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When storms go bad: their impact on gutter cast distribution and dimensions, based on new data from the Miocene of eastern Borneo

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Summary

Gutter casts are downward bulging sole structures formed by a process of (scour) erosion followed by deposition. First described in 1975, published descriptions range from structures a few centimeters in size to gutter casts around a metre wide and decimetres deep. New data from a huge, Miocene section in eastern Borneo provide dimensions of giant gutter casts that may reach five or more metres in width and metres in depth. The extent of the outcrop allows for the examination of lateral variation as well as vertical changes in gutter cast size and concentration. This data demonstrates that these features result from net offshore transport over a wide area, rather than the isolated cells more typically of rip currents. The size and density of the gutter casts is interpreted to reflect the ferocity of the storms bombarding the Miocene Borneo coastline.

Supporting data both from other outcrops of the Sandakan Formation, as well as gutter casts from the Ordovician and Jurassic of the United Kingdom, from the Cretaceous Book Cliffs, and from Cretaceous carbonate deposits of the Zagros Mountains, provides further data on the typical fills of these scour features. In contrast to earlier published material, the fills appear to be dominated by hummocky and swaley cross-stratification, with some indication of scour edge parallel stratification. The scoured surfaces characteristically show terraced surfaces, with steep sidesteps, sometimes with overhanging sandstone deposition, scouring into fine grained mudstone beds. Other scours are more undulating in character. The size and scouring of these deposits is of relevance for reservoir connectivity.

Introduction

The term "gutter cast" was coined to describe a number of scour and fills structures previously called by a variety of names (Whitaker 1975). They are down bulges on the baottoms of sedimentary strata, usually one mtre or more in length, and up to several decimetres in depth. In cross-section they may occur as U or V shapes, often with flat bases, and may have vertical or even overhanging sides (Whitaker 1975). They have a gutter-like appearance in cross-section. Loaded gutter casts appear to be rare, ands the overhanging walls are original features.

Whitaker describes the fill as dominantly calcareous or sandstone (referring to gutter casts from the Silurian of southern Norway). Where the fill is laminated the laminae are flat lying or slightly sagging (Whitaker 1975), or massive (Myrow 1992). The gutters appear current parallel, as demonstrated by aligned fossils and other features, and are oriented perpendicular to the coastline (Myrow 1992 and other authors). They may include striation casts and sole marks (Myrow 1992) along the margins.

The gutter casts form by eroding currents. Several models have been proposed (Myrow 1992), but the most appropriate appears to be helical flow vortices. Gutter casts characterise sedimentation in the bypass zone, and develop during storms when strong currents transport sediment to the outer shelf (Perez-Lopez 2001). They are often associated with tempestites deposited on a muddy ramp, where the beds comprise hummocky cross stratified sediments. They may display an increase in width/thickness ratios towards the outer shelf (Perez-Lopez 2001).

Data collection

The data set comprises a series of sedimentological logs from outcrops across the Sandakan Peninsula. The Peninsula itself is approximately 20 km wide and 10 km from north to south. Large gutter casts have been identified from at least 30 separate outcrops, mostly defining a facies belt that stretches from West to East (Noad 2013). Every outcrop was logged at a cm scale, and numerous photographs taken to capture the gutter cats and other sedimentological features.

In addition to the logs, a detailed photo panel was captured at Taman Inda. At this locality a hill was literally carved in half to provide a flat area to construct a new housing estate. This left a unique (especially in southeast Asian terms) outcrop with just under 100 m of vertical section exposed over a lateral distance of some 600 m. The section preserves an overall progradational sequence commencing with lower shoreface to muddy shelfal deposits, shallowing up to a sand dominated upper shoreface sequence at the top of the outcrop. Of key significance to this study is the middle portion of the logged section, covering an interval of around 50 m. This section comprises heterolithic middle shoreface deposits, many of which exhibit extensive gutter casts. The lateral extent of the outcrop means that the vertical and lateral distribution of these features can be evaluated.

Observations from Borneo

The gutter casts of the Sandakan Formation are preserved within interpreted storm dominated, middle shoreface deposits (Noad 2013). Two lithofacies associations occur as end members of a submarine depositional system. Both are strongly heterolithic, featuring interbeds of hummocky cross-stratified sandstone. One end member is represented by very laterally persistent, tabular sandstone beds with flat bases. The sandstone beds are typically 20 to 100 cm in thickness, with hummocky cross-stratification capped by climbing ripples. There is a gradation to similar sandstone beds with deeply scoured bases, which may erode up to 2 m into the underlying mudstone beds.

These erosive surfaces are interpreted as gutter casts, and have a variety of characteristics. Some of the surfaces are undulating and rounded, with a channelized appearance. Others are terraced, with several flat lying steps, each parallel to bedding, stepping down to the base of the sand body. A typical scoured interval may range form 50 cm to as much as 20 m in width. In addition there are small gutter casts more typical of those in the published literature, with steep sides, sometimes overturned, and commonly exhibiting a V or U shaped cross-section. These are usually less than 50 cm in width.

The vertical distribution of the gutter casts at Taman Inda suggests that, as long as there is some sand in the system, then there is every chance that gutter casts will develop AND be preserved. The heterolithic part of the logged section spans some 50 m vertically, and interpreted gutter casts occur form the base to the top of the sequence, with one notable exception. A muddier portion midway up has few of these features, and may well represent a relative highstand. Data from other localities in the Sandakan Formation show that even where the net:gross reaches 100%, in the upper shoreface, it is still possible

to discern gutter casts. Here there is a sand on sand contact, but the style of erosional scour is similar, usually undulating in character.

Figure 1. Section exposed at Taman Inda in Sandakan

Most published material considers the fill of gutter casts to be massive or planar laminated. In contrast the gutter casts of the Sandakan Formation are typically filled with hummocky cross-stratified (HCS), fine grained, sandstone beds. Organic material deposited on the cross-strata picks out these structures. The fill is typically capped by climbing ripples. The intervening mudstones are generally featureless, but may contain starved ripples or thin sandy siltstone beds a couple of centimetres in thickness, thought to be deposited during small storms.

Figure 2. Large gutter casts exposed in the Sandakan Formation.

Other localities

Gutter casts are extremely common in the fossil record, and typically occur in shelfal settings characterised by heterolithic interbeds of sandstone and mudstone. Typical dimensions are similar to those proposed by Whitaker (1975), with a width of 20 to 100 cm and a depth of a few centimetres. While isolated pods of sandstone have steep or overturned margins, more typically the scour has a gently (concave up) curved base, which soles out to rejoin the flat base of the sand body. Good examples of these are seen in the late Devonian Pilton Shales exposed at Croyde Bay in northern Cornwall. Gutter casts with a similar character have also been identified in the Cretaceous Kazhdumi Formation of the Zagros Mountains.

Gutter casts of similar dimensions to those seen in the Sandakan Formation (and elsewhere in eastern Borneo, such as in Brunei) can be readily observed in a small side canyon branching off Tusher Canyon, close to Green River in Utah. These Cretaceous deposits bear an uncanny resemblance to those of Sandakan, with undulating or stepped, scoured, bases to the sandstone beds. Occasional steep margins may even be overturned in places, and the fine grained sandstone comprises HCS. The scour features typically have a width of 5 to 20 m. The intervening mudstone beds may include sandy stringers, also gutter casts as defined by their HCS fill and steep sides, or starved ripples.

Discussion

The apparent ubiquity of gutter casts in heterolithic, storm dominated shelfal deposits, suggests that where storms interact with muddy shelves, the likelihood is that scour will occur. A helical character to the currents is inferred by the steep sides to many of these features. The scour surfaces are either undulating, eroding down into presumably homogeneous mudstone, or terraced. In the latter case this is interpreted to indicate cyclic deposition within the mudstone intervals, which is picked out by the erosive nature of the scours.

The large size of the gutter casts recorded from Sandakan and Tusher canyon are interpreted to indicate unusually ferocious storms, with strong, offshore directed currents. Supporting evidence is provided by the HCS fill of these gutter casts. This may relate to climatic conditions, but could also relate to the coastal gradient. Some of these currents may be driven by the storms forcing water up onto the very shallow shelfal areas, close to the palaeo-coastline. This head of water would then be available to drive the offshore currents. The outcrop at Taman Inda readily demonstrates that the currents are spread along at least 500 m of coastline, and probably much more. Examining the section at Taman Inda, it is clear that the scouring of the gutter casts may significantly increase overall reservoir connectivity.

Previous interpretations of these scour structures by the author (e.g. Noad 2013, based on previous work by Gruszczynski et al 1993) postulated that rip currents were responsible for creating these scours. However re-examination of the extended section at Taman Inda suggests that the offshore directed currents are fairly laterally extensive. In contrast rip currents are usually quite narrow. When wind and waves push water toward the shore, that water is often forced sideways by the oncoming waves. This water streams along the shoreline until it finds a suitable exit route back out to the open water, straight out, at a right angle to the beach as a rip current. Rip currents are usually quite narrow, and are located in places such as where there is a gap in an offshore bar. Rip currents can potentially occur wherever strong longshore variability in wave breaking exists. Rips tend to be more common, wider and faster, wherever (and whenever) breaking waves are large and powerful.

Conclusions

New data from middle to upper shoreface deposits of eastern Borneo and the Book Cliffs demonstrates that gutter casts may be significantly larger than previously documented. Extensive outcrops also show that the driving force that created these scour features was not rip currents, but rather a laterally extensive body of water, associated with a storm surge, flowing in an offshore direction. Rip currents would show a more restricted series of outflow nodes. The large size of the gutter casts recorded in both localities suggests that storms in these areas were significantly larger than in many other areas of the world where gutter casts have been described in the fossil record. Overall gutter casts appear almost ubiquitous on muddy shelves wherever storms occur.

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