Bioturbation Intensity: A Proxy for Evaluating Environmental Stresses in the Bluesky Formation, Northeastern Alberta

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Introduction

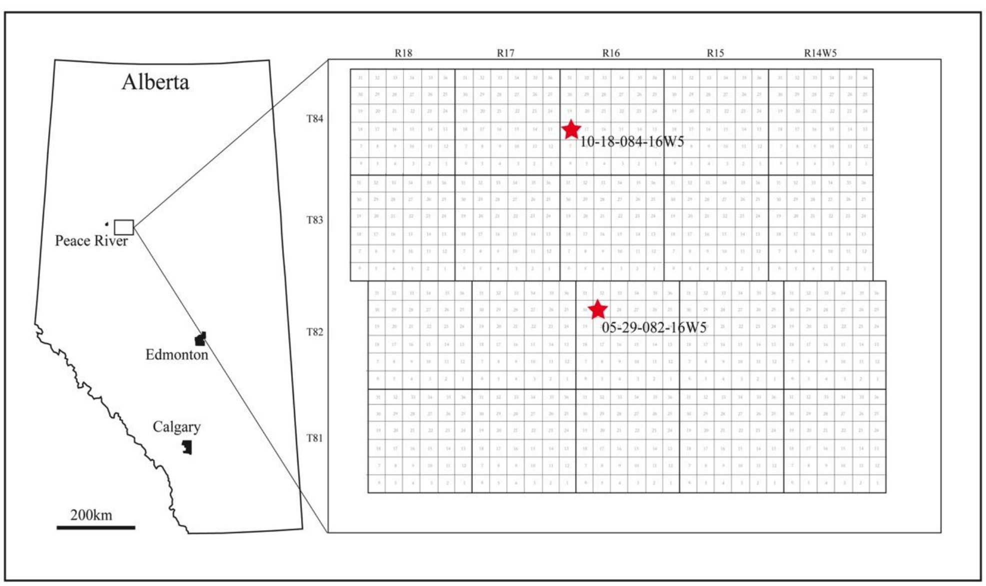
The late Aptian to early Albian Bluesky Formation comprises complex marginal marine environments, for which the stratigraphic correlations are poorly understood (Hubbard et al. 1999). As such, several depositional models have been proposed (e.g. Brekke, 1995; Hubbard et al., 1999, 2002; MacKay and Dalrymple, 2005, 2011). These interpretations differ not only in their broad environmental affinities (e.g. delta, estuary, barrier island) but also in the dominant physical processes affecting the system (wave-dominated vs. tide-dominated). This study attempts to use bioturbation intensity (BI) and ichnofossil assemblages to establish the primary environmental stresses present during the deposition of the Bluesky Formation. Stresses affecting burrowing organisms include high sediment deposition rates, salinity fluctuations, reduction of bottom water/substrate oxygenation, elevated water turbidity, prolonged subaerial exposure, introduction of substrates that limit burrowing, and variations in energy conditions (MacEachern et al., 2010). These stresses affect ichnological characteristics such as ethology (behaviors) and trace fossil assemblages. With the incorporation of ichnological characteristics, lithology, physical structures and lithological details (i.e. pebble lags, shell fragments, coal, etc.), the establishment of reliable facies interpretations is possible.

This study particularly focuses on the documentation of BI and it's relationship to sedimentary process using 2 Bluesky Formation cores (05-29-082-16W5 and 10-18-084-16W5).

Study Area

The two wells documented for this study are located within the Peace River Oil sands, east of the town of Peace River in northeastern Alberta between Twp. 82-84 and Range 16W5.

Figure 1. Location map of Wells 10-18-084-16W5 and 05-29-082-16W5.



Methods

Two cores were logged in detail using AppleCore© logging software. At the individual box scale (1.5m core length) the lithology, nature of contacts, sedimentary structures, lithologic accessories, fossils, trace fossils, average grain size, and bitumen saturation were recorded. Bioturbation Intensity (BI) was assessed (and averaged) for every 10cm interval of Bluesky formation core following Taylor and Goldring (1993). This method is a quantitative assessment of bioturbation from 0-6, where 0 indicates un-burrowed sediment and 6 reflecting 100% bioturbation. This data was then used to construct graphs showing the relationship of bioturbation intensity vs. depth.

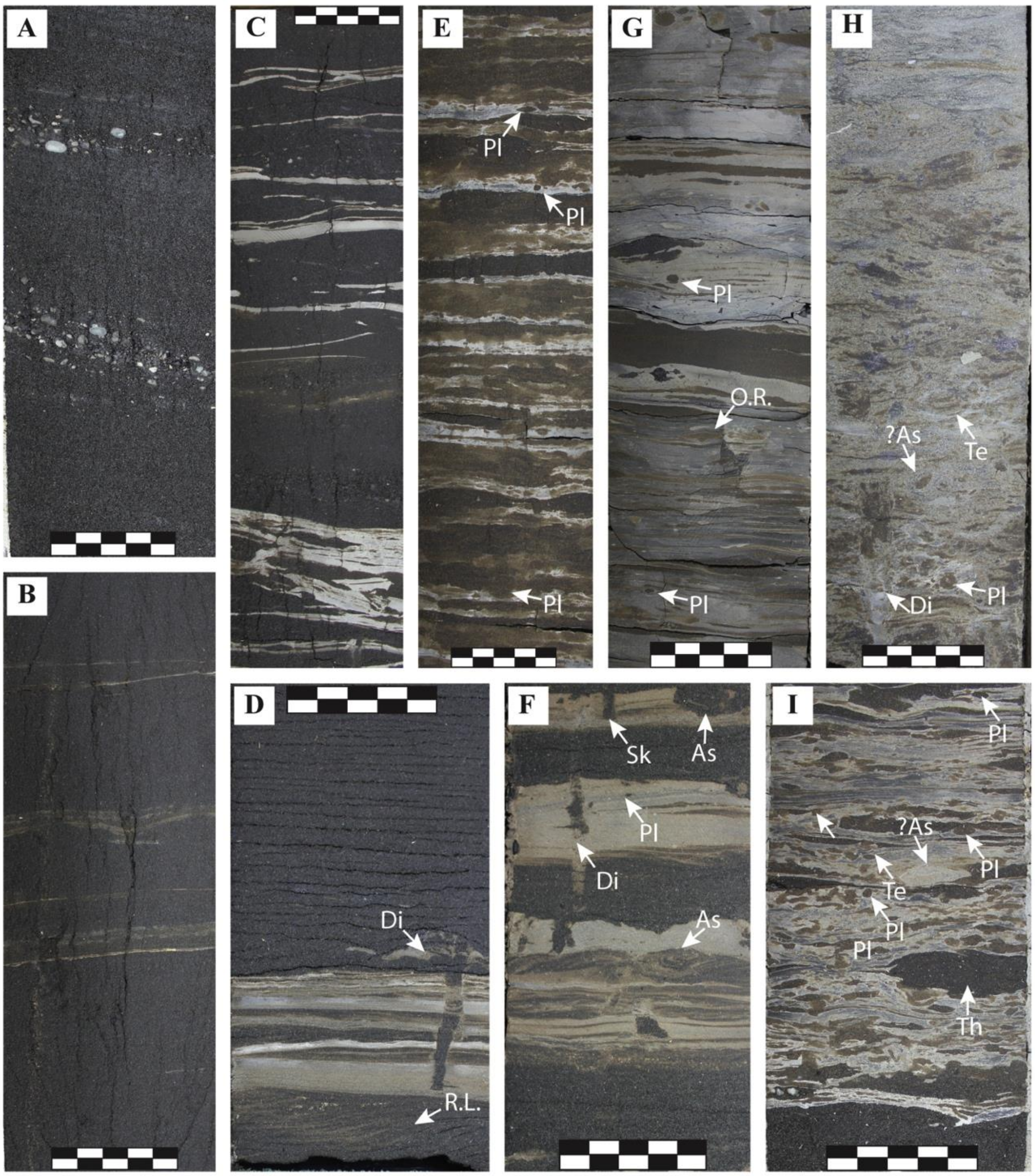
Results

Using the data collected, seven distinct facies were identified, F1-F7 (Table 1, Figure 2). These facies are primarily divided by lithology and include, sand-dominated (<10% mud), heterolithic (10-90% mud), and mud-dominated (<10% sand). Subdivision of these lithologies were based on the primary physical structures for sand-dominated facies, whereas heterolithic and mud-dominated facies were sub-divided based on bioturbation index and trace fossil assemblage.

Table 1. Summary of facies characteristics identified in cores 05-29-082-16W5 and 10-18-084-16W5.

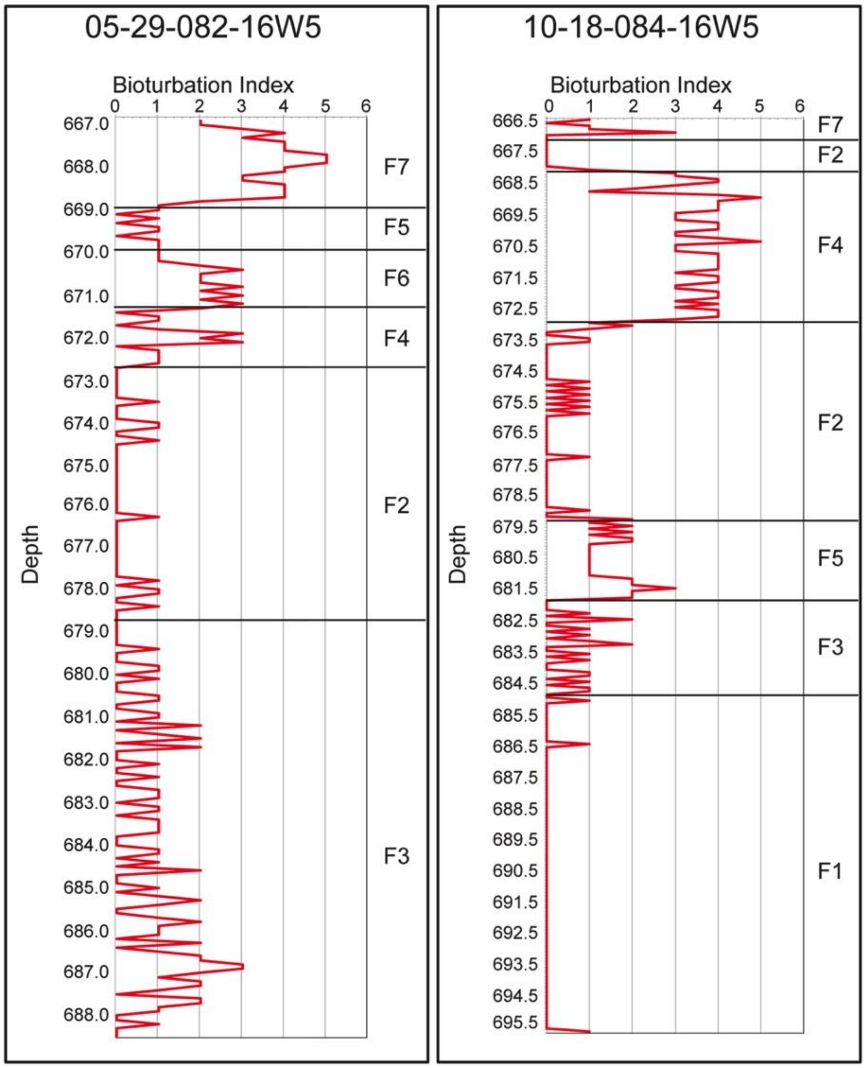
Facies	Physical Sedimentary Structures	BI	Trace Fossils	Lithologic Accessories	Depositional Interpretation
F1 High-angle planar bedded sandstone	High-angle planar tabular bedding, cross-bedding, scour surfaces, current ripples.	0	*None observed*	Pyrite & coal lamina, pebble lags, shell fragments, mud clasts	Distributary Channel
F2 Low-angle planar bedded sandstone	Low-angle planar tabular bedding, minor wavy parallel bedding, and rare scour surfaces.	0-2	*Planolites, Skolithos, Paleophycos, Thalassinoides*	Coal lamina, mud clasts, shell fragments, mica flakes, shell debris	Bay-Margin Shoreface
F3 Heterolithic sandstone and mudstone	Wavy parallel bedding, low to high-angle planar tabular bedding, combined flow ripples, scour surfaces, possible HCS	0-3	*Planolites, Skolithos, Paleophycos, Teichichnus, Thalassinoides, Arenicolites, Asterosoma, Cylindrichnus*	Mud clasts, coal fragments, pyrite, shell fragments, occasional pebble lags, coal lamina	Bay-Margin Delta Front
F4 Bioturbated heterolithic sandstone and mudstone	Wavy parallel bedding, bioturbated bedding	2-5	*Thalassinoides, Teichichnus, Planolites, Skolithos, Arenicolites, Cylindrichnus, Paleophycos*	Mud clasts, pyrite, coal fragments, shale lamina, shell fragments	Sheltered Bay-Margin Delta Front?
F5 Laminated Mudstone	Wavy parallel bedding, lenticular bedding, combined flow ripples, soft sediment deformation	0-3	*Skolithos, Planolites*	Sand lamina, pyrite, shell debris, coal fragments	Prodelta?
F6 Bioturbated Mudstone	Wavy parallel bedding, bioturbated bedding, lenticular bedding	3-5	*Planolites, Thalassinoides, Teichichnus, Asterosoma, Skolithos, Arenicolites*	Pyrite nodules, sand lamina, mud clasts	Bay
F7 Bioturbated muddy sandstone	Bioturbated bedding, *Glossifungites* surface	0-5	*Diplocraterion, Skolithos, Asterosoma, Thalassinoides*	Abundant glauconite, mud to pebble sized grains, pyrite	Open Marine (Offshore)

