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Small-scale polygenetic mélanges in the Ligurian accretionary complex, Northern Apennines, Italy, and the role of shale diapirism in superposed mélange evolution in orogenic belts

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ABSTRACT

The *Argille varicolori* (Varicolored scaly clays) of the External Ligurian Units of the Northern Apennines have been widely described as a typical unmetamorphosed broken formation (i.e., a chaotic unit without exotic blocks), produced by offscraping and tectonic imbrication during the evolution of the Ligurian accretionary wedge. Geological mapping and integrated structural and stratigraphic observations show that the *Argille varicolori* consist of diverse types of small-scale mélanges (non-mappable at a 1:25,000 scale) forming a composite chaotic unit, in which the superposition of tectonic, sedimentary and diapiric processes resulted in the occurrence of polygenetic chaotic bodies at different scales. These mélange units record the evolution of the Ligurian accretionary wedge from subduction to collision and intracontinental deformation. Tectonically Disrupted Body 1 (TDB1) comprises boudinage and pinch-and-swell structures formed by layer-parallel extension/contraction at the wedge front of the Ligurian accretionary complex during the late Cretaceous–middle Eocene. It is interleaved with non-mappable Gravity-driven Chaotic Bodies (GCB) developed during alternating episodes of accretion and removal of material at the wedge front. The late Oligocene–early Miocene out-of-sequence thrusting related to the collisional episodes in the Apennines overprinted the previously formed chaotic bodies and formed a polygenetic tectonic mélange (Tectonically Disrupted Body 2, TDB2). This unit is characterized by a structurally ordered block-in-matrix fabric and by the gradual decrease of stratal disruption away from the regional thrust. Overpressurized fluids concentrated along the shear surfaces, and the scaly cleavage planes facilitated the diapiric upward movement of unconsolidated sediments in the early Miocene. This process produced non-mappