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Evidence to support near-steady flows (?) in an alluvial sandy system: the plateau formation Bako National Park, Sarawak

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Abstract: The sandstones at Bako are interpreted as having been deposited in a sandy braided stream environment. This system is characterized by variable discharge, high bedload, complex bar forms, high lateral mobility with low preservation of fine material. The dominant sediments, concurrent with this interpretation are large-scale cross-bedding and parallel laminations. However, other sediments, particularly thick units of structureless sands commonly liquified are thought to be anomalous to this type of setting. Three methods of 'massive' sand deposition are recognized (i) bed amalgamation, (ii) 'near steady' turbulent flow, and (iii) liquifaction. A turbidity current is thought to only be able to form during the 100 to 1,000 yr. storm event where a high concentration flow with high turbulence passes over a hydraulic jump. The unison of these three factors may allow the process of 'continual aggradation' to occur. Although this is thought to be rare these mega-storms have a high capacity to deposit large amounts of sediment, highly preservable in the rock record. However, with the benefit of extensive outcrops it can be recognized that the majority of structureless sands located at the Bako Peninsula are formed from the amalgamation of sands in the channel thalweg and the liquifaction of climbing ripple destroying the primary depositional fabric.

INTRODUCTION

The Bako Sandstones, form thick deposits, characterized by stacked channels infilled with cross-bedded, medium to coarse-grained sands. This type of sedimentology is common to many clastic systems, namely, fluvial, aeolian, deltaic and marine, and environments dominated by channels can often be so similar they can only be differentiated by microfossil analysis. The depositional process of cross-bedding is fairly well understood and is attributed to tractional transport developing ripple and dune morphologies (Allen, 1985). However, other features at Bako include thick 'massive' sands. A sedimentary feature often observed in the rock record but little understood, particularly in off-shore shelf settings, such as the Nummidian Flysch, Sicily, is where up to 320 meters of structureless sands are observed (Johansson *et al.*, 1998). The mode of transport and deposition of the structureless sands remains an enigma, with the deposits exhibiting few clues regarding the hydrodynamic processes involved. Understanding their formation in an alluvial environment may provide some insight into the processes depositing equivalent sediments in a deep marine setting.

LOCALITY

The rocks in question are located in the Kuching area, Southwest Sarawak, Malaysia Borneo and form the Bako Peninsular; a flat, gently dipping headland which can be seen protruding into the South China Sea (Fig. 1). The area is preserved as a National Park and numerous paths allow easy access to the outcrops (Johansson, 1997).

FACIES AND DEPOSITIONAL ENVIRONMENT: A SUMMARY

The summary of the facies and depositional environment is based on a paper written by Johansson (1999). Four types of clastic sediments are observed; pebble conglomerates, pebble-sands and medium-coarse grained sandstones. Each of

