Basal Wealden of Mupe Bay: a new model

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Abstract: Angular stratal relationships associated with the Mupe Bay palaeo-oilseep in the Lower Cretaceous Wealden Group of South Dorset have previously been viewed as evidence of angular unconformity. An alternative (preferred) interpretation is that the succession represents rotational channel-bank collapse at the margin of a large Early Cretaceous fluvial channel. The new interpretation explains observed bedding-plane orientations and palaeocurrent directions.

A previous paper (Hesselbo & Allen 1991) has described and interpreted the depositional environments of the Lower Cretaceous basal Wealden Beds at Mupe Bay in South Dorset (Fig. 1). In that paper angular stratal relationships at the level of the Mupe Bay 'palaeo-oilseep' (Selley & Stoneley 1987; Cornford *et al.* 1988; Allen 1989, p. 547) were interpreted as representing angular unconformities. Subsequently, the timing of oil migration as evidenced by the oilseep (i.e. oil-cemented clasts penecontemporaneous with deposition) has been the subject of much discussion (Miles *et al.* 1993, 1994; Kinghorn *et al.* 1994; Wimbledon *et al.* 1996; Parfitt & Farrimond this volume) and it has become important to re-assess our original interpretation of the sedimentological context of this horizon. In this paper it is argued that the angular relationships were generated not by tectonic tilting as initially proposed, but rather by rotational bank collapse on the margin of a large Wealden river channel.

Rotational bank collapse

Rotational bank collapse is a very common phenomenon in modern fluvial systems (Fisk 1944; Stanley *et al.* 1966; Turnbull *et al.* 1966; Laury 1971; Thorne 1982; Ullrich *et al.* 1986), but there have been rather few cases well documented from ancient deposits (e.g. Williams *et al.* 1965; Laury 1968, 1971; Alexander 1987; Guion 1987; Williams & Flint 1990). Uncommon occurrence within the geological record is ascribed by most of these authors to the unlikelihood of preservation within the active river channels of the majority of fluvial systems.

Rotational bank collapse can take place by 'base failure', 'toe failure' or 'slope failure' (Thorne 1982, and references therein). In 'base failure' the shear surface passes below the level of the thalweg of the channel; this process takes place preferentially in channels cut into clay- or silt-rich, cohesive, sediments. The preservation of rotationally collapsed banks is aided by 'base failure' rather than 'toe' or 'slope failure' because material is carried below the level of active erosion, although clearly the debris from 'toe' or 'slope failure' may be preserved, particularly if the channel is subsequently abandoned (Laury 1971; Guion 1987).

An exceptionally well-preserved and instructive example of channel-bank collapse through base failure has been described from the Miocene of the Lower Rhine Basin, Germany (Williams & Flint 1990). There, bank collapse took place in a channel at least 50 m wide and greater than 4 m deep and was accomplished by movement along a glide plane that extended below the channel floor. Both an extensional 'head' and a compressional 'tail' have been preserved; the intact blocks at the extensional end were rotated by about 30° and the initial collapse structure shows evidence of at least one phase of reactivation. This example provides an excellent analogue for interpreting the Mupe Bay palaeo-oilseep.

The Wealden Group of the southern Wessex Basin was deposited by lacustrine, lagoonal or fluvial systems which were often dominated by muddy sediment (see, for example, Allen 1975, 1981, 1989; Stewart 1981, 1983). Hence, channel fills and associated near-bank sediments commonly comprise material that would have been cohesive shortly after deposition and thus liable to collapse of the full bank height (see Laury 1971). In some respects then, it is surprising that rotational bank collapse is not a more common feature of Wealden deposits.

The Mupe Bay succession

The sedimentary succession and facies of the basal Wealden Beds of Mupe Bay and Bacon

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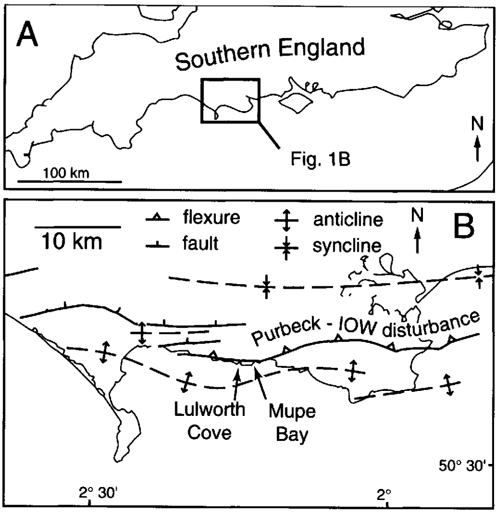

Fig. 1. Location map for the Mupe Bay Lower Cretaceous (modified from Stoneley 1982).

