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BEDLOAD TRANSPORT OF MUD ACROSS A WIDE, STORM-INFLUENCED RAMP: CENOMANIAN–TURONIAN KASKAPAU FORMATION, WESTERN CANADA FORELAND BASIN—DISCUSSION

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We would like to comment on a recent paper by Plint et al. (2012) that discusses mud transport across a Cretaceous shelf. The authors have taken to heart recent research that advocates looking for evidence of bedload transport of aggregated clays, and we are comfortable that much of the clay component in the Kaskapau Formation did indeed arrive via bedload transport rather than simply settling out of the water column. However, whereas we are perfectly comfortable with the proposed mode of transport, we do have several concerns and suggestions concerning one type of mud aggregate discussed by Plint et al. (2012).

In the depositional model that the authors present (their fig. 16), they envision that cohesive mud is reworked by storms into intraclasts and that these then are carried across the seabed in bedload. That in itself is no problem, because it can be shown in experiments that surficial muds with as much as 85% water content can be transported as millimeter-size aggregates for considerable distances (Schieber et al. 2010). One class of aggregates, however, described as intraclastic aggregates (IAs for the remainder of this manuscript) by the authors, did capture our attention. The authors state that "*Storm wave reworking of the seafloor produced intraclastic aggregates…because the mud had been rendered cohesive by the chemical compaction and biostabilization processes that operated shortly after deposition.*" We are aware that surficial sediments can gain enhanced cohesion and improved erosion resistance due to mucus from benthic worms and endo-sedimentary microbes, but we are not quite sure what the authors mean by chemical compaction. If they mean that cementation renders the muds firmer and more cohesive, it would have been rather appropriate to document this critical factor in the aggregates in question. By definition, intraclasts are grains that form by syndepositional erosion of partially lithified sediment, yet looking at the images provided by the authors, there does not seem a preponderance of cement in evidence. Also, given the overall high sedimentation rates that the authors mention in their introduction, it seems rather difficult to accomplish much in the way of early cementation in these sediments.

What is even more problematic is the remarkable degree of lithification that their IAs display. The authors describe them as "*partially compacted intraclastic aggregates the composition of which is dominated by clay minerals with some organic carbon and pyrite.*" No mention of early diagenetic cementation is made. While we agree that their images do show some deformed aggregates that may have been still soft at the time of deposition, a remarkable proportion of these IAs appear well rounded (their fig. 12B) and do not appear to have suffered vertical shortening due to burial compaction. Even those IAs where one could make an argument for burial compaction (their fig. 10F) do suggest that the grains still had about 50% porosity. This is perplexing to us because on one hand the authors propose that these grains were derived from seafloor sediments during storm wave reworking, yet neither of us has ever encountered near-surface (meaning the uppermost few meters) ocean sediments with such a high degree of consolidation.

Many papers have been written on the state of compaction of surficial sediments, and the literature on the topic has been well summarized in a recent paper by Kominz et al. (2011). Our own experience with muddy ocean sediments, from shelf, slope, and deep-sea settings, collected on numerous coring expeditions in particular by one of us (Bennett), as well as from experimental work (Schieber 2011), suggests that as a rule surficial muds start out with 80–90% porosity (or water content), and that it takes considerable burial before these muds are compacted to even 50% porosity (e.g., Bennett et al. 1991). According to Kominz et al. (2011) we should actually expect between 200 to 300 m of burial for such a degree of compaction and dewatering. One could of course argue that under certain circumstances, such as very slow rates of deposition, surficial muds might attain higher levels of compaction close to the sediment–water interface, but as far as we are aware no such occurrence has been documented from modern sediments, and neither has a single compelling case been made for ancient mudstones.

In the introduction to the paper by Plint et al. (2012) both flocculation and reworking of surface muds by wave action are called upon as aggregate-forming processes. Yet, because such particles are likely to have an initial water content of 80–90% they would be severely flattened by the time we have a chance to observe them in the rock record (see examples in Schieber et al. 2010, Schieber 2011). They would be thin streaks with a H/W ratio of 0.1 to 0.125 and show compactional deformation and bending around harder grains (Schieber et al. 2010). The general absence of these features in the IAs of the Kaskapau Formation is a clear indication that these grains were close to the compaction state of the present rock when deposited, and as such are more plausibly attributed to either (1) pedogenic particles (e.g., Nanson et al. 1986), or to (2) material that was generated by eroding older mudstone successions that were exposed in the source area due to tectonic uplift or lowering of sea level. As such, the so called IAs may actually not be intraclasts at all, but lithoclasts that were derived from outside the environment of deposition.

In the photomicrographs that the authors supplied of these mudstones, the IAs in question are in the very fine sand to silt size range, and the rocks also contain quartz grains in that same size range. Assuming that bedload transport was responsible for moving these grains across the Kaskapau shelf, and applying the principle of hydraulic equivalence to IAs and quartz grains, this strongly suggests that at least the well rounded IAs were of a density similar to that of quartz grains and thus were most likely fully consolidated mudstone particles. Such a relationship makes perfect sense if the IAs were derived from older consolidated strata, but is

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very hard to explain if one prefers to erode them from the contemporaneous seabed. In the former case, the IAs are nothing more than detrital grains of an unusual composition (they are rounded mudstone clasts), and that circumstance may also explain another observation related by the authors. Plint et al. (2012) state that although they expected to find evidence for wave-enhanced sediment gravity flows, the supposedly diagnostic "triplet" style of bedding (Macquaker et al. 2010) was notably absent from their samples. They concluded that this type of sediment gravity flow was apparently not active on the Kaskapau shelf. The reason for the absence of wave-enhanced sediment gravity flows is actually rather simple if one accepts that the so-called IAs are lithoclasts and were not reworked from the contemporaneous seabed. Wave-enhanced sediment gravity flows imply sediment transport in the form of a bottom-hugging fluid mud layer (Macquaker et al. 2010). However, if, as suggested by the authors, the transported material was predominantly very fine sand to silt size particles (quartz grains and mudstone lithics), wave reworking would not have been able to generate a fluid mud layer from this material, and the search for "triplets" is therefore moot.

Whereas at first glance the Kaskapau Formation seems dominated by mudstones, closer examination by Plint et al. (2012) has shown that, from a sediment transport perspective at least, a good portion of these strata are actually siltstones. Although we disagree with the authors on the origin of the contained mudstone clasts (their IAs), the presence as well as abundance of these clasts nonetheless suggests that we would be well advised to examine other shelf mud successions for comparable grain types. It may very well be that mudstone lithoclasts are much more common in the sedimentary rock record than currently appreciated. In opposition to this view, some might argue that mudstone clasts are rather soft when compared to quartz silt and thus should be reduced in size rather rapidly during transport. Yet, whereas this is definitely the case for centimeter-size clasts (Smith 1972), the same argument probably does not apply to silt-size mudstone clasts. Just as silt-size quartz grains do not show significant rounding because they spend much of their transport history in suspension, and when in bedload experience only small impact forces (Blatt 1992), one may reasonably assume that silt-size mudstone clasts should be able to survive large transport distances for the very same reason. The study by Plint et al. (2012) reinforces the notion that careful petrographic examination of the mudstone rock record is long overdue, and when applied systematically is likely to radically change the way we think about the origin and deposition of these rocks that constitute two thirds of the sedimentary rock record (Schieber 1998, 1999).

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