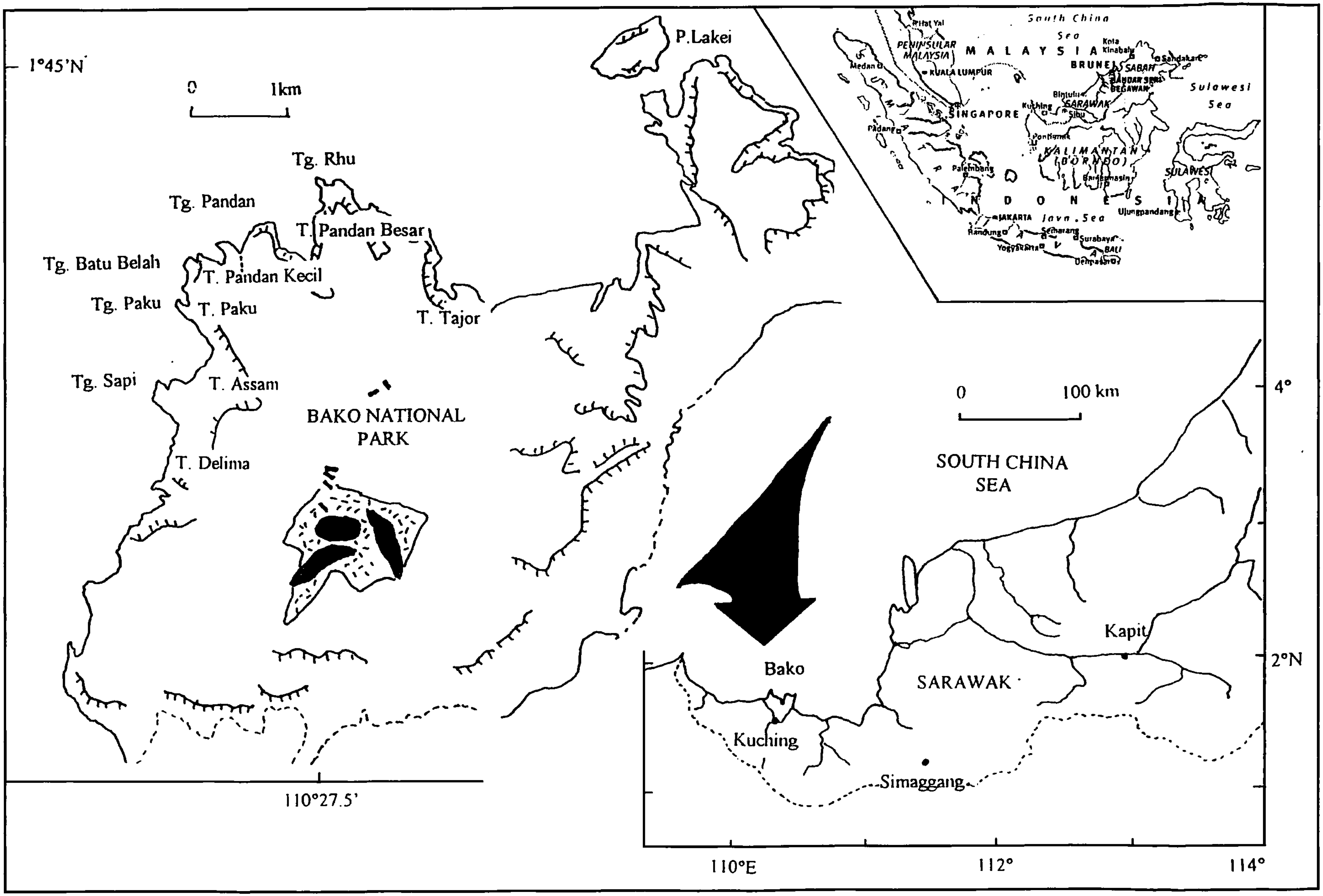

Figure 1. Locality map of Bako National Park, Sarawak.

these sediment types exhibit similar sedimentary structures. The dominance of parallel lamination and cross-bedding, indicate that the mode of transport was predominantly tractional, varying from lower to higher phase velocity currents. Other less common sedimentary structures, provide further information regarding the mode of deposition, particularly the dewatering features, which are intensely developed in some of the beds.

The sandstones and conglomerates at Bako Peninsular are interpreted to have been deposited in an alluvial sandy braided channel system, flanking a tectonically active scarp. The cross-bedded sandstone and conglomerates indicate a complex array of dunes and ripples, which migrated along a braided channel floor, gradually in-filling the accommodating space. The sandstone and conglomerate lenses, are thought to represent multiple channel fragments, which have stacked to form a composite channel body.

Channel Geomorphology

Two main channel morphologies are recognized in the Bako Sandstones. These include;

i. a lenticular shaped body, with little lateral extent (not more than a couple of meter's in length), characterized by cross-bedded sands and a gravel basal lag, and,
ii. a broad based channel, more laterally extensive (between 10–50 m), characterized by large- and small-scale cross-bedding, planar laminations and structureless beds.

The channels interfinger laterally and amalgamate vertically to form a tabular sandstone body, comprising Type (i) and Type (ii) geometry.

METHODS OF DEPOSITION

The Bako Sandstones are interpreted as having been deposited in a braided river system (Johansson, 1999). Continual flow, characteristic of this environment is inferred from the laterally extensive cross-bedded forsets and the paucity of mud (not observed even in the form of clay-drapes or rip-up clasts). These features suggest few sedimentation breaks within this type of environment. However changes in flow velocities are recognized and these variations are reflected in the sedimentary structures and grain-size.

Tractional bedload is dominant mode of transport during both normal and flood flow regimes. The sandstone beds exhibiting laterally extensive large-scale cross-bedding features represent dune migration during normal flow conditions, and the coarser lensoidal, sometimes conglomeratic units travel as tractional bedload during the high energy flash flood events.

The sediments infilling the scoured channels accumulate through vertical aggradation, and evidence of high rates of vertical bed accretion is demonstrated by the occurrence of climbing ripples sometimes cosets, up to 4 m thick. Lateral aggradation of the channel, is indicated by the numerous channel fragments, which are a result of the active conduits switching within a tract. Resistance to this lateral movement is low, due to the lack of fine material in the system, thus preventing the formation of a clay plug after channel abandonment.

