Discussion

Deep-water massive sands: facies, processes and channel geometry in the Numidian Flysch, Sicily — reply

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Abstract

The Oligo–Miocene Numidian Flysch of northern Sicily provides an interesting and important outcrop analogue for deep-water sedimentary systems. It is also a limited reservoir for gas in its own right. However, structural complexities, including deformation and nappe emplacement, render a very full understanding of its depositional history elusive at this stage. It was partly for this reason that we concentrated on depositional processes and architecture in our earlier paper (Johansson et al., 1998), paying particular attention to the deep-water massive sandstone facies. We therefore welcome the detailed comments and additional information provided by Parise et al. (1999) in their discussion of our paper, although we are somewhat mystified by their sharpness of tone and surprised at their poor reading of our text. We do find it particularly helpful, however, that Parise et al. (1999) have drawn attention to further work on the Numidian Flysch, both in Sicily and North Africa, that is tucked away in meeting abstract volumes, field excursion guides and doctoral theses. Indeed, we had missed much of this literature — and have now read it diligently! We take this opportunity to address their specific concerns, to focus attention on these superb outcrops of channel-form geometry and to further suggest that they represent part of a sand-prone sinuous to meandering channel complex across a muddy slope apron system.

1. Turbidite systems

The comments made by Parise et al. (1999) about the field techniques used and data presentation are largely unfounded or erroneous, although they do raise some interesting points.

(a) Sole marks. Indeed we did use sole marks and other current indicators in our analysis (see p. 241, sect. 6.1) although this reference to them was apparently missed by Parise et al. (1999). We also measured shale-clast plunge, but the results were inconclusive. We believe that the very variable paleocurrent directions obtained by different workers is both explicable and very significant (see below, Section 5).

(b) Paleogeography. All our examples are geographically located on figs. 2 and 3 as well as...
with compass orientations on the photographs and sections. If Parise et al. (1999) really do mean “paleogeographically situated” then that is clearly a matter of interpretation rather than fact for the whole of the Numidian Flysch.

(c) Perpendicular channels. The channels indicated at Ponte Finale are indeed at a high angle to one another. Far from being “most unlikely in ... such a small localised area”, we suggest it is entirely probable for meandering channels (see below, Section 5).

(d) Biostratigraphy. We clearly state in our paper that we have not studied the biostratigraphy of the Numidian Flysch nor attempted precise paleogeographic reconstruction. These are enormously complex issues that require considerably more work throughout northern Sicily. Our general comment on the more distal aspect of the Internal Numidian, based on earlier work and fitting well with our facies observations, does not imply direct chronostratigraphic correlation with the External Numidian.

(e) Sedimentation rates. Similarly, we believe that our broad estimate of accumulation rates for the whole of the Numidian Flysch (between 250 and 500 m/m.y.), even despite tectonic and biostratigraphic complications, is a valid approximation. It serves to show relatively rapid rather than excessively high rates of sedimentation, commensurate with a well supplied slope apron. There are insufficient data to elucidate the precise nature of allocyclic and autocyclic controls on this sedimentation.

2. Numidian basin and sediment supply

Although we have not attempted to enter the continuing debate on either a North African or South European provenance for the Numidian Flysch, we did make our own observations and considered carefully some of the arguments on both sides. As stated in our original paper, much of the direct paleocurrent evidence we observed indicated generally west to east directed flow. This was not inconsistent with a North African Nubian Sandstone source, which we favoured on petrographic grounds.

Clearly, it is interesting to speculate and we welcome the further data provided by Parise et al. (1999), although we suspect a certain selectivity in the very uniform data set presented in their fig. 1. There are three important points to make in this regard.

(a) Paleocurrent measurements in tectonically deformed terranes must be open to question, especially when some of the sand bodies in the Internal Flysch are, in fact, overturned.

(b) The greater the degree of channel sinuosity, the greater the expected variation in paleocurrent direction.

(c) For our consideration of facies, processes and geometry of the Sicilian Numidian Flysch, the ultimate provenance of the short sandy channel segments encased in fine-grained turbidites is of little relevance.

Furthermore, we must take issue with the sweeping generalisation made by Parise et al. (1999), apparently based on their work in the Numidian Flysch in Tunisia (El Maherssi and Beaudoin, 1996), that “the Numidian turbidite systems are ... close to fan deltas.” Whereas this may be the case for parts of the Numidian Flysch in Tunisia, the proximity of fan deltas is not evident in Sicily nor, of course, for all the rest of the 2000 km orogenic belt in which the Numidian Flysch outcrops.

3. Facies and processes

Several of the comments given by Parise et al. (1999, sections 3 and 4) relate to the facies described and to our interpretation of processes. They somehow imply that we have described just three facies: “Johansson et al. (1998) have recognised turbidites, slumps and massive sandstones ...” and “their non-identification of sandstone sills and heterogeneous turbidites ...”. In fact, we document eight distinct facies within the Massive Sandstone Facies Association and at least nine associated facies. Far from being simple, the pattern is extremely complex, as it is for many deep-water systems (Stow, 1994; Stow et al., 1996). In addition to the enigmatic massive sands, for example, we recognise various chaotic units (some including elements of slides/slumps, debrides and/or injection features), megaturbidites, shale-clast conglomerates, and a variety of other coarse-grained facies. These, we believe, are less easy to interpret than the more standard
sand–mud and mudstone turbidites that dominate the encasing facies.

The reality is that large-scale resedimentation events in the deep sea commonly involve several different processes, including sliding, slumping, debris flow and turbidity flow. They may cause significant basal erosion, induce channel bank collapse, be dissipated by late-stage dewatering, and so on. All these features are readily observed in northern Sicily.

Whereas we note the observation of “heterogeneous turbidites” by Parise and Beaudoin (1986), fig. 2 in Parise et al. (1999), which are perhaps equivalent to our “contorted chaotic facies” we would caution against the use of the term “turbidite” for these particular sediments.

Furthermore, we are of course aware of past claims for contourites within the mud-rich intervals of the Numidian Flysch in Sicily, first proposed by Wezel (1970). However, such interpretations should not be made lightly, and certainly not solely on the basis of field observations of sedimentary structures. Many more criteria must be carefully assessed prior to firm identification of contourites (Stow et al., 1998).

4. Massive sands: facies and processes

Prior to our Numidian Flysch paper (Johansson et al., 1998), we had investigated some 70 examples of deep-water massive sands worldwide (Stow et al., 1995). Now that figure is close to 100 and includes some of the 50–100 m thick subsurface successions referred to by Parise et al. (1999) (see also, Stow and Johansson, 1999). On the basis of this broader canvas, we should like now to reaffirm and amplify some of the conclusions given in our earlier paper.

(a) Deep-water massive sands in general, and certainly those deposited in northern Sicily, were deposited in beds typically between 2 and 8 m thick. Most very thick successions described are, in fact, amalgamations of thinner depositional units that can only be observed by very careful analysis of subtle grain size variation, sequences of water-escape structures, ghosts of amalgamation horizons, etc. Single massive sand beds in excess of 20 m are more rare. More commonly, a very thick apparently massive sand interval will occur as part of an even thicker graded megaturbidite/debrite. These are important points when we are trying to infer likely depositional processes and settings. They are strong evidence against the mystique of truly gigantic uniform sand flows being commonplace.

(b) The massive sand facies may show a variety of subtle attributes including dispersed pebbles and shale clasts, water-escape structures, pseudo- or very indistinct lamination, and very slight top and or basal grading. These deposits typically occur as part of a larger massive sand facies association including pebbly sands, conglomerates, shale-clast conglomerates, thin-bedded turbidites, mudrocks and others. This is also an important point, as the generation of multiple events and facies types requires a different system than simple massive sands encased in muds (e.g. Surlyk, 1987).

(c) The two fundamental processes that appear capable of transporting large volumes of sand over relatively long distances downslope in the deep-marine environment are sandy debris flows (SDFs), with or without hydroplaning, and high-density turbidity currents (HDTs). It is important to emphasise that transformation between these processes and with other resedimentation processes is the norm, so that criteria we are beginning to develop for distinguishing between the two processes and with other resedimentation processes is the norm, so that criteria we are beginning to develop for distinguishing between the two processes on the basis of their deposits can only ever be partially satisfactory. Both were probably operational in the Numidian Flysch of Sicily.

(d) Following transport, final deposition occurs by one of four mechanisms: freezing of an SDF plug; collapse fall-out from the turbulent flow of an HDT; continuous aggradation beneath a sustained HDT; or continuous traction beneath a sustained HDT. These are not separate transport processes (as apparently believed by Parise et al., 1999, their section 4), but are mechanisms that can inhibit the development of significant sedimentary structures, including grading, and hence give the deposit its massive appearance. This is the main answer to the simple question “why are they massive?” — a point we made in Johansson et al. (1998) but apparently not understood by Parise et al. (1999). It is important also to note that these are normal depositional processes that occur from SDFs and HDTs and that they are not mutually exclusive.

(e) Post-depositional liquefaction and remobilisation is common, particularly where thick sand bodies
are encased in fine-grained sediments. There are many features that attest to such sand flow including protrusion and flank steepening, sand injection, collapse of internal fabric and structure, grain realignment, etc. Parise et al. (1999) refer to their extensive work in this field, and suggest that synsedimentary injections are more common than post-depositional ones. In either case, extreme remobilisation will have the effect of destroying original sedimentary structures and hence further enhancing a massive appearance, but our experience shows that this is not normally the case for the main sand body.

5. Sand supply and channel geometry

Thick accumulations of sands in deep water (massive sands and associated facies) require either a large sandy source, such as clean winnowed outer shelf sands, and an efficient mining process, or a continuous sand supply to the slope over a period of time, either from a fan delta or major river delta. The Numidian Flysch in Sicily is, overall, a mud-dominated system with abundant evidence of thin-bedded turbidites and hemipelagites indicating an ample supply of fine-grained material. The sands and other coarse-grained facies for the most part occur in clearly erosive channels and channel complexes that focused sand transport across a muddy slope apron.

In our earlier paper (op. cit.) we amply documented the nature of these channels, their exposed dimensions and fill geometries. What is less certain, but most interesting, is the possibility that these channels actually had sinuous to meandering planform geometries. Evidence for this comes from the very varied paleocurrent directions in closely spaced locations, adjacent channel segments that are clearly at a high angle to one another, and from the present-day distribution of channel-fill facies within the Numidian Flysch mud-rich slope system (Fig. 1).

This potential ancient analogue of deep-water meandering channels requires further study in order to better elucidate many of the features discussed above.

![Fig. 1. Schematic representation of inferred sinuous to meandering channels in the Numidian Flysch of northern Sicily. Stippled ornament shows outcrop areas of massive sand and associated channel facies.](image_url)
References


