare isolated ripples; typically gradational with:
3. thin (0.2 to 2cm) relatively silt/sand-free dark shale, with probable recrystallized radiolarians.

Based on silt and sand point counts in lithology 1, the average framework composition of these litharenites is quartz 41%, sedimentary lithoclasts 13%, carbonate grains 8%, feldspars 7%, and chert 6% with minor amounts of volcanic lithoclasts, organic matter/bitumen and glauconite. Other than rare, heavily calcite or siderite (?)-cemented beds, authigenic minerals are limited to traces of chlorite and undifferentiated clays. Sorting is generally moderate with sub-angular to sub-rounded grains. No systematic vertical grain size variation in individual thin, coarse silt/vf sand beds has been detected.

This basic cycle is similar to the Mowry shale "graded siltstone and mudstone" cycle of Davis et al., (1989). Like Davis et al., we interpret these cycles to be the deposits of individual storm events. The basal silt/vf sand characterized by micro-HCS (Easthouse and Driese, 1988) represents oscillatory (i.e., wave-induced) bed load deposition of the coarsest available sediment fraction. The laminated silt and shale portion represents deposition from suspension during waning phases of a storm, grading upward into pelagic mudstone that caps the cycle.

Figure 6 (thin section-derived percent continuous laminations plot) shows that the lower member of the 11-24 core (i.e., below 323m) is characterized by partially intact bedding. Figure 8 includes a thin section photograph from the upper part of this member (330.05m) illustrating a complete storm cycle with partially burrow-disrupted, over- and underlying beds. Figure 9 shows a similar storm cycle with striking laminated silt and shale component. Throughout the lower member, permeability is concentrated in the un-burrowed or lightly burrowed, basal coarse silt/vf sand component of storm cycles.

Near the base of the lower member, numerous storm beds appear to lack the basal coarse silt/vf sand component, consisting only of a scour-based laminated silt and shale overlain by a well-preserved shale cap (Figure 10). Davis et al. (1989) suggest this may indicate deposition, below storm wave base, of sediment suspended in a waning, distal storm-generated current. Thin section examination indicates that little effective permeability can be attributed to these more distal variants of the storm cycle.

Figure 11 illustrates the high level of burrow-homogenization typical of the upper member of the 11-24 core (i.e., above 323m). Thin section examination suggests that this homogenized facies is rarely an effective gas reservoir.

Comparison of MRE at Abbey/Lacadena with MRE to the South-Southwest

South Part of Alberta MRE Gas Pool

Meijer-Drees (1972) and Myhr and Meijer-Drees (1976) divided the MRE into a lower unit with numerous very thin (0.3 to 2.5cm) laminated, very fine sand or coarse silt beds in a silty shale, and an upper sand-rich unit with burrow-mottled, shaly sands, up to 20cm thick, interbedded with silty and sandy shale. The sands commonly contain intervals, up to 20cm thick, with preserved lamination. This upper unit grades northward into a silty shale with very thin silt/sand beds similar to the lower unit. The basic depositional unit is a scour-based sand to burrowed shale cycle. Clearly, portions of the MRE in this area are much sandier than the interval represented in the 11-24 core at Abbey, and are characterized by significantly thicker, possibly amalgamated beds. The cored section at Abbey appears to be very similar to the lower unit described by Meijer-Drees (1972).

South Central Hatton Field Area, Saskatchewan

Several mid-MRE cores were examined in south-central Hatton Field, approximately 100km “landward” of Abbey (Figure 4) in an area of locally increased “sandiness.” Figure 5 shows that the sandy interval can be correlated with the upper member in the 11-24 Abbey core. A typical core log in the sandy area (for 8-7-15-28W3M) is included as Figure 12. The interval is divided into very sandy upper and less sandy lower coarsening- or shoaling-upward members that together correlate with the upper member in the 11-24 Abbey core. The upper member in 8-7 begins with a thin (~1m) interval of moderately silty/sandy shale with preserved thin beds, which grades up to fully burrow-homogenized, very silty/sandy shale resembling the upper portion of the upper member in 11-24. In 8-7, however, the upper member is capped by a 3m burrow-homogenized, moderately shaly but porous sand with individual beds up to 10cm in thickness, suggesting a significantly higher volumetric proportion of sand in the original storm-bedded section. Although un-burrowed thin silt/sand beds are present above and below, it is evident that the massive, moderately shaly sand is the primary gas reservoir in this part of Hatton, and this lithology appears to have much greater porosity capacity per meter than the thin-bedded facies.

Discussion of Abbey/Lacadena MRE Sedimentologic Characteristics – Implications for Regional Interpretations

Davis et al., (1989) and Davis and Byers (1989) describe variations in storm beds deposited at different water depths on the Mowry (late Albian) shelf. Their shallowest water beds lack many of the features of the full hummocky cross-stratification model (Dott and Bourgeois, 1982), but do exhibit a certain amount of amalgamation resulting in relatively thick sand beds. Storm deposits in deeper water are characterized by centimeter-scale cycles comprised of thin basal silts overlain by laminated silt/mud, which grades into a pelagic mud cap. Sedimentologic observations in the present study and in earlier reports (Meijer-Drees, 1972) suggest a similar variation in storm cycle characteristics in the MRE. The lower member in the 11-24 core at Abbey consists of repeating distal/deep water storm cycles that are well preserved. The upper member, however, is intensely burrowed and may represent a significant, shelf-wide shallowing event. Since burrow-homogenization in the upper member has left only massive silty/sandy shales, it is inferred that the precursor storm beds were still of relatively distal aspect, with significant preservation of mud caps below storm scours. As indicated earlier, this upper member can be correlated with a thick, burrow-homogenized sand to the south at Hatton.

The 11-24 Abbey core and other MRE cores suggest that storm-generated currents were capable of transporting (and eroding) coarse silt/vf sand grade sediment across large areas of the shelf through much of MRE time. This is consistent with an extensive literature concerning MRE-age shelf deposits in the U.S. Rocky Mountain area (for example Rice and Shurr, 1983 or Berg, 1975). Like the historical U.S. studies, we do not see evidence of lowstand surfaces of erosion or incised shoreface deposits.