'Massive' Sandstone Deposits

One type of facies that seems to poorly fit the braided-stream model is the thick beds (> 1 m) of structureless sands, that are observed intercalated with the cross-bedded, rippled and laminated sandstones (Fig. 2). The 'massive' sandstone beds tend to average 1 meter in thickness but can measure up to 6 m in height. The beds comprise medium to coarse-grained sandstone, commonly with small granules and pebbles dispersed throughout. The beds commonly exhibit non-erosional, planar or gradational basal surfaces, overlying and passing into either cross-bedded or laminated sandstones or dewatered sediments. No distinctive delineating surfaces are observed, except occasionally a thin veneer of pebbles.

Three modes of 'massive' sand deposition, are recognized in the Bako sands and are discussed here;

(a) Amalgamation

One type of process which appears to generate thick bodies of structureless sand, is bed to bed amalgamation. The merging of two beds requires the reworking of the predeposited sediments by a subsequent flow, which thus destroys the primary depositional fabric. The accumulation of numerous amalgamated beds can allow the build-up of thick structureless sands. The structureless beds are no longer delineated by bedding surfaces, but by incipient horizons. The lateral extent of these beds are very limited, and there occurrence is limited to the thalweg, tending to become cross-bedded towards the margin of the channel.

(b) 'Near Steady Flows'

A steady flow is defined as a succession of fluid particles through a point fixed in space having identical velocity vectors (Allen, 1985). In near steady flows, the fluid flow doesn't remain totally unchanged with time, but has short-term fluctuations due to turbulence. The characteristics of some of the thick sandstone beds at Bako suggests a near steady flow with a transitional phase

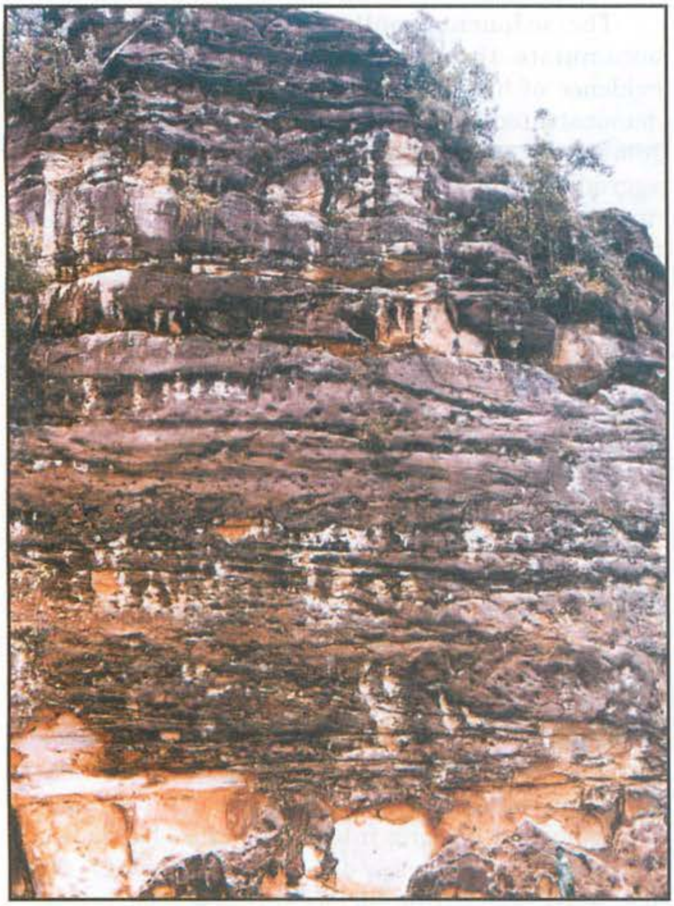

Figure 2. Vertical section through cliff face, Telok Assam (person for scale).

