Abstract

In Pursuit of a High-Latitude Signature During the Late Cretaceous Greenhouse: A Comparison Between Shallow Marine Storm Deposits in the Schrader Bluff Formation, Alaska, and the Kenilworth and Grassy Members of the Blackhawk Formation, Utah

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Identifying a latitudinal signature in marine deposits from greenhouse periods can be difficult because few studies describe ancient high-latitude, siliciclastic systems or compare them to time-equivalent, lower-latitude depositional systems. The purpose of this investigation is to compare high- to mid-paleolatitude Late Cretaceous (Campanian) progradational shallow-marine clastic successions. Storm-dominated shallow-marine deposits of the Schrader Bluff Formation (Fm) deposited at ~83–84° N in the paleo-Arctic Ocean are compared to the Kenilworth and Grassy members of the Blackhawk Fm deposited at ~46° N in the Western Interior Seaway. This study describes 54 m of stratigraphic section measured at Shivugak Bluffs along the Colville River in Arctic Alaska, and compares it to 75 m of stratigraphic section measured in the Book Cliffs, near Woodside and Green River, Utah, in the United States. Preliminary results suggest that there are recognizable and quantifiable differences between storm deposits formed in the paleoArctic Ocean and those of the Western Interior Seaway. These differences can be seen in stratigraphic architecture; paleotopographic relief on bounding surfaces; and the thicknesses of amalgamated hummocky cross-stratified (HCS) sandstones, lithofacies, and trace-fossil assemblages. Because the measured interval in the Schrader Bluff Fm contains well-sorted sandstones and thick (3.0–4.0 m) amalgamated HCS sandbodies, we suggest that variations may reflect stronger, more frequent, or longer-lasting storms at high latitudes. In contrast, measured intervals in the Blackhawk Fm typically contain poorly sorted sandstones with thin (0.5–2.0 m), amalgamated HCS sandbodies commonly separated by waning-flow sedimentary structures and muddier intervals. Single- and multistory channels interbedded within the Schrader Bluff HCS succession may have formed during coastal set-down events or from onshore storm runoff. *Ophiomorpha* is extremely rare in the Schrader Bluff Fm, but is ubiquitous at lower latitudes during the Campanian, suggesting water-temperature or wave-energy control. This study presents new possibilities as to possible high-latitude signatures during the Cretaceous greenhouse climate.

Introduction and Background

Studies of modern marine systems indicate that storm frequencies and intensities vary with latitude and climate (Allan and Komar, 2000). Arctic and temperate coasts experience a *storm wave climate* due to frequent storm activity, whereas low-latitude coasts experience a consistent, year round *swell wave climate* owing to infrequent storms (Davies, 1980). Waves generated by storms are controlled by wind speed, storm duration, and fetch length (Komar, 1998). As a result of winter sea-ice conditions, sediment transport and deposition along modern Arctic shorelines occur almost exclusively from summer and autumn storms (Hill et al., 1994). Unlike seas of the modern Arctic, the Late Cretaceous Arctic Ocean is thought to have been predominantly ice free because of elevated greenhouse temperatures (Francis and Frakes, 1993). Therefore, the frequency, intensity, and duration of storms in the Late Cretaceous Arctic Ocean may have been greater than those in the modern Arctic (Brandt and Elias, 1989), and storm events recorded in the rock record at lower latitudes may be less dramatic. Hummocky cross stratification (HCS), identified as a signature of storm-wave activity, is used as an indicator of storm-dominated shallow marine environments (Brandt and Elias, 1989). Quantitative relationships between HCS wavelengths and wave orbital diameters have been used to predict wave-height variations for paleoenvironmental reconstructions (Yang et al., 2006). The goal of this study is to use characteristics of Upper Cretaceous storm-dominated shallow-marine strata to address the following questions: (1) Are disparities between storm processes active at high and middle paleolatitudes during greenhouse conditions preserved in the rock record? (2) If so, are these distinctions a product of the geographical setting or varying sedimentation rates, or can these distinctions be used to identify a high-latitude signature? (3) Can modern observations about storm frequency and intensity at high and lower latitudes be applied to the geologic past?

All three successions compared in this investigation are Campanian; however, constraining sedimentation rates for each interval are problematic. Also, the geologic setting of the Colville Basin along the paleo Arctic Ocean is different from the Cretaceous Western Interior Seaway (CWIS). The Colville foreland basin was not affected by dynamic subsidence (slab pull from a subducting slab below the basin), which affected the North American Cordilleran foreland basin in Utah (Aschoff and Steel, 2011). The paleo Arctic Ocean is also thought to have had larger fetch dimensions and was deeper than the CWIS, and had a greater shelf-slope break. The distance of sediment source-to-sick was also up to three times longer in Alaska than in the CWIS. Shoreline orientations were similar, trending N–S for the Schrader Bluff Fm, NNW–SSE for the Kenilworth Member, and N–S or NNE–SSW for the Grassy Member. There are also some fundamental differences in the biota that comprise the Late Cretaceous biozones, owing to temperature and water-mass controls.