The recent discovery of Abbey/Lacadena has rejuvenated interest in the MRE in Saskatchewan and, as mentioned earlier, recent interpretations suggest the presence of a major lowstand surface of erosion within the MRE (Ridgley, 2000 and Pederson, 2003). Pederson, based partially on the geometry of well log correlations, considers the lower member in the 11-24 Abbey core to be a “sandy lowstand deposit” that onlaps a significant lowstand surface rising stratigraphically to the southwest. Whatever the origin of the correlation patterns documented in his report, the interval in question is not “sandy,” but rather consists entirely of very thin storm cycles of distal/deep water aspect.

Summary and Conclusions

Core cut in mid-MRE at Abbey, Saskatchewan includes portions of two subtle coarsening- or shallowing-upward members. The lower member consists of relatively distal/deep water storm cycles exhibiting low to moderate burrowing intensity. This member is the prime contributor of gas production in the Abbey and Lacadena fields, with reservoir consisting of large numbers of widely spaced (averaging 9 per meter), thin beds of coarse silt/vf sand retaining good porosity and permeability.

The upper member in the Abbey core represents full burrow-homogenization of original storm-bedded packages that had a high volumetric proportion of cycle-capping shales. Reservoir potential of this member in the Abbey/Lacadena area is probably very limited. The equivalent interval in the central part of the Hatton field, some 100km “landward,” is capped by burrow-mottled sand that constitutes the main reservoir there.

Sedimentologic observations presented in this report suggest that storm-induced currents were capable of transporting coarse silt/vf sand across great distances on the shelf through much of MRE-time. Variation in individual storm cycles, as well as composite storm-bedded intervals across the MRE shelf is consistent with documented examples of variation across other Cretaceous shelves. The Abbey/Lacadena MRE reservoir is hosted in a section composed of stacked distal storm cycles, a lithofacies typical of a large portion of the MRE shelf.

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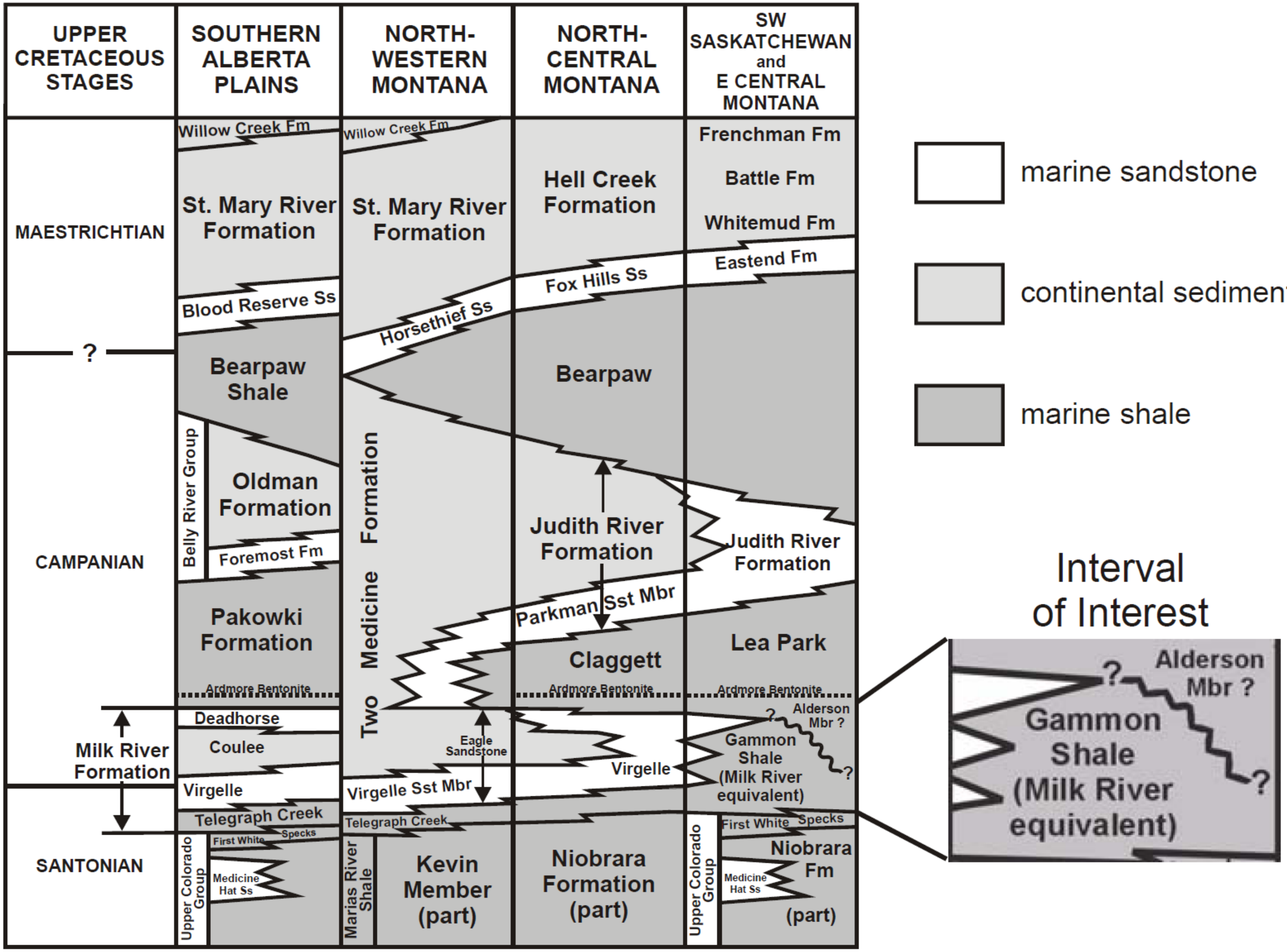

Figure 1. Correlation chart indicating regional stratigraphic relationships (modified from Rice and Shurr, 1983). The interval of interest in this report is indicated.

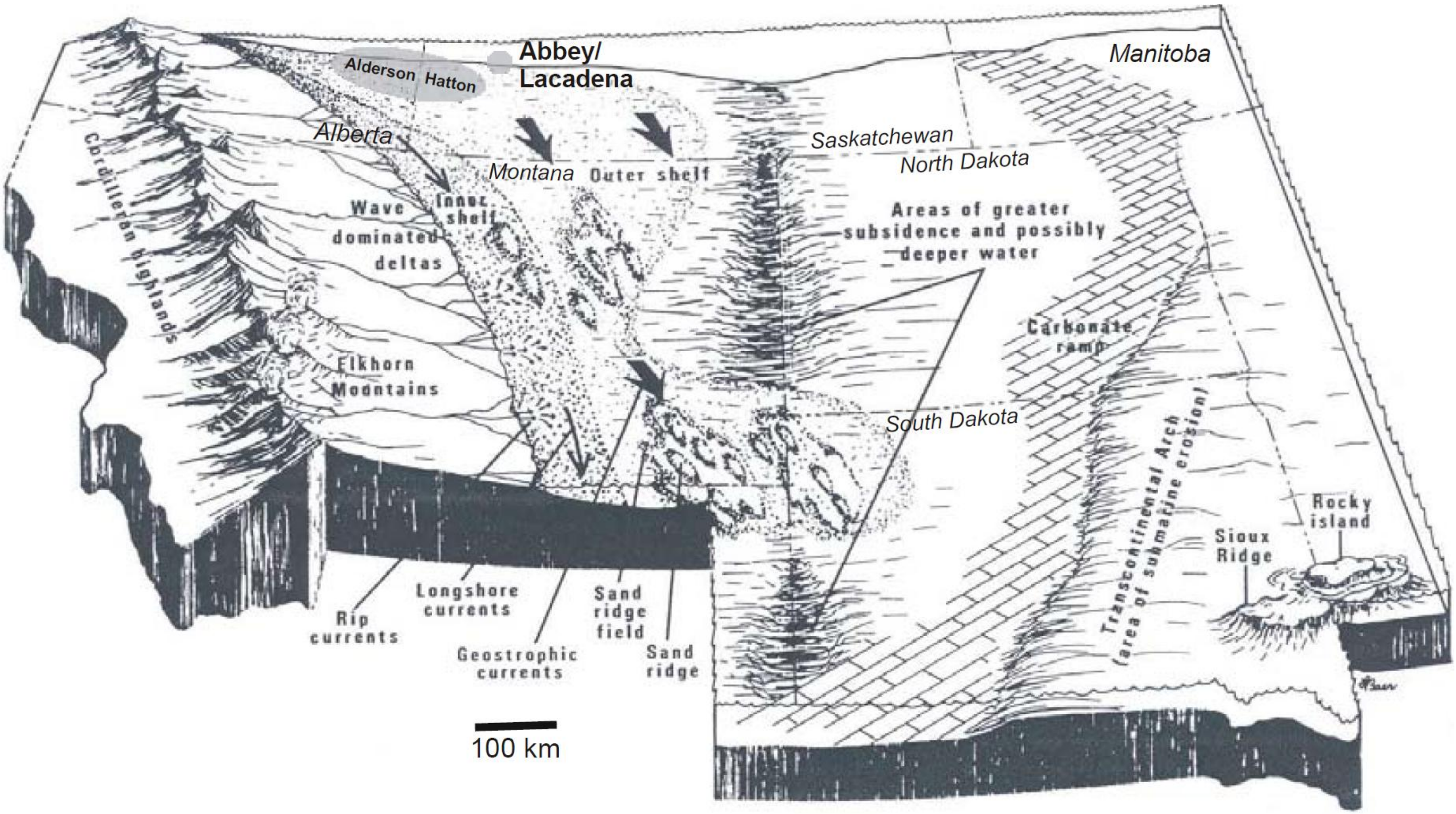

Figure 2. Regional paleogeographic reconstruction of the Late Cretaceous seaway during deposition of the Milk River Formation (modified from Rice and Shurr (1983)). The location of the main Milk River equivalent gas-producing regions in Alberta and Saskatchewan are indicated by shading.

