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Textural Trends in Deposits of Collapsing Turbidity Currents: Sedimentology of Turbidites and Slurry Beds from the Oligocene Flysch of the East Carpathians, Romania

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Normal size grading has been considered one of the characteristic features of turbidites. However, there is growing evidence that textural trends in relatively thick sandy turbidites are more complex. In addition to vertical textural trends, the distribution of detrital mud is another important property of sand-rich sediment gravity flow deposits. Lowe and Guy (2000) described 'slurry beds' of the Britannia Formation, deposits of mud-rich gravity currents transitional between turbidity currents and debris flows. This report focuses on deep-water sands of the Oligocene flysch of the East Carpathians, Romania. In three outcrops in the Buzau Valley area, that expose deep-water rocks of Oligocene age (Fusaru Sandstone and Lower Dysodilic Shale), layers of mud-rich sand occur not only as individual sedimentation units, but also as parts of sequences with turbidite divisions of Bouma (1962) and Lowe (1982). Mud-poor and mud-rich sedimentation units were selected for quantitative textural study. A total of 87 thin sections were point counted for grain size. Three hundred quartz and feldspar grain lengths were measured in each thin section.

Textural trends and flow evolution

Mud contents in the studied sandstones have a polymodal distribution: samples tend to contain about 3-13% or more than 20% detrital mud. The grain size ranges from granules up to 7 mm in diameter to very fine-grained sand. However, most beds consist of sand with a mean grain size of 2.5 to 3.25 ϕ. Cross-laminated sandy-silty divisions in the upper parts of sedimentation units have finer average grain sizes (3.25 - 4.3 ϕ). The mud-rich sands can be divided into two groups: the coarser-grained mud-rich sands have mean grain sizes of about 3ϕ and poor sorting, whereas the finer-grained samples have an average grain size of slightly more than 4 ϕ and good sorting.

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Mud-poor sands

In general, the studied sedimentation units tend to be inverse-to-normally graded, normally graded or ungraded-to-normally graded. Sorting tends to improve upwards in inversely or normally graded intervals (Fig. 1) and does not show significant variations in ungraded intervals.

Previously described examples and data collected for this study suggest that thick *inversely graded* intervals tend to occur at the base of many thick sedimentation units. The 240 cm thick inversely graded S_3 division of TB1 (Fig. 1a) is far too thick to have formed as a single traction carpet supported by dispersive pressure (Lowe, 1976). Interpretations that link grain-size variations to changes in flow velocity (Kneller, 1995; Mulder and Alexander, 2001) fail to consider that most depositing turbidity currents are overloaded, suspended-load fallout rates are high, and it is capacity, not competence, that drives sedimentation (Kuenen and Sengupta, 1970; Lowe, 1988; Allen, 1991; Hiscott, 1994).

The upward improvement of sorting that is associated with normally and inverse-to-normally graded sedimentation units can be interpreted in terms of the relative importance of *suspended-load fallout rate* and *flow velocity* during sediment deposition from a collapsing turbidity current. In the case of turbidite TB1 (Fig. 1a), as deposition begins, suspended-load fallout rates are highest. The sediment close to the base of the bed will contain the entire range of grain sizes available in the flow. Under conditions that are comparable to the experiments of Vrolijk and Southard (1997), deposition rates are high enough that neither traction nor traction carpets develop. Winnowing of fines is limited by the high near-bed sediment concentration and by the short time the grains spend in this layer before they are incorporated into the static bed. As the rate of suspended-load fallout declines, the flow is able to winnow some of the finer-grained sediment. This is reflected in progressive loss of the finer size classes upward within the division, and as the anticlockwise rotation of cumulative probability plots.

The few existing quantitative textural studies of turbidites give little attention to the fine tail. The results from the Fusaru Sandstone suggest that inverse fine-tail grading is common in T_a/S_3 divisions (Fig. 1a) and it indicates winnowing of fines during decreasing rates of suspended-load fallout. The inverse fine-tail grading tends to be associated with coarse-tail normal grading.

Mud-rich sands

One of the key observations for the interpretation of the mud-rich sands described here is that some mud-rich or ‘slurried’ intervals occur in sedimentation units with “normal” low-mud turbidite divisions (Fig. 1b). The development of mud-rich divisions seems to be limited to certain stages of deposition from the flows. This stage either corresponds to the transition from the T_a/S_3 division to the traction-structured parts of a turbidite or it is associated with very fine-grained T_c divisions. These observations suggest that the mud-rich sands, although exhibiting some evidence of cohesive behavior, were deposited by the same turbulent flows responsible for the deposition of the other divisions. They are the products of depositional processes operating during late-stage evolution of mud-rich turbidity currents, similar but not identical to the slurry flows of Lowe and Guy (2000), rather than deposits of cohesive debris flows or of near-bed laminar layers that would exist along the entire path of the turbidity current.