Data

Three stratigraphic sections containing HCS were measured: 54 m from the Schrader Bluff Fm in Alaska, 41 m from the Kenilworth Member and 34 m from the Grassy Member of the Blackhawk Fm in Utah. The outcrop expression of the Schrader Bluff Fm consists of steep, cliff-forming walls of sandstone (up to 14-m high), whereas the outcrop expression of the Blackhawk Fm consists of multiple tiers of irregular ledges ranging from 0.10–2.20 m high. The Schrader Bluff succession contains amalgamated packages of HCS that stack horizontally and discordantly, causing deposits to build laterally. Typically, the Alaska succession has greater erosional relief on bounding surfaces, whereas the Utah successions have near-horizontal, flat-lying bounding surfaces. Interbedded in Schrader Bluff Fm HCS intervals are pockets of soft-sediment deformation (0.5 m thick) and single- and multistory channel deposits (up to 2 m thick) with basal lags consisting of logs, black chert pebbles, shell debris, and mud-rip-up clasts. On the basis of the Myrow (1992) classification scheme, gutter casts in the Blackhawk Fm commonly are laterally discrete, deeply rounded, and have a structureless infill, whereas only a few gutter casts in the Schrader Bluff Fm are laterally connected by thick beds, are shallowly rounded, and infilled with matrix-supported basal lags. Very fine- to fine-grained amalgamated HCS sandbodies are 0.5–2.0-m thick in Utah and are 3.0–4.0-m thick in Alaska. On the basis of relative abundances, the preservation of symmetric and asymmetric ripples is greater in Utah than in Alaska. Overall, the Alaska succession is better sorted compared to the Utah successions. Grassy and Kenilworth bedforms have muddier bases that clean upward and are often separated by lenticular, wavy laminations, or thin beds of ripples. Inoceramid shell debris is common in the Schrader Bluff Fm, but was not documented in the Blackhawk Fm. Mid-latitude successions in Utah typically contain abundant *Ophiomorpha* burrows, whereas high-latitude successions in Alaska lack *Ophiomorpha* but contain abundant *Helminthopsis* and *Phycosiphon* (vermiform) burrows.

Preliminary Results, Discussions, and Conclusions

The high-paleolatitude Schrader Bluff Fm may have been subjected to stronger and perhaps longer storm events compared to coeval shoreface successions of the Kenilworth and Grassy members of the Blackhawk Fm at lower latitude. This dissimilarity is evidenced by the complexity of discordant stacking patterns within HCS architecture, greater relief on erosional bounding surfaces, thicker amalgamated HCS sandbodies, and the presence of basal lags within subaqueous channels and gutter casts. The Schrader Bluff Fm contains better-sorted sandbodies preserved as vertical walls of clean sand, whereas the Blackhawk Fm contains frequent muddier or thin-bedded intervals with lenticular or wavy laminations between amalgamated HCS beds. Compared to the Blackhawk Fm, the Schrader Bluff Fm generally lacks waning-flow indicators (ripples) or fairweather deposits (mudstone) between HCS intervals. The lack of waning-flow indicators in the Schrader Bluff Fm suggests either storm reworking or longer storm events occurring within the system. If we assume that a storm event is indicated by the sandbody thickness preserved between an erosional base and waning-flow indicators at the top, the Schrader Bluff storm events can be up to four times as thick as the Blackhawk Fm storm events, suggesting that the Arctic was subjected to stronger, longer, or more-frequent storm activity. This assumption, however, can be problematic because of the lack of constraints on sedimentation rates and accommodation. Single- and multistory channel bodies interbedded with HCS in the Schrader Bluff Fm contain sedimentary structures (trough crossbedding) that indicate a seaward paleoflow during deposition. Subaqueous channels are interpreted as rip channels that formed from erosion and deposition related to coastal set-down following either large coastal set-up events or storm runoff from onshore. Subaqueous channels are not found encased in HCS intervals within the Blackhawk Fm. Preservation of trace fossils and type of biota are different between these two latitudinal regimes, which was not surprising because strata in the CWIS have better biostratigraphic control than strata in Arctic Alaska. Abundant *Ophiomorpha* burrows within the Blackhawk Fm indicate that the CWIS supported large populations of shrimp. The absence of *Ophiomorpha* in Alaska deposits suggests that the Arctic Ocean may have been too cold or energetic to sustain shrimp populations.

Although prior research suggests HCS wavelength may reflect wave heights and storm intensities (Yang et al., 2006), the upper portion of the bedform may not always be preserved, or HCS may be amalgamated. Although similar HCS wavelengths were recorded for both the Schrader Bluff and Blackhawk formations, data may be insufficient to merit proper statistical analysis or conclusions about storm intensity. HCS wavelength can also depend on the depth and shape of the ocean floor (McInnes et al. 2003). Relatively wide and shallow continental shelves may cause storm-surge heights to amplify. Although the Schrader Bluff and Blackhawk formations were deposited in different geographical settings with varying tectonics and distance to sediment source, and sedimentation rates for each section are unconstrained, preliminary results suggest the presence of drastic variations in storm deposits as well as the biota in these latitudinal regimes. Overall, the paleo Arctic shoreline and shelf appear to have been influenced by conditions stormier than those affecting the CWIS. Results from this investigation indicate that uniformitarism may be applied, because key differences preserved in the rock record suggest evidence for heightened storm activity at high latitudes. Storm deposits interpreted in this investigation support the concept that the degree of storm-driven sedimentation may serve as a high-latitude signature during the Cretaceous greenhouse.

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