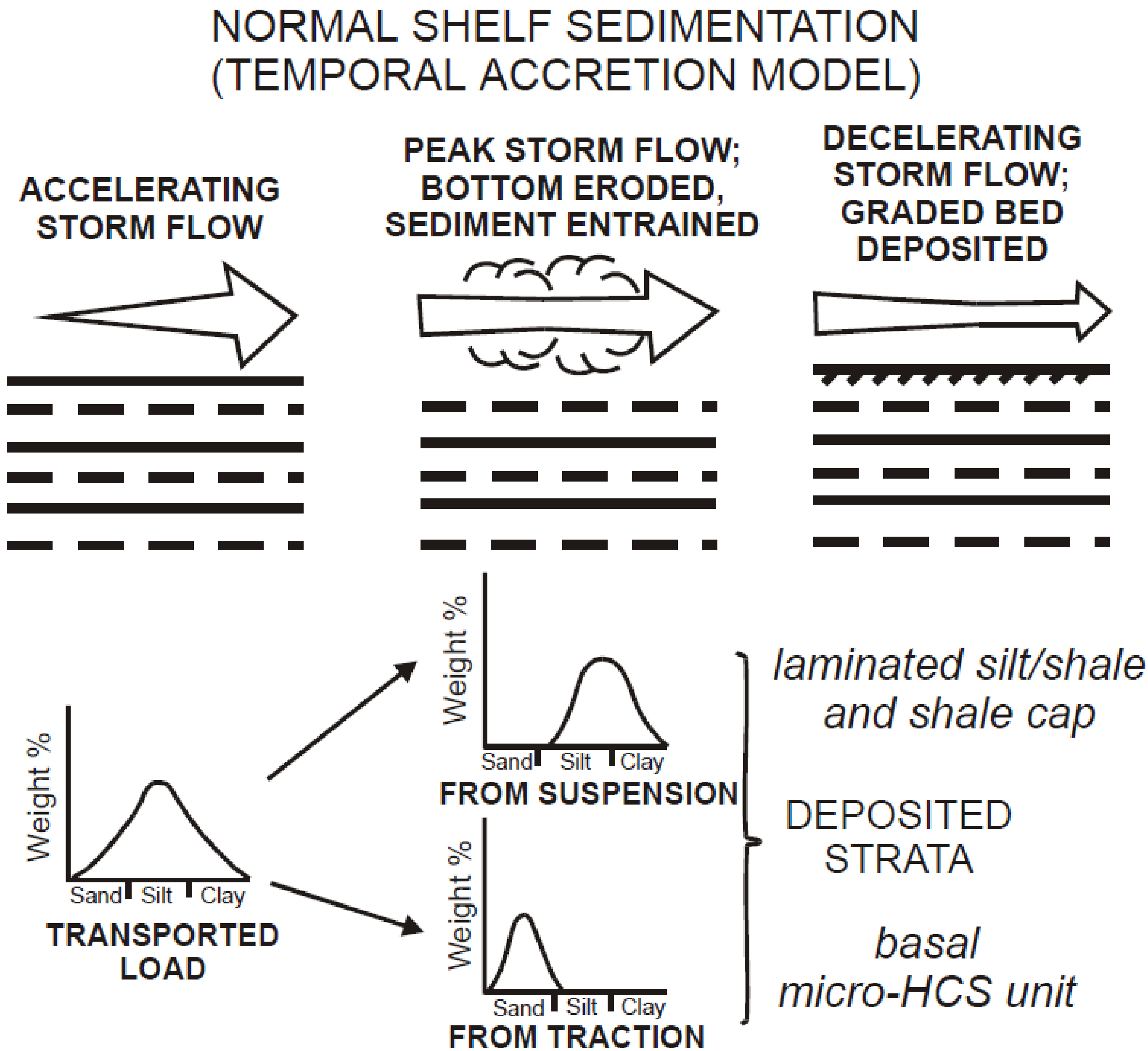

Figure 3. Schematic of shelf depositional processes (after Swift and Rice, 1984).

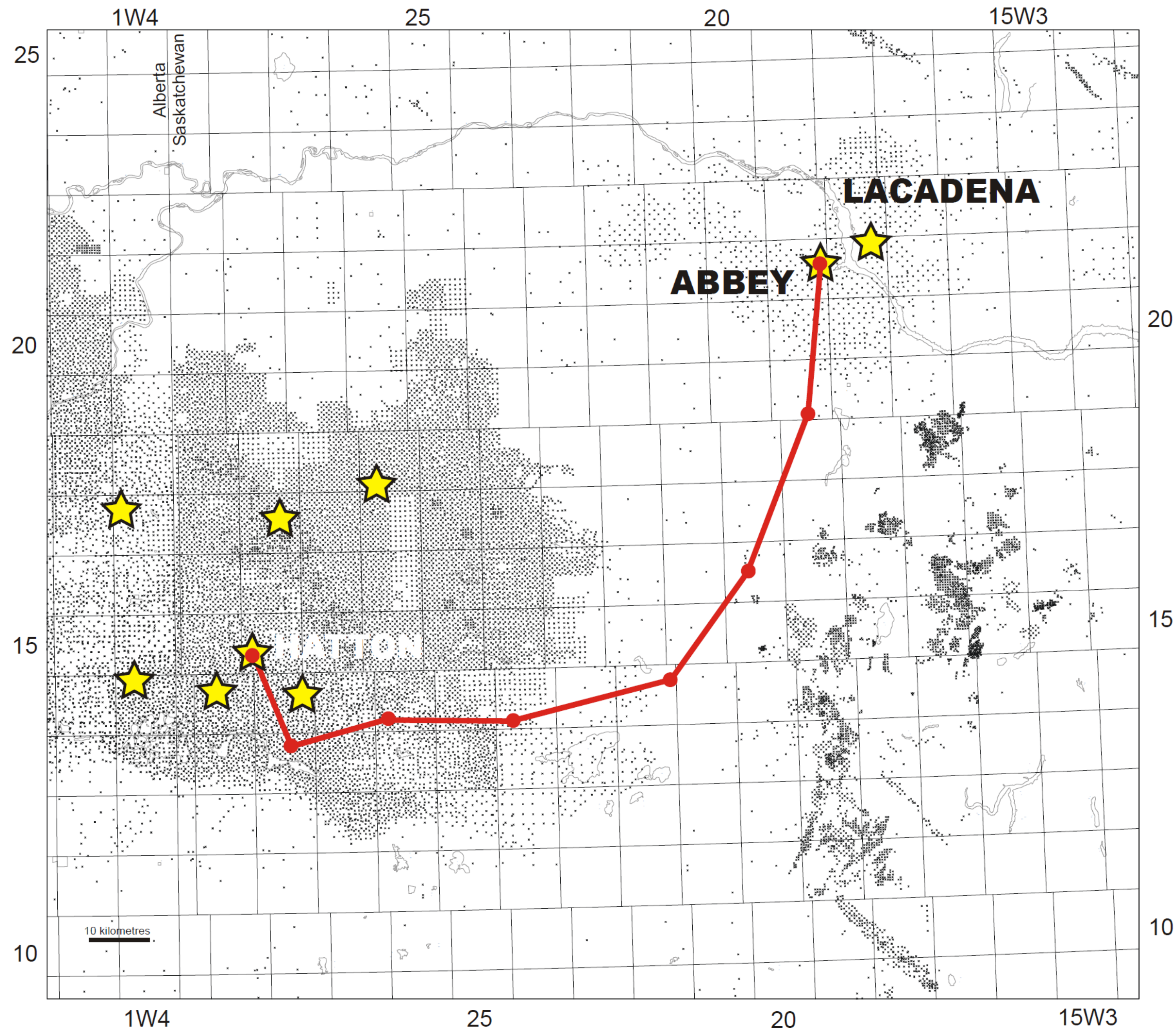

Figure 4. Location map indicating the line of cross-section in Figure 5. Locations of cores examined are indicated by stars.