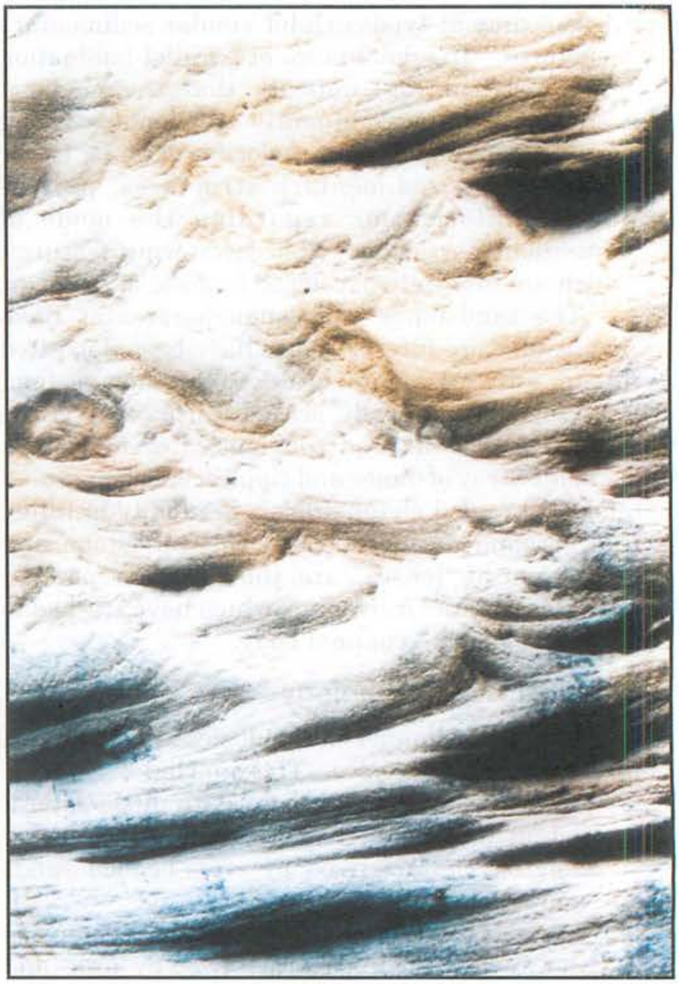

Figure 4. Water escape features — convolute lamination (lens cap for scale).

Figure 3. Water escape features — dish structures (lens cap for scale).

occurring between flow regimes, during one single depositional event (Kneller, 1995). This type of bed contrasts with the lenticular shaped channel granular sands, which are thought to form from multiple depositional flash flood events.

The thick structureless sands are likely to form during the very large storm events (100 to 1,000-yr. storms), where these rare conditions can mobilize large amounts of sediment (e.g. through slumping) and produce high velocity flows. The increase in sediment input could cause a density difference to develop between the storm waters and the ambient fluid, enough to create a turbidity current. The longevity of the current would depend on the continuation of sediment supply and high discharge. To facilitate rapid deposition, a hydraulic jump (i.e. change of slope) would be necessary to increase intergranular friction below the traction carpet. The friction prevents transportation and causes a localized grain flow to develop and deposit structureless sands (Johansson & Stow, 1995; Stow *et al.*, 1996).

(c) Liquifaction (fluidization)

Liquifaction describes any process that transforms a sediment into a liquid-like state (Allen, 1985). Fluidization is where the grains will no longer be supported by static grain-to-grain contact, but instead will be supported within the fluid flow and therefore the sand will be free to liquify (Davidson and Harrison, 1971). Fluidization produces fluid escape and dish structures (Tsuji and Mivata, 1987). It is possible for granular sediments to behave as a liquid-like layer at the final stages of deposition, immediately above the already deposited sediment. However, as granular material is only liquified during sedimentation the structures are restricted to within a single sedimentary unit or at the boundary between a single sedimentary unit and the material immediately underlying it (Nichols, 1995). Dewatering features are very common in these thick sandy units at Bako. Liquifaction features are commonly exhibited as intensely contorted laminations, the intensity of which can destroy most of the primary depositional fabric (Fig. 3). On close inspection the base of the disturbed horizons are transitional with thick beds of climbing ripples (Fig. 4). This suggests that the rapid aggradation of the migrating ripples trap pore fluid which on compaction 'burst through' the sedimentary fabric, causing much disruption. The disruption becomes more intense up the bed, until the original sedimentary structure is unrecognizable. This section covers over 3 m before the unit is overlain by a couple of granular stringers and passes into structureless sands.

DISCUSSION

Based on field evidence, three possible methods of sedimentation are capable of depositing structureless sands at Bako National Park. However, commonly these large sand bodies are associated with localized amalgamation or intense dewatering of ripples. It is certainly rare to see evidence of deposition from 'near steady' high concentration turbulent flows. Certainly out of all three possible modes of deposition, 'Near-Steady Flow' appears to be the most anomalous, in comparison to the other processes, particularly in context to the interpreted environment.

However, turbulent flows cannot be totally disregarded, and in some outcrops, the display of thick structureless beds are difficult to explain by just flash flood events. It is therefore considered that unusual climatic conditions, which prevail during the 100 or 1,000 year storm, could deposits a substantial amount of sediment. These climatic catastrophes are known to have a high precipitation rate and an immense ability to mobilize large amounts of sediment.

CONCLUSION

It is concluded, therefore that the thick units of structureless sand occurring in an alluvial setting are generally formed from amalgamation or liquifaction. Both processes can destroy the primary depositional fabric and produce a 'structureless' facade. Therefore, when looking at core or analyzing FMI[1]/STAR[2], where only a limited data set is available, much caution must be used in interpreting a structureless sand as a turbidity event, although this process cannot totally be discounted.

1. Fullbore Formation MicroImager — Schlumberger Product
2. Star Imager — Baker Atlas Product

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