Hole have already described in some detail by Selley & Stoneley (1987) and Hesselbo & Allen (1991). In the following discussion reference is made to the sedimentary sequence shown in figs 2 and 3 of Hesselbo & Allen (1991); the interested reader should consult this paper for a more detailed discussion of the facies and environments of deposition. The major features of the exposure at Mupe Bay are illustrated here in Fig. 2.

The stairway to the beach (SY 844 797) is sited in a gully that undoubtedly represents a poorly resistant lithology: the upper 160 cm of this interval is a pale grey, weakly laminated mudstone. By correlation with nearby Bacon Hole, 300 m to the west (SY 841 797), the remainder of the interval probably comprises a mottled red/grey-green mudstone likely to have a fluvial overbank origin (Hesselbo & Allen 1991). At the time of writing (January 1996) 150 cm of red/grey mottled mudstone were exposed near the foot of the stairs at Mupe Bay, confirming the correlation. Above this argillaceous unit is Bed 5, a very fine- to fine-grained sandstone which is truncated westwards by an erosion surface labelled WB2 in Fig. 2. The depositional environment of this sandstone is obscure. Above erosion surface WB2, and apparently concordant with it, is Bed 6, a laminated and deformed purple-grey mudstone deposited in a quiet-water environment subject to periodic influx of coarse sand, possibly a lake or lagoon. Both the mudstone, Bed 6, and the underlying sandstone, Bed 5, are truncated westwards by another erosion surface labelled WB3 in Fig. 2. The horizon of the palaeo-oilseep immediately overlies surface WB3: the oil-cemented clasts lie within a heterolithic coarse to very coarse sandstone and mudstone. The conglomeratic interval is separated on its northern side from a fluvial, micaceous grey mudstone by an almost vertical fault of unknown throw which was could be seen in January 1996.

Discussion

Although it has been suggested before that the boulders in Bed 7 were derived through bank collapse (e.g. Miles *et al.* 1994; Wimbledon *et al.* 1996) the whole exposure has not hitherto been viewed in that context. A possible sequence of events leading to formation of the palaeo-oilseep through channel-bank collapse is shown in Fig. 3

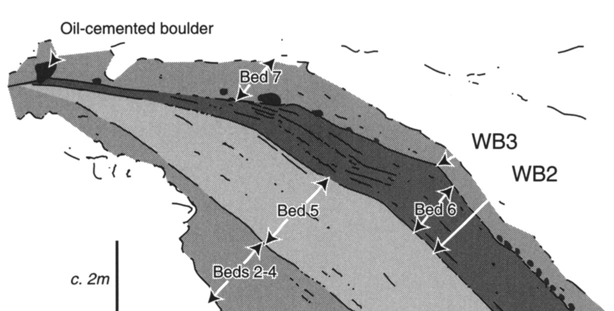

Fig. 2. Line drawing from a photograph of the Mupe Bay palaeo-oilseep showing the main erosion surfaces and beds discussed in the text (from fig. 7 in Hesselbo & Allen 1991). Bed 7 contains oil-cemented pebbles, cobbles and boulders.

(see caption for detailed commentary). Because of the potentially large scale of bank collapse features, incompletely exposed examples may commonly be mistaken for the products of tectonic deformation (Laury 1971; Guion *et al.* 1995). Re-interpretation of the angular relationships associated with the Mupe Bay palaeo-oilseep as due to rotational bank collapse is compatible with documented deep channelling at similar levels in the neighbouring Weald Basin and beyond (cf. Allen 1975, 1981; Ruffell 1995), and it also explains some features of the local succession otherwise unaccounted for.

The angular discordance between the palaeo-oilseep and the underlying strata is estimated to be about 5°. Because of the nature of the exposure, it has proved impossible to measure bedding orientations with sufficient accuracy to demonstrate the discordance quantitatively. Nonetheless, it is undeniable from the field observations that both surfaces WB2 and WB3 cut out progressively more of the underlying strata in a westward direction (Fig. 2). Palaeocurrent indicators in the sandstone immediately above the boulders show a northerly direction (long axis of log aligned 146°, dip 30°N; tabular(?) cross-bedding strike 078°, dip 56°N; tectonic tilt close to strike 090°, dip 40°N). Therefore, the palaeocurrent direction in the overlying channel deposit is perpendicular to the discordance with the underlying strata, which is compatible with rotational slip of the bank into a channel having a local north–south-oriented axis west of the present exposure and northward palaeoflow (cf. Laury 1971).

The co-occurrence of a rotational bank-collapse structure with the palaeo-oilseep may be viewed as connected, because bank collapse would have been associated with a topographic depression in which seeping oil could pond (either an abandoned channel or the head region of the slipped mass).