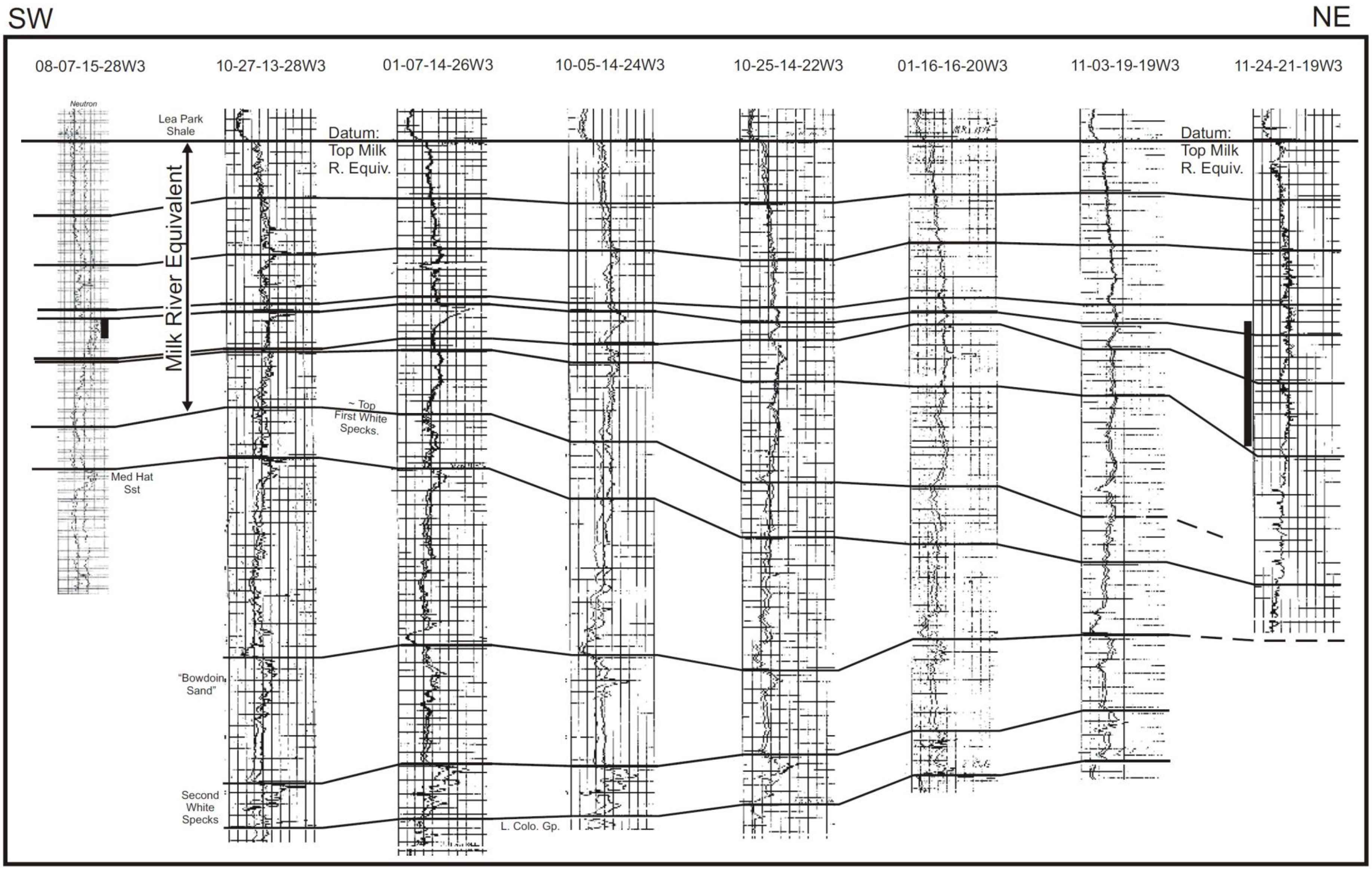

Figure 5. Regional cross-section from Hatton field to Husky Abbey 11-24-21-19W3 location. Cores discussed in the report are indicated by black vertical bars.