Conclusions

It is suggested here that the fine-tail inverse grading, which can lead to inverse grading in the mean size as well, results from the increasing effectiveness of winnowing by the current as the suspended-load fallout rate declines. Vertical changes in mean grain size of thick-bedded deep-water sands lacking traction structures might differ substantially from the flow hydrograph of the depositing current at the same location. An initially high, but declining sedimentation rate is probably due to deposition from collapsing turbulent flows. How could a sustained turbidity current deposit be distinguished from a collapsing one? The model outlined above predicts that inverse fine-tail grading, an upward improvement in sorting, and the restricted range of grading styles are characteristic of collapsing flows. There is no reason why these regular textural patterns, and specifically the upward improvement in sorting and inverse fine-tail grading should be present in sustained-flow deposits (Fig. 2). However, distinguishing collapsing flows from sustained currents might be problematic in the case of thick, truly ungraded sand beds.

With relatively high flow velocity, initially high, but rapidly declining suspended-load fallout rates result in S_3 divisions that are inversely graded in the mean grain size, with a well-sorted and well-structured T_t unit at the top (Fig. 2a). With the same flow velocity and high suspended-load fallout rates that decline relatively slowly, the S_3 unit will show subtle normal grading in the mean grain size (Fig. 2b) or will be ungraded. These conditions favor the deposition of mud floccules along with sand, resulting sometimes in mud-rich divisions at the top or in place of the S_3 unit.

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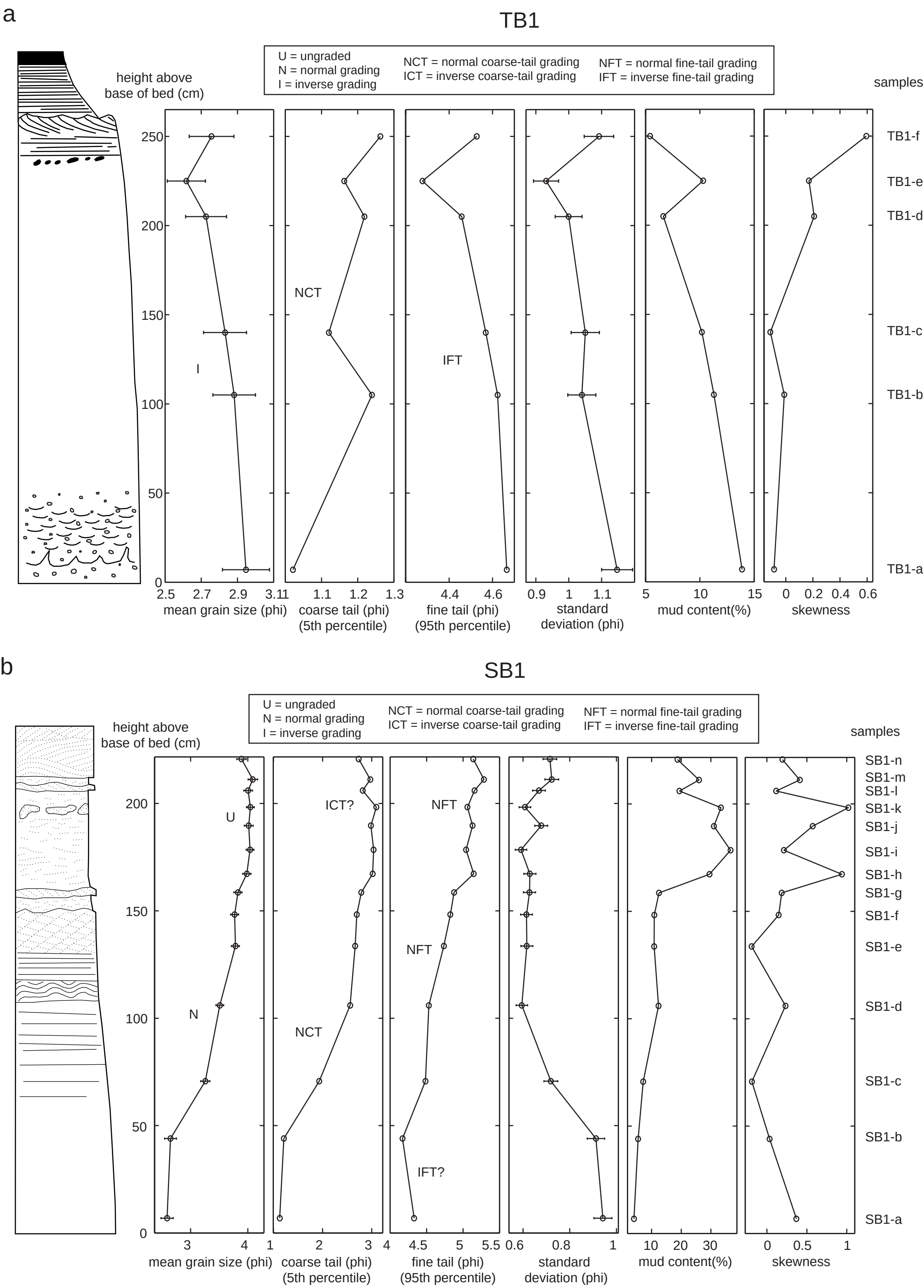

Figure 1. Grain-size trends in (a) turbidite TB1 and (b) slurry bed / turbidite SB1. Error bars on mean grain size and standard deviation represent a 95% confidence interval obtained with standard statistical techniques. Note that sorting improves upward in both beds, although TB1 is inversely graded in the mean and SB1 is normally graded in the mean.