Figure 2. Seven Bluesky facies identified from Wells 05-29-082-16W5 and 10-18-084-16W5. A) F1-High-angle planar tabular bedding and pebble lags. Well 10-18-084-16W5. B) F2-Low-angle planar tabular bedding with disseminated pyrite lamina, Well 10-18-084-16W5. C) F3-Heterolithic sandstone with mud drapes, note coarse-grained lags, Well 10-18-084-16W5. D & F) F3-Heterolithic sandstone with thicker mud beds, ripple lamination (R.L.) and trace fossils *Diplocraterion* (Di), *Skolithos* (Sk), *Asterosoma* (As) and *Planolites* (Pl), Well 05-29-082-16W5. E) F4-Heterolithic, wavy parallel sandstone and mudstone showing mottling of sand and mud beds due to higher degrees of bioturbation, Well 10-18-084-16W5. G) F5-Wavy parallel and lenticular bedded mudstone, low BI index with *Planolites* (Pl) and small oscillation ripples (O.R.) in very-fine sand lens, Well 10-18-084-16W5. H) F7-Highly bioturbated muddy & silty sandstone with trace fossils *Asterosoma (As), Teichichnus (Te), Planolites (Pl) and Diplocraterion (Di),* Well 05-29-082-16W5. I) F6-Bitourbated mudstone with sand lenses and trace fossils *Thalassinoides* (Th), *Planolites* (Pl), *Teichichnus* (Te) *and ?Asterosoma* (As).



The results of graphing the bioturbation intensity vs. depth are shown in Figure 3. In general, a few observations can be made. The uppermost stratigraphic facies of both wells display the highest bioturbation intensity (F7). Although better developed in 10-18-084-16W5, both wells display an overall increase in bioturbation upwards. Finally, although certain facies (F4, F6 and F7) display moderate to high bioturbation intensity, the overall bioturbation is relatively low.

Figure 3. Graph showing the relationship of bioturbation index versus depth within the Bluesky formation interval.



Interpretation

It is difficult to confidently prescribe depositional environments to the data set based on its limited size. However, combining the lithologic, physical and accessory properties of the facies with the observed bioturbation intensity and trace fossil assemblage, preliminary interpretations can be attempted.

F1-High-Angle Planar Bedded Sandstone (BI 0)

This facies is interpreted as a distributary channel. This is based upon the high-angle planar and cross-bedding nature of beds, overall coarse grainsize, numerous scour surfaces, granule to pebble lags, and current ripples. Numerous coal/pyrite rich beds suggest strong fluvial influence introducing terrestrial organic debris into the system. Additionally, the nearly complete lack of trace fossils suggests an extremely stressed environment uninhabitable to burrowing organisms. This stress is interpreted to result from persistently shifting substrates.

F2-Low-Angle Planar Bedded Sandstone (BI 0-2)

This facies is interpreted as a wave-influenced bay-margin shoreface. Bedding appears as low-angle planar and wavy parallel bed sets with a scarcity of current generated structures. These features, combined with a general lack of mud suggest wave reworking of the sediment. The presence of coal/pyrite beds, and local scour surfaces suggest a proximal location to the shoreline. In addition, bioturbation index for this facies is low, and an Ichnofossil assemblage consisting of suspension/deposit feeding *Planolites, Skolithos, Thalassinoides* and *Paleophycos.* This assemblage, combined with the observed sedimentary structures indicates higher wave energy conditions during deposition of this facies.

F3-Heterolithic Sandstone and Mudstone (BI 0-3)

This facies is interpreted to be a wave-influenced bay-margin delta front. High-angle planar tabular bedding, combined flow ripples, scour surfaces, and occasional granule and pebble lags suggest a strong current influence affecting this facies. Wave influence is suggested by the presence of hummocky cross-stratification (HCS) and low-angle planar tabular bedding, indicating that tidal/current energies were insufficient to completely rework the sediment. This facies displays mm to cm thick mud beds which are seen to locally truncate underlying sand and mud beds. We interpret these mud beds as freshets deposited during periods of high river discharge. This interpretation is supported by the presence of numerous vertical trace fossils, including *Diplocraterion, Skolithos* and *Cylindrichnus,* which appear to originate from the sand below these mud beds and terminate in the sandy units above.

F4-Bioturbated Heterolithic Sandstone and Mudstone (BI 2-5)

The interpretation of this facies is less certain. Given the low energy nature of sedimentary structures (dominantly wavy parallel), with the high degree of bioturbation mottling we interpret this facies as sheltered bay-margin delta front. The trace fossil suite present is diverse with a mixture of deposit and suspension feeding forms including *Planolites, Skolithos, Thalassinoides, Arenicolites, Cylindrichnus, Teichichnus* and *Paleophycos.* This assemblage, coupled with BI values of up to 5, infer an environment with low sedimentation rates and high biomass, which can be used to infer abundant food resources (Gingras et al. 2008). Abundant food resources are often present in bay environments (M.K. Gingras, pers. comm., 2014).

F5-Laminated Mudstone (BI 0-3)

The interpretation of this facies is uncertain. Given the overall mud-dominated lithology and the thin, combined flow rippled sandstone lenses, we interpret this facies as occurring within a prodelta environment. The low degree of bioturbation and general lack of diversity suggests that this environment was inhospitable to burrowing organisms. Stresses limiting the ability of organisms to burrow in the prodelta environment can result from rapid sedimentation and influence of brackish water associated with hyperpycnal flows (Bhattacharya, 2010).

F6-Bioturbated Mudstone (BI 3-5)

This facies is interpreted as an offshore bay environment. The wavy parallel and bioturbated nature of the bedding coupled with dominance of silt and mud sized sediment suggest deposition in a quiet environment largely unaffected by physico-chemical stresses. The Ichnofossil assemblage is diverse and is characterized by *Planolites, Thalassinoides, Teichichnus, Asterosoma, Skolithos,* and *Arenicolites*. This assemblage is consistent with marine salinities and low energy, deposit-feeding behaviors.