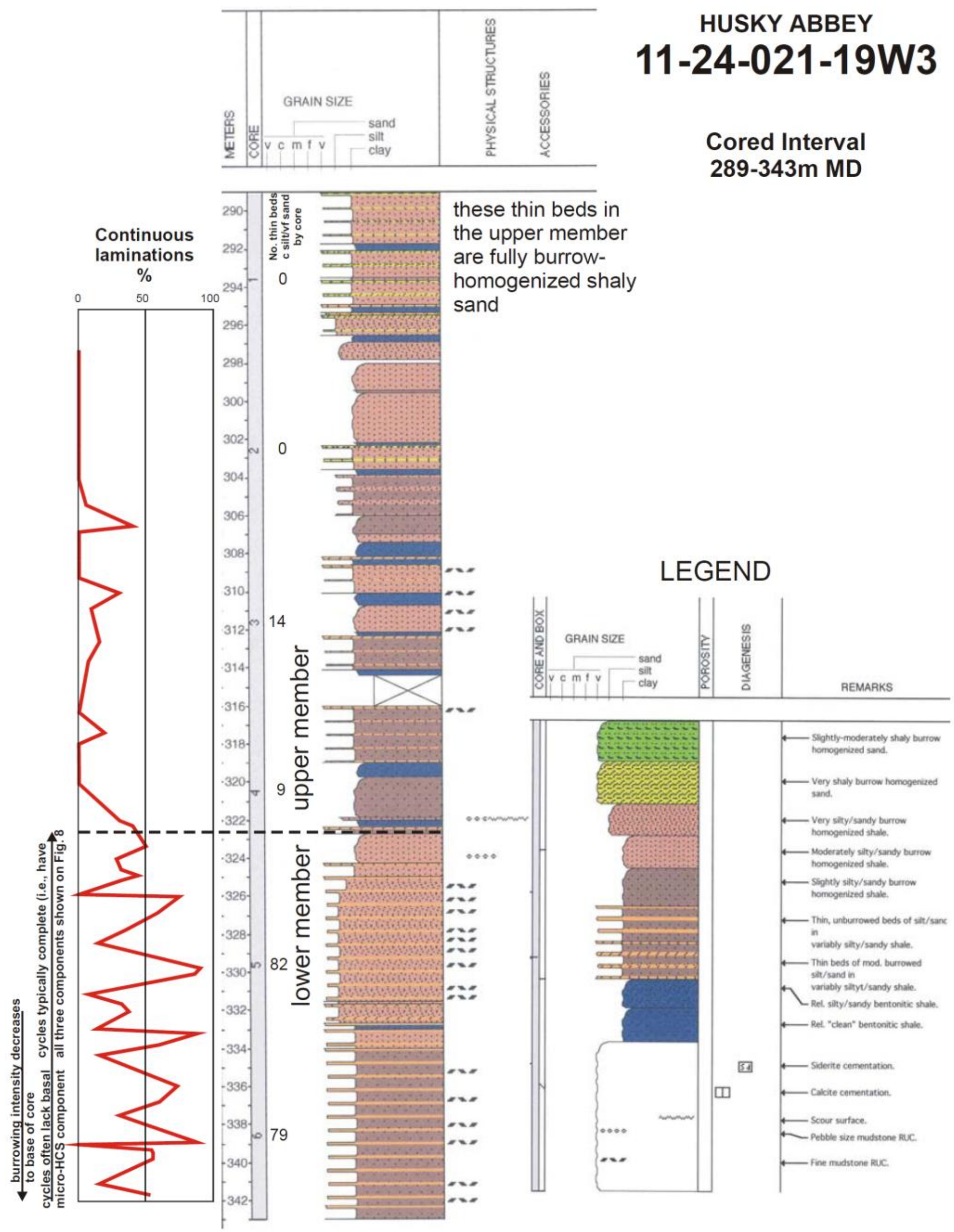

Figure 6. Core log of HUSKY ABBEY 11-24-21-19W3.

Figure 7. Comparison of slabbed core from (a) homogenized facies (upper member) and (b) the Abbey reservoir facies (lower member). Note preserved silt/vf sand laminations ranging from 1mm to 2cm (arrows). Core tends to break at silt/vf sand thin beds.

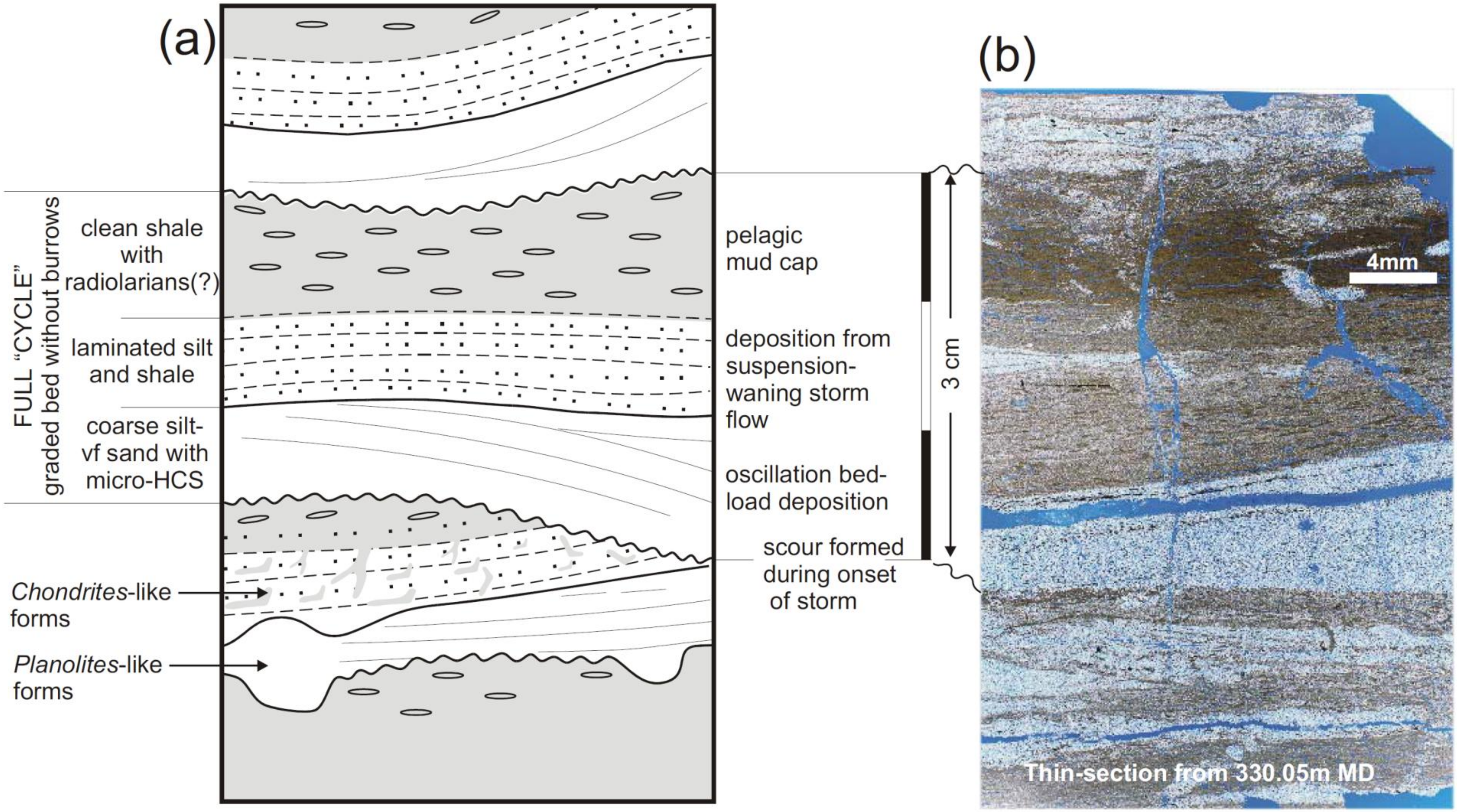

Figure 8. Thin section-derived lithofacies scheme of the silt/vf sand to shale cycle described in the text: (a) is a generalized model of the cycle; (b) is an actual thin section photograph from 330.05m MD.