Our original hypothesis that surface WB2 and possibly surface WB3 represent angular unconformities now appears incorrect and, indeed, would have demanded a quite remarkable coincidence of critical geological relationships in a very small-scale exposure. However, the revised interpretation presented here does not exclude the possibility that these surfaces are unconformable. Comparison may be made with the study of Williams *et al.* (1965) who, working on the Carboniferous of western Pennsylvania, used the occurrence of anomalously thick successions within collapsed and rotated channel-bank blocks to argue that substantial unconformities occurred associated with channel cutting. In effect, they interpreted the channels as

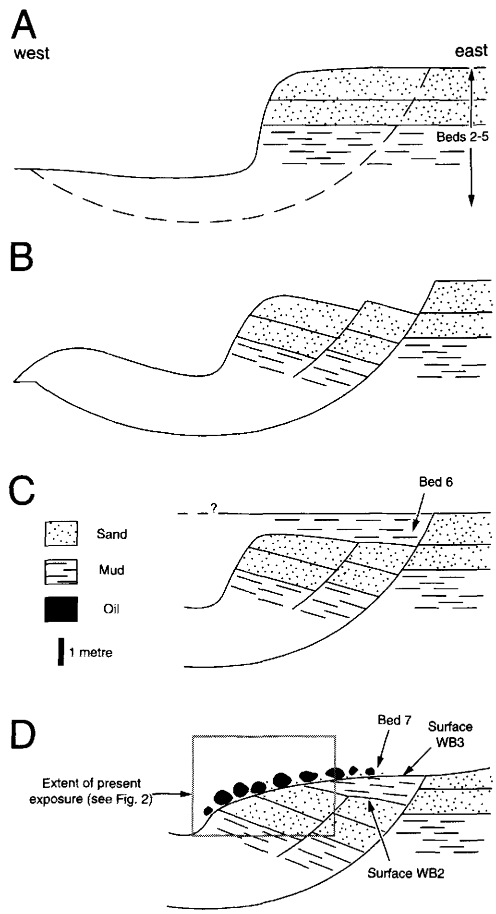

Fig. 3. Cartoon illustrating proposed stages in the genesis of the Mupe Bay palaeo-oilseep by rotational bank collapse: vertical axis exaggerated for clarity. The cartoon shows collapse by 'base failure' below the level of the channel thalweg: a more shallow failure involving only the channel wall is also a possibility. **(A)** A large fluvial channel cuts into Beds 2–5 of the Mupe Bay section. The position of the surface of bank failure is shown by a dashed line. **(B)** The channel bank collapses by rotation of blocks in the head region away from the channel axis. **(C)** Further argillaceous sedimentation occurs across eroded tops of rotated blocks (Bed 6). Sediment may have completely filled the channel, or may have been restricted to depressions between rotated blocks. At this stage seep oil could accumulate in sands within topographic depressions. **(D)** Further minor rotational failure occurs along the initial shear surface, possibly as a result of renewed fluvial activity in the channel. Deformation of the rotated blocks occurs and includes intrusion of sand dykelets within Bed 6. The crest of the rotated block is eroded and 'draped' with a remanié of oil-cemented boulders, possibly through the mechanism of 'slope failure' (Bed 7). The boulders are subsequently buried in sand transported by currents flowing in a northerly direction.

'palaeovalleys' in a sequence stratigraphic sense (see van Wagoner *et al.* 1990; Dalrymple *et al.* 1994). Exposure at Mupe Bay is not good enough to apply their criteria, and probably only refined chronostratigraphical work will resolve the unconformity issue.

Controversy over interpretation of the Mupe Bay palaeo-oilseep centres on the timing of oil migration. Most previous authors have recognized that this horizon indicates oil generation and migration (probably up fault planes associated with the Purbeck–Isle of Wight structure) during the Early Cretaceous (West 1975, p. 211; Selley & Stoneley 1987; Cornford *et al.* 1988). In contrast, Miles *et al.* (1993) claimed that the oil did not migrate until later in the Cretaceous and the Mupe Bay horizon was charged with oil substratally, a conclusion based principally on organic geochemistry and burial history analysis. This claim has been strongly disputed by Kinghorn *et al.* (1994). In defence of their hypothesis, Miles *et al.* (1994) cite the preferential oil staining in trace fossils within Bed 5 (Hesselbo & Allen 1991) as evidence that the oil charge occurred post-depositionally. This may be the case for Bed 5, but it is incredible that the sandstone boulders within Bed 7, with their unusual embayed margins, could have survived intact in an active fluvial channel if they had not been oil-cemented. Recently, in describing an oil globule with a laminated silty mudstone wrap, Wimbledon *et al.* (1996) have produced the most compelling evidence yet for pencontemporaneous migration of oil to the surface at the palaeo-oilseep.

Conclusions

The Mupe Bay palaeo-oilseep is re-interpreted as occurring immediately above rotated blocks of a channel-bank collapse structure. The palaeo-oilseep cannot be regarded as definitively marking the position of a major unconformity or unconformities near the base of the Wealden succession, although these possibilities, equally, cannot be excluded. Interpretation of the succession as a channel-bank collapse structure provides a possible explanation for accumulation of oil via ponding in a collapse-related depression or abandoned channel.

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