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Outcrop examples of soft-sediment deformation associated with normal fault terminations in deepwater, Eocene turbidites: A previously undescribed conjugate fault termination style?

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ABSTRACT

A set of small-scale, layer-bound faults developed in a package of three Eocene turbidite sandstone beds in a wave cut platform, Thandwe Beach, Myanmar display unusual downward terminations between converging conjugate faults. The faults were initially triggered by loading during deposition of the uppermost turbidite sandstone in the fault-affected stratigraphic package. The growth of a small gravity-driven anticline, and subsequent loading by a post-deformation turbidite modified the initial fault geometry, and re-mobilized part of the layer-bound sequence causing thinning of the sequence to zero in the vicinity of the fold crest. Typically conjugate faults display an X-shaped pattern of intersection, while the observed faults before reaching the point of intersection die out in a drastically thinned basal sandstone located in a keystone block, which requires either an underlying detachment or that a volume of sand and fluid was lost from the basal layer. Probably a combination of gravity-driven detachment (primary) movement and volume loss (secondary) permitted development of the faults. The structures described represent yet another aspect of the wide variety of gravity-driven features that form in the deepwater turbidite fan settings. It is thought that such features have not been previously described in the literature, and represent a new style variant within the general theme of conjugate fault development.

1. Introduction

This paper documents an unusual layer-bound minor fault style found in deepwater Eocene turbidites of the Arakan Yoma hills of western Myanmar. The basic geometry of the faults is described. In particular the way displacement is lost downwards is believed not to have been previously documented in natural examples and is the main feature of this article.

The outcrop locality is a coastal section of Eocene deepwater sediments at Ngapali Beach, in western Myanmar (Fig. 1; Brunnschweiler, 1966; Bender, 1983). The sediments are part of an extensive series of outcrops that include *Globotruncana*-bearing Late Cretaceous sandstones, shales, limestones and radiolarian cherts, unconformably overlain by Eocene sandstone and shale deepwater deposits, whose basal sandstones contain *Nummulites* (Brunnschweiler, 1966). The outcrop lies within the Indo-Burman ranges, which contain Cretaceous-Neogene turbidites, olistostrome mélanges, with blocks of gabbro, pillow basalt, serpentinite, banded chert, limestone and schist (Brunnschweiler, 1966; Mitchell, 1993; Bender, 1983; Acharyya, 2007; Maurin and Rangin, 2009). These deposits developed as a result of oblique N to NE plate convergence between India and SE Asia, which resulted in Palaeogene subduction that later became inactive and was replaced by oblique dextral transpression (Rangin et al., 2013). Deformation in parts of the Arakan Yoma has continued until the Present Day as the Himalayan Orogeny has evolved (e.g. Maurin and Rangin, 2009).

The Eocene section at Ngapali is over 300 m thick and is completely exposed along an extensive wave cut platform (Fig. 2). Bedding strike and bedding dip at the faulted locality is about 025° 80–85° ENE, younging direction is to the ENE. The section is composed predominantly of turbidite sandstones and shaley mass transport deposits; background deepwater pelagic sediments are a minor component. Thin (in the order of

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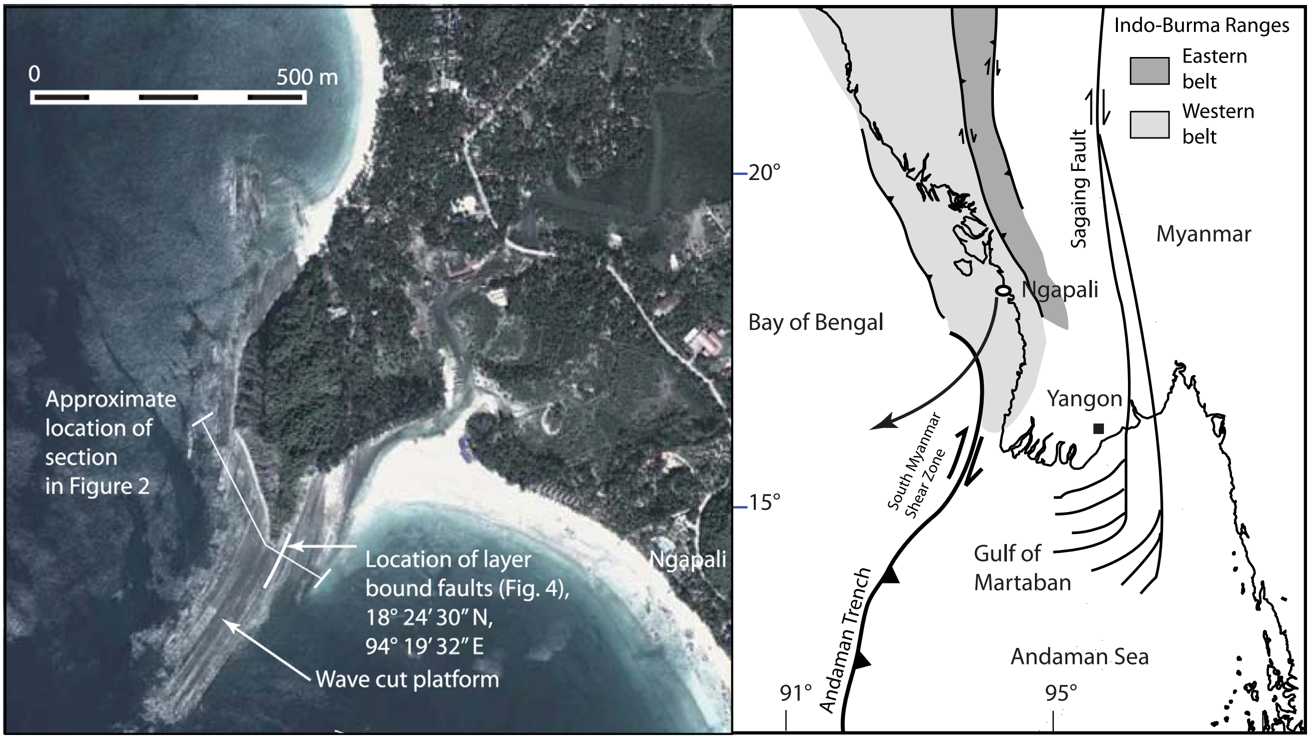

Fig. 1. Location map for the Ngapali Eocene turbidite outcrops. Map of geological features of Myanmar based on Rangin et al. (2013).

centimetres) to moderately thick (10–150 cm) beds of silty to medium grained turbidite sandstones, deposited in predominantly tabular beds dominate the succession. Thin shales either separate these beds, or the sandstones are amalgamated to form sandstone bodies up to 2–3 m thick. The beds frequently exhibit loading structures at the base, grading, parallel laminations, climbing ripples, and more occasionally convolute bedding. They are interpreted as turbidite lobes deposited in a middle to outer fan setting. Channelized turbidites suggesting a more inner fan setting are only seen at the top of the section. Many beds display carbonate cement patterns that produce either well-defined oval concretions, or less discrete honeycomb network-type cemented masses. These concretions are probably associated with anaerobic decay of organic matter or methane by sulphate-reducing bacteria shortly after burial (e.g. Coleman et al., 1993; Mortimer et al., 1997).

2. Description of the layer bound fault zone

Only one zone, located in the lower part of the section contains layer-bound faults (Figs. 1 and 2). The zone is up to 2.5 m thick, and extends for over 70 m along strike (Fig. 3). The layer-bound faults affect three turbidite sandstone units that grade upwards from fine grained sandstones to siltstones. The key sandstones are labelled as follows: sandstone I = sandstone underlying the conjugate faults, II, III, IV = sandstones affected by the faults, V = capping sandstone (Figs. 3 and 4). Thin shales or siltstones a few centimetres thick cap each sandstone. Since the beds dip sub-vertically the wave cut platform provides a cross-sectional view (Figs. 3 and 4). The northern end of the layer bound fault zone comprises converging conjugate fault sets, passing south the zone thins towards a broad anticlinal structure (wavelength ~30 m, amplitude 3 m). In this zone of thinning the layer bound faults form a series of tilted fault blocks, or much broader zones affected by grain flow within the sands where bends become amalgamated. When bedding is rotated to horizontal the faults dip to the NNE and SSW (Fig. 5B). The structural thinning of the beds within the layer bound fault sequence is closely associated with development of the anticline in the central part of the section (Figs. 3 and 4). Locally within the anticline there are small thrusts with up to 60 cm offset, also dipping to the NNE and SSW (Figs. 4, 5C and 6). Thrusts occur in the units underlying the normal faults as well as in the capping unit, suggesting that the thrusting and broad folding maybe a slightly later feature than the conjugate faults, or that the thrusts developed in two stages. Thinning of sandstone IV onto the southern limb of the anticline (Figs. 3 and 4) indicates the anticline began to develop between deposition of turbidites layers III and IV or entirely during deposition of IV. One thrust cutting through the centre of the anticline offsets the very thin brecciated veined part of the faulted zone, which confirms that there was also minor thrusting post-folding. There is clear expansion of sandstone IV in the hanging walls of the largest normal faults (Figs. 4 and 7), hence it is certain that the normal faulting occurred during deposition of this turbidite.

Sandstone V caps the layer bound fault zone. It is not deformed by the underlying normal faults except in one location near the crest of the antiform (Figs. 4 and 6). At this location a normal fault cuts across the base of the sandstone V, but does not affect the overlying bed. At the base of sandstone V the hangingwall and footwall dip towards the normal fault in a synformal geometry overlying the anticline (Figs. 3 and 4). Two metres south of the normal fault sandstone V is cut by a small thrust fault which has shale injected along it (Fig. 6). At this location the layer bound fault interval is very thin, and comprises a sandstone that has weathered to a very irregular pattern that gives an almost brecciated