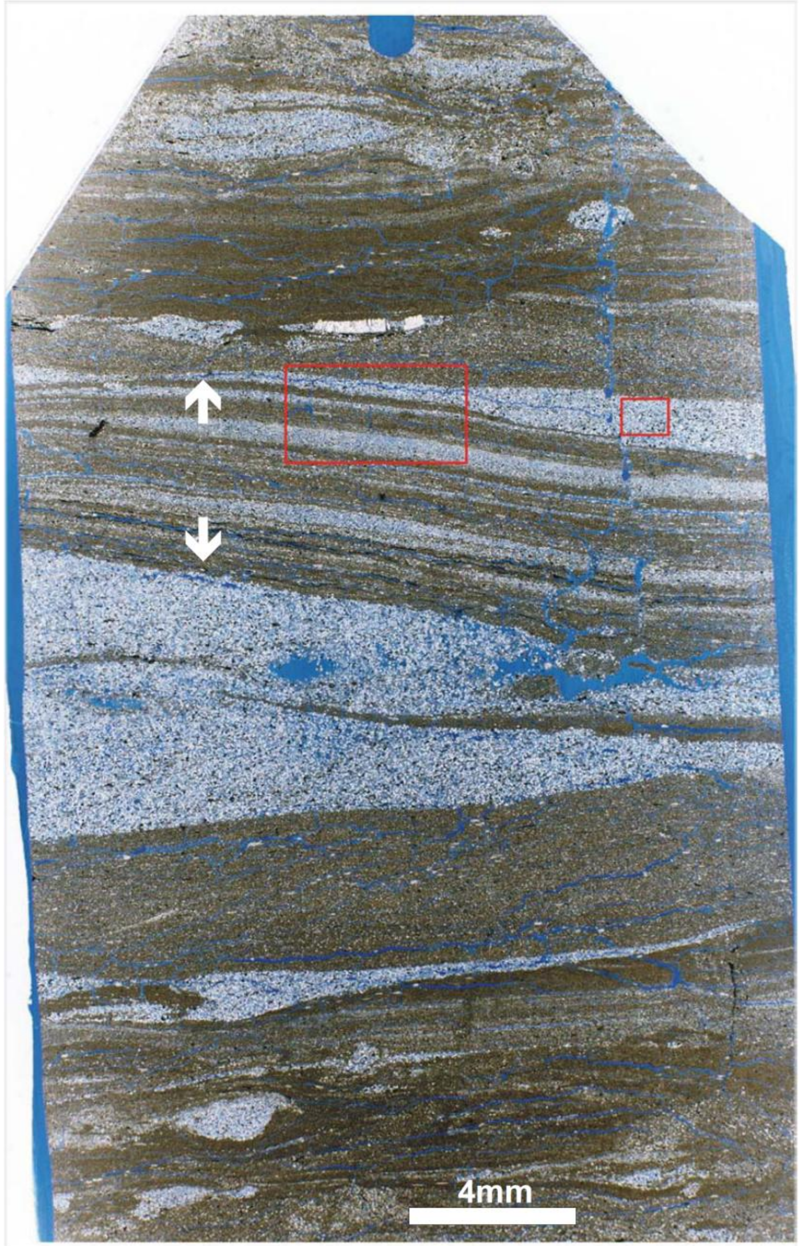

Figure 9. Thin section photograph from depth 333.80m. This section illustrates a storm cycle with striking laminated silt-shale component (indicated).