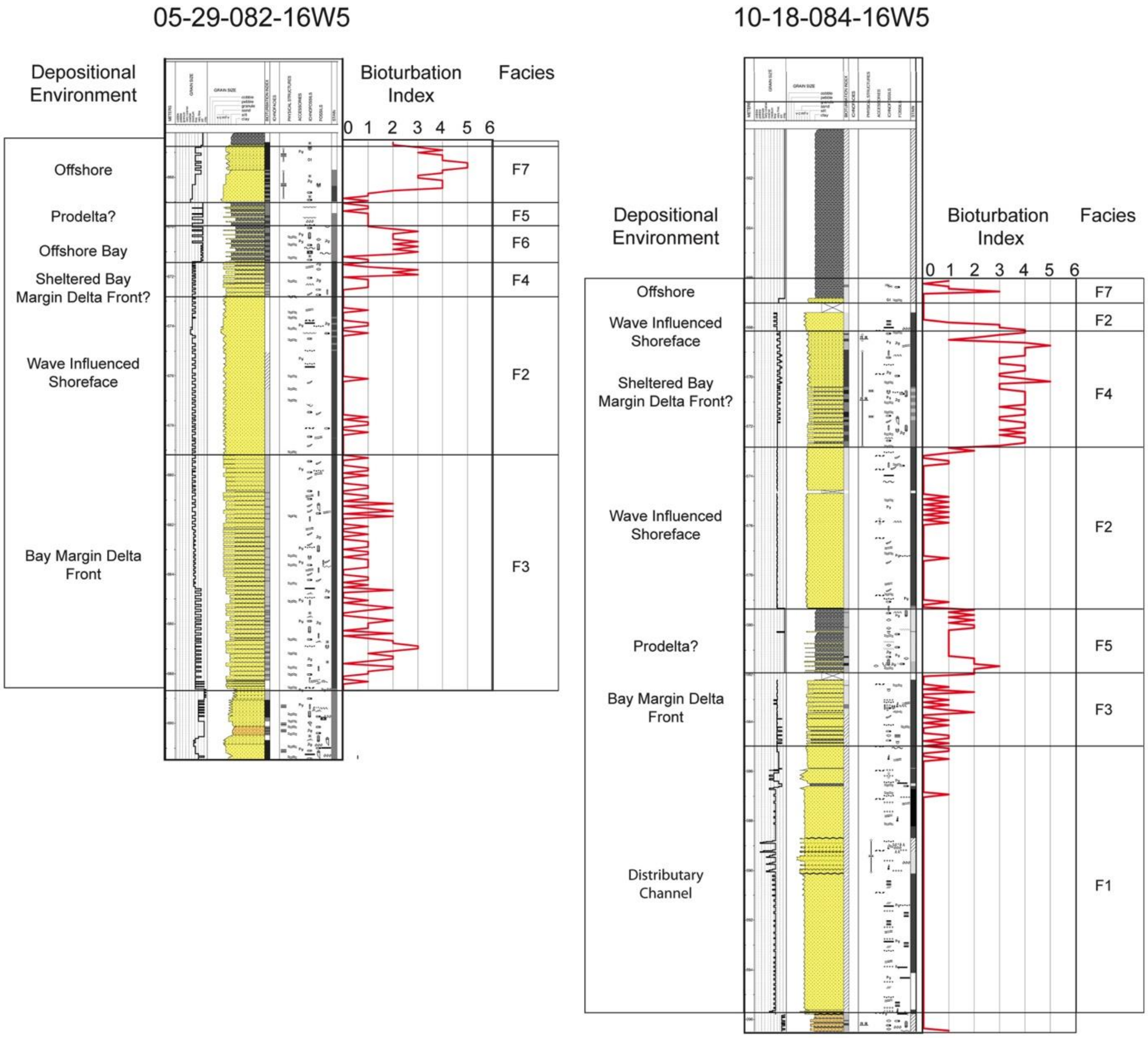
F7-Bioturbated Muddy Sandstone (BI 0-5)

This facies characterized the uppermost unit in both wells documented. It is interpreted as an open marine, offshore environment. Bedding is frequently obliterated by bioturbation, with trace fossils including, *Thalassinoides,* robust *Diplocraterion, Asterosoma* and *Skolithos,* representing a marine assemblage. Further evidence of the open marine setting is the abundance of glauconite grains and the transition into marine offshore shales of the Wilrich Member above.

Discussion of the Importance of Observing Bioturbation Intensity

Overall, BI increases upwards stratigraphically, and when coupled with the progressively more marine trace fossil assemblage shows an overall transgressive nature of Bluesky formation (Figure 4). The presence of the overlying marine shales of the Wilrich Member above the offshore marine deposits of F7 further supports these observations. However, combining BI with lithology we can also identify apparent regressive parasequences within this overall transgression. Parasequence tops showing high BI values (indicating low stress, more distal conditions, and limited accommodation) are erosionally truncated by facies with low BI values (indicating higher stress, more proximal conditions). An example is seen in Well 10-18-084-16W5 where shoreface deposits of F2 erosionally overly prodelta deposits of F5. The observed BI values also illuminate possible physico-chemical stresses acting upon each environment. For instance, the lithologic composition of prodelta deposits (F5) and offshore bay deposits (F6) are essentially the same but their BI values differ significantly. From this, we can infer that physico-chemical stresses acting upon the prodelta (low BI) such as high sedimentation rates and brackish water input are largely absent in the offshore bay environment. This study shows that the careful documentation of bioturbation intensity and trace fossil assemblages, in combination with sedimentary properties can enhance the ability to make reliable facies interpretations. In addition, BI helps infer physico-chemical stresses acting upon these facies that when based solely on sedimentary characteristics may not be possible.

Figure 4. Visual comparison and correlation of bioturbation index, lithology, facies and inferred depositional environments from Wells 05-29-082-16W5 and 10-18-084-16W5. Note the general increase in overall bioturbation upward and the individual parasequences identified by sharp changes in lithology and bioturbation index.



Acknowledgements

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