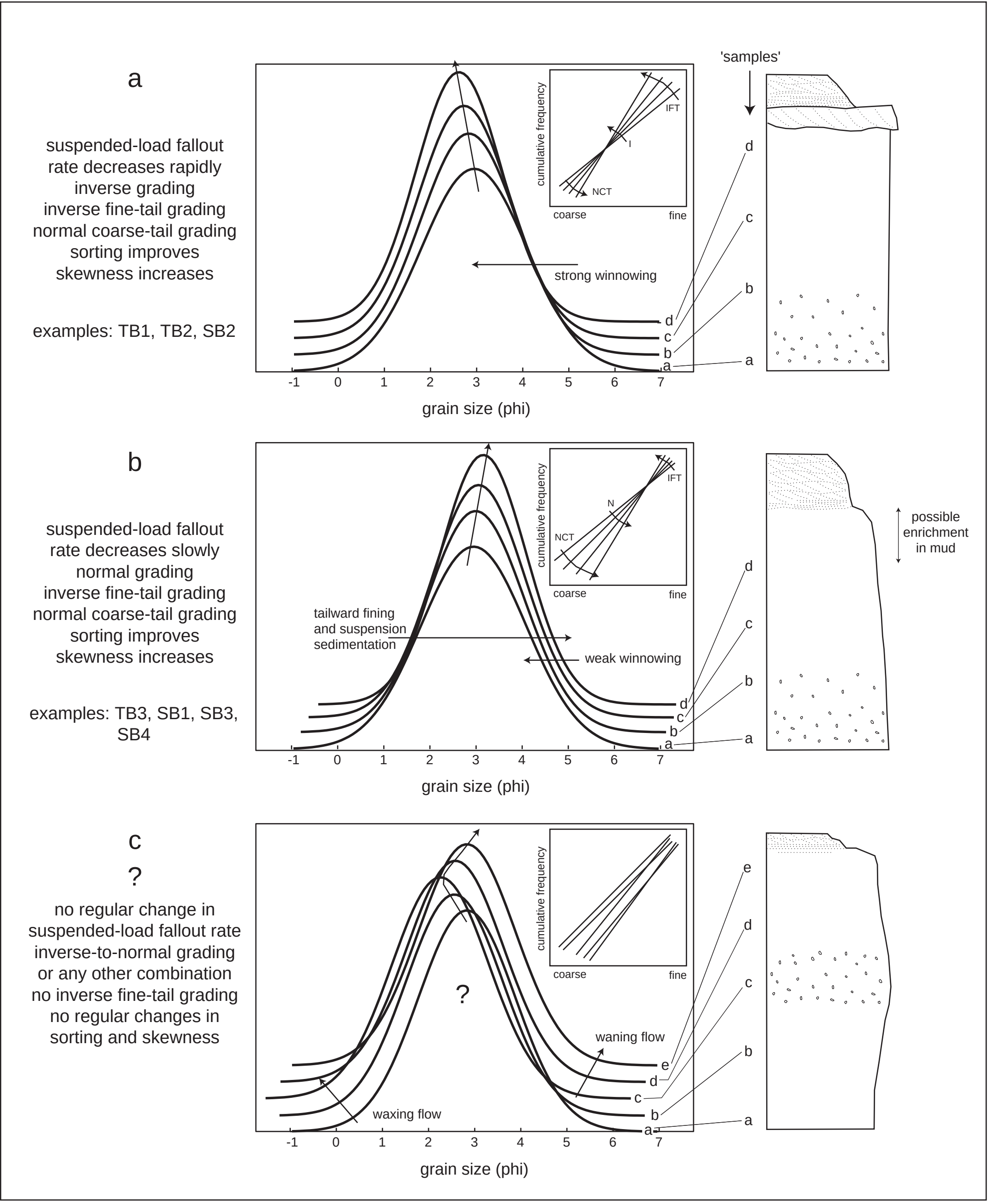

Figure 2. Conceptual diagrams showing the differences between vertical textural changes in S_3/T_a deposits of collapsing (a and b) and sustained (c) high-density turbidity currents. All three flows are assumed to have similar overall velocities, but grain-size changes in (c) are mainly governed by fluctuations in velocity, whereas in cases (a) and (b), declining suspended-load fallout rates are more important than variations in flow velocity. Initially high, but rapidly declining suspended-load fallout rates (a) lead to strong winnowing of the top S_3 deposits by the remaining low-density turbidity current that bypasses this location. Inverse grading in the mean grain size can result. If the suspended-load fallout rate declines more slowly (b), significant amounts of mud can be deposited with fine sand (mean grain size = 3ϕ) towards the top of the S_3 unit. Development of cohesiveness in this layer prevents winnowing. (c) shows a hypothetical example of a sustained-flow deposit, which should lack the regular upward changes in grain-size parameters characteristic of collapsing-flow deposits.