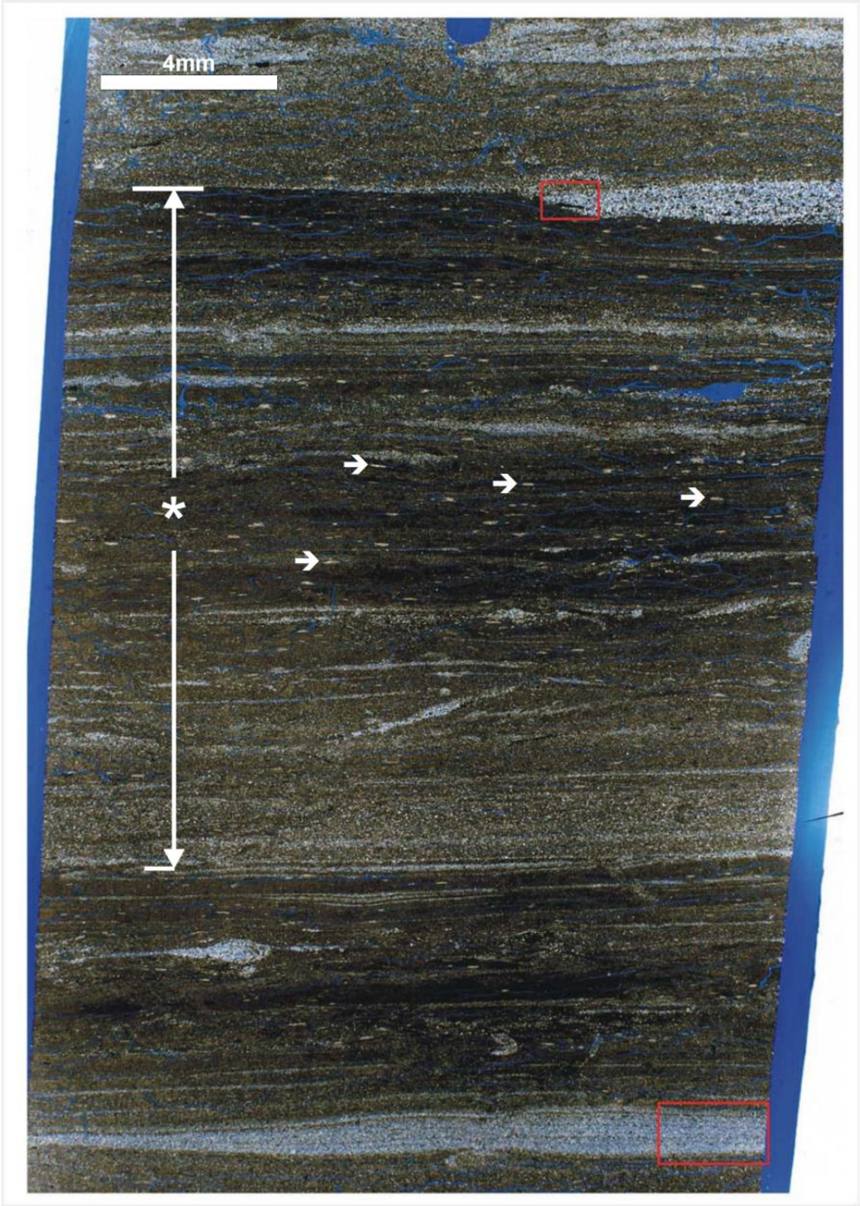

Figure 10. Thin section photograph from depth 338.86m. This section illustrates a storm cycle lacking basal micro-HCS thin beds (*), but with a well-preserved shale cap. Note low burrowing intensity and possible compacted radiolarians (examples highlighted by arrows) in shales. Interpreted as a distal/deepwater storm cycle.

Figure 11. Thin section photograph from depth 291.37m. This section illustrates the almost complete burrow-homogenization characteristic of the upper member in the 11-24 core.

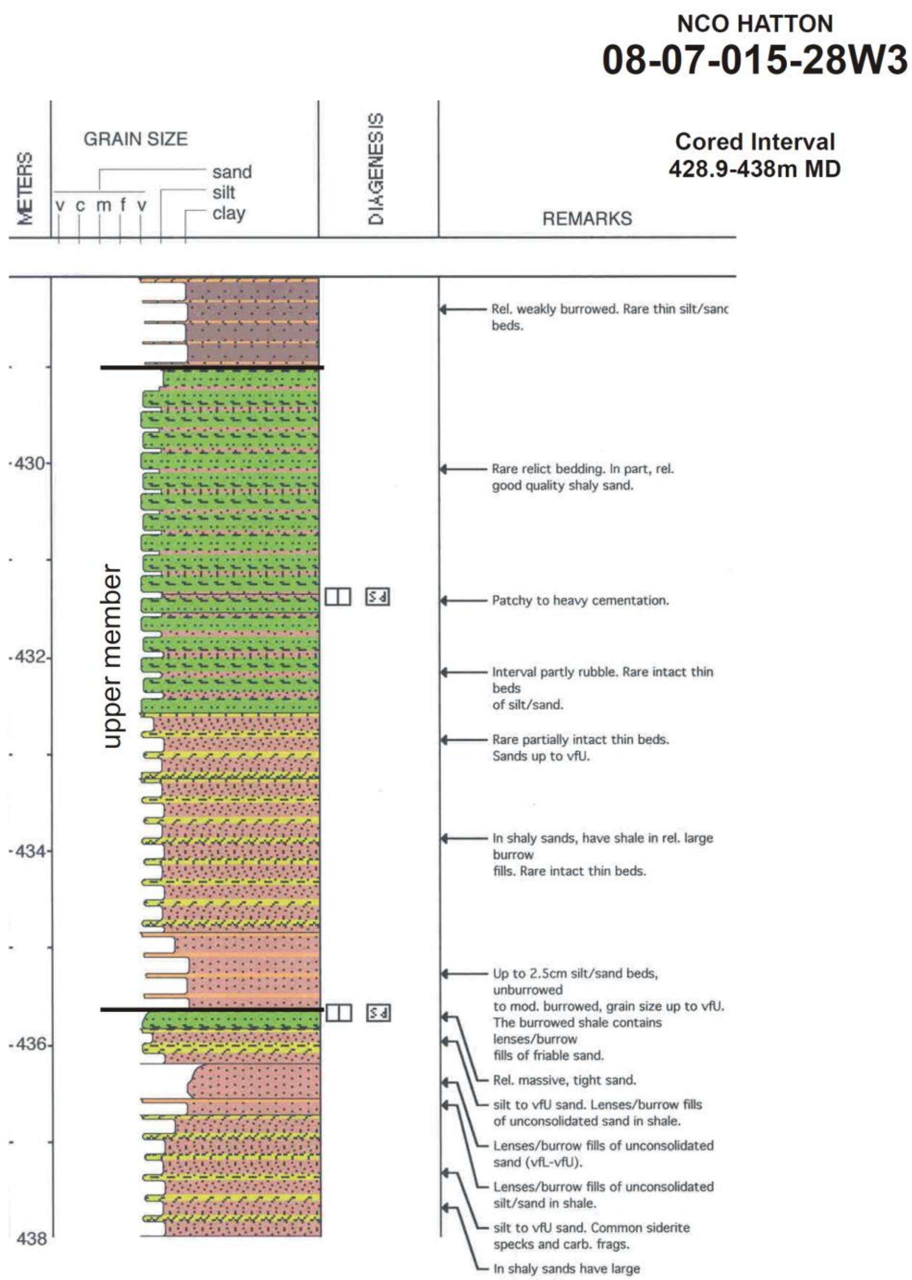

Figure 12. Core log of NCO HATTON 8-7-15-28W3. Legend is the same as that shown in Figure 6.