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Discussion

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

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### 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. © 1999 Elsevier Science B.V. All rights reserved.

### 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

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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, debrites 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

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.

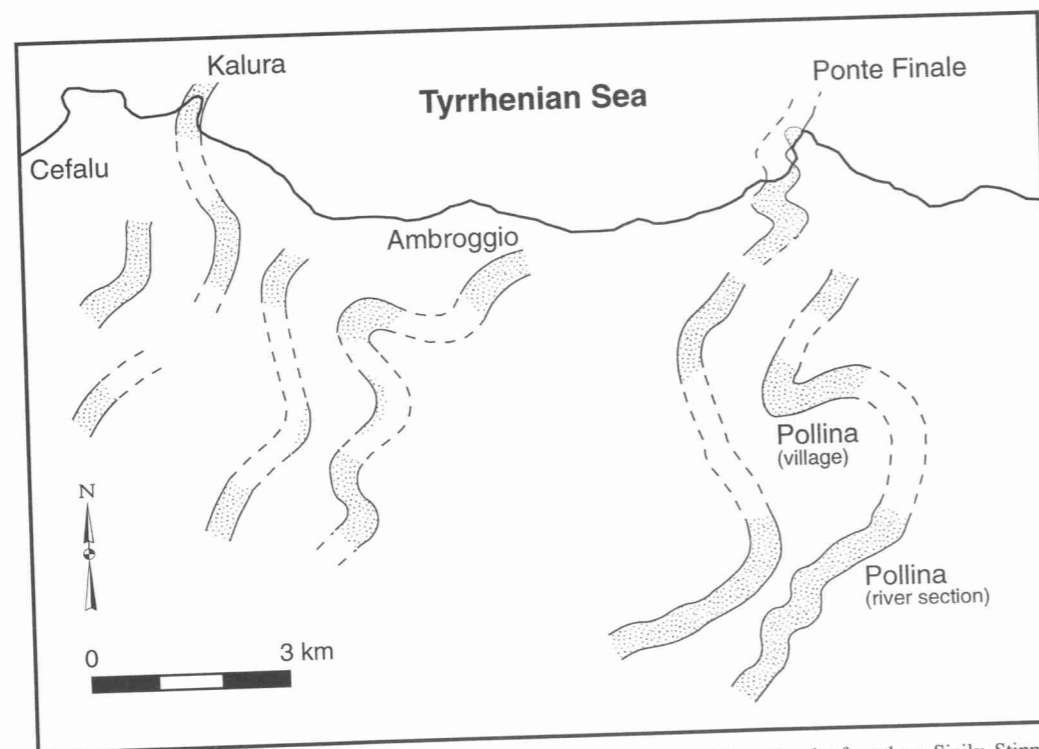


Fig. 1. Schematic representation of inferred sinuous to meandering channels in the Numidian Flysch of northern Sicily. Stippled ornament shows outcrop areas of massive sand and associated channel facies.

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