DISCUSSION

THE FAN THAT NEVER WAS?—DISCUSSION OF "UPPER CARBONIFEROUS FINE-GRAINED TURBIDITIC SANDSTONES FROM SOUTHWEST ENGLAND: A MODEL FOR GROWTH IN AN ANCIENT, DELTA-FED SUBSEA FAN"[1]

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Melvin (1986) has proposed a facies model for the Bude Formation whereby deposition is supposed to have taken place on a southward-prograding "subsea fan" which developed "within relatively shallow (shelf as opposed to abyssal) water depths" (p. 26). Among several lines of evidence for shallow water, Melvin (p. 26 and 32) cites my own paper (Higgs 1984a), in which I report the presence of wave-influenced sedimentary structures throughout the Bude Formation. The implication is that the alleged fan lay above storm-wave base; this begs two questions—How could a fan develop at such shallow depths, where the normal topographic configuration is a wave-cut *shelf* (Swift and Niedoroda 1985)? and—Are the beds labeled "turbidites" by Melvin *really* turbidites?

Melvin points out that his paper is based upon his doctoral thesis, completed ten years ago (Melvin 1976). More recently, I have conducted a detailed facies analysis of the Bude Formation (Higgs 1983, 1984a, b, 1986a, b). My own research has revealed, besides the above, numerous additional difficulties with Melvin's fan model. In particular, I wish to draw attention to the following:

1) According to Melvin (fig. 13), there are profound east-west facies changes in the Bude Formation, with channel facies passing laterally into levee and interchannel facies, over implied distances of hundreds of meters to kilometers. However, it is impossible to demonstrate that such facies changes actually take place, since exposure of the Bude Formation "is generally limited to the north-south coastal cliff section" (p. 20); east-west control is limited to the width of the wave-cut platform, which seldom exceeds 100 m, and which is largely obscured by encrusting organisms. Hence, one of the basic tenets of Melvin's model, namely that the amalgamated "thick-bedded sandstone" units (his Lithofacies 5, p. 24) occupy channels, lacks field validation.

2) Further doubt about channeling in the Bude Formation stems from the fact that, in my experience, the "thick-bedded sandstones" never show any erosional relief on their lower surfaces (flutes excepted). I have seen no evidence to substantiate Melvin's claim (p. 24) that "in places . . . the bases are erosional and channelized." Outcrop-scale evidence of channeling is limited to rare shallow scours with gently sloping ($<20°$) walls, which occur *within* and at the *tops* of relatively thick (>1 m) sandstones. These scour surfaces are decimeters to tens of meters across, and up to a meter deep; they are cut in sand, and are usually draped with a veneer of *mud* (Higgs 1986b). The scours in question have only been observed in two dimensions (either in east-west beach section or in north-south cliff section), so it is uncertain whether or not they are actually channel-like in three dimensions.

3) Melvin interprets his Lithofacies 6 ("Contorted Silty Sandstones") as slumped units and/or mass-flow deposits (p. 25). However, this interpretation conflicts with his own observation that one particular unit of Lithofacies 6 passes gradationally into uncontorted (muddy) sediment when traced laterally (p. 25). This observation strongly suggests that the contorted units are *not* resedimentation phenomena, as postulated by Melvin, but that they formed in situ; I propose that they are seismites (Seilacher 1969). Soft-sediment folds within the contorted units show no strongly preferred orientation (Whalley and Lloyd 1986); this is consistent with the idea that lateral translation was minimal. If the contorted units are indeed autochthonous, then the very fact that they stayed in place during deformation suggests that the gradient of the depositional surface was exceedingly low, since subaqueous sliding and slumping is known to occur on slopes as gentle as 0.5° (Coleman 1981). Hence, it is unlikely that the environment was a fan, since fans typically have average gradients of a few degrees (Stow 1986).

4) Melvin proposed that the "thick-bedded sandstone" units were deposited on a southward-prograding fan, in channels oriented approximately north-south (see his fig. 13). However, my own research has shown that the majority of the "thick-bedded sandstones" show sole marks oriented essentially *east-west* (Higgs 1986b, fig. 2.88; see also Melvin's fig. 10b).

5) The cyclic deltaic deposits of the Bideford Formation, lying immediately north of the outcrop of the Bude Formation (see Melvin, p. 29 and fig. 1a), not only pass *laterally* into Bude Formation strata, as mentioned by Melvin (p. 29), but also *upward* (Edmonds et al. 1979). This configuration is difficult to reconcile with Melvin's suggestion (p. 31) that the Bude Formation is a *regressive* succession resulting from progradation of a "base-of-slope fan"/"pro-delta slope" system.

I submit that the foregoing evidence militates strongly *against* a fan model. Elsewhere (Higgs 1986a, b), I have proposed that the Bude Formation was deposited on a storm-dominated lake shelf. The graded sandstone beds, interpreted by Melvin (p. 32) as turbidites produced by resedimentation (i.e., slump-generated), may instead be the product of river-fed underflows generated by storm flooding in the catchment area; for these, I have coined the term *underflowites* (Higgs 1986a). The underflow hypothesis is consistent with the paleontological evidence that the basin water was fresh or brackish (see Melvin, p. 26; see also Higgs 1986a, b). The shelf is thought to have sloped south, in which case underflows evidently traveled not only *down* the shelf gradient but also laterally *across* it (see Melvin's fig. 10); the implied ability of the underflows to defy gravity is attributed to deflection of the underflows by wind-driven circulation of the water mass (Higgs 1986b).

Melvin's most critical error, in my opinion, is in failing to recognize that the (asymmetrical) cross-lamination visible at the tops of many Bude Formation sandstone beds is mostly of a combined-flow variety, formed under the influence of waves (see above; Higgs 1984a, b). Hence, whereas Melvin interprets the beds in question to be slump-generated turbidites, and attributes the cross-lamination to the Bouma-C division (p. 23 and 24), I believe that this is incorrect, and that the beds are actually *underflowites* modified by storm-wave action. It is not unreasonable to suppose that the waves and underflows were operating simultaneously, and were produced by the same storm. Melvin points out (p. 23) that some beds exhibit "sharp, rippled tops," and that "some thin sandstones pinch out over short lateral distances" (see Melvin's fig. 6); both of these characteristics are more typical of storm beds than of turbidites (Goldring and Bridges 1973; Seilacher 1982b). Furthermore, two structures which are common in ancient turbidite successions, namely rib-and-furrow and (Bouma-C) convolute lamination (Seilacher 1982b), are *absent* in the Bude Formation.

The relatively fine grain size of the Bude Formation (maximum = fine sand; Melvin, p. 19 and 21) is consistent with the most likely low velocity, hence limited competence, of a river-fed underflow crossing a shelf (Higgs 1986b).

As shown in Melvin's figure 12, the Bude Formation can be viewed as an alternation of sand-rich and sand-poor intervals, on a scale of decimeters to meters. Trace fossils and other evidence (Higgs 1986a, b) suggest that this alternation represents a transgressive-regressive cyclicity, reflecting depth (and salinity) fluctuations. These fluctuations are interpreted (op. cit.) in terms of sea water periodically overtopping the

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sill of a hydrologically open lake, possibly in response to glacioeustatic sea-level oscillations (cf., the late Quaternary history of the Black Sea (Scholten 1974)). The scarcity of obvious bed-thickness sequences (Melvin, p. 26, 29) is thought to be an artifact of the syndepositional removal of large quantities of mud from between the sandstone beds, making up the thick (amalgamated) sandstone units; in this respect, it is significant that even in the thickest (5–10-m) sandstone units, the constituent beds appear to be relatively *thin* (10–40 cm) (although bed junctions are commonly obscure). The implication is that the lake-floor muds were, at times, unusually prone to being resuspended whenever a sand bed was emplaced. This behavior is attributed to the presence of methane bubbles in the surficial muds during fresh-water interludes (Higgs 1986a, b). Another feature of the thick sandstone units is that they "commonly display discontinuous undulating laminae" (Melvin, p. 24); these undulatory partings may represent wave scours (cf., Boyles and Scott 1982; also Walker et al. 1983).

It remains to be explained why the inferred shelf cycles of the Bude Formation invariably lack nearshore and emergent facies; in other words, why is it that the cycles do not "shallow-upward" further than they do? The only reasonable explanation is that, during each regressive episode, shallowing was somehow arrested once a certain minimum water depth was attained. Such a depth-regulating mechanism occurs on storm-dominated shelves, where shallowing can proceed no further than the storm-wave-controlled "equilibrium surface" (Seilacher 1982a, p. 171): sediment finding itself *above* the equilibrium level, due to 1) a fall in absolute water level, and/or 2) fair-weather sediment aggradation, is winnowed back down by waves the next time a storm occurs, the surplus sediment being swept over the shelf edge into deeper water by storm currents. (This model does not apply to those parts of the shelf (e.g., near deltas) where the rate of sedimentation far outweighs the effects of (rare) storm erosion.)

The depositional models for the Bude Formation put forward by Melvin and me are fundamentally different. The conflict has profound implications for hydrocarbon exploration, particularly with regard to sand-body geometry. Melvin's fan model predicts elongate, channelized sand bodies, oriented essentially north-south (p. 31 and 32, and fig. 13). In contrast, the shelf-underflow model proposed here implies sand bodies of a more laterally extensive character.

Finally, and quite apart from the foregoing considerations, Melvin's nomination of the Ebro and Crati Fans as modern analogs for the Bude "fan system" is curious, since both of these modern fans are marine, whereas the Bude Formation appears to have been deposited in a *nonmarine* basin (Melvin, p. 26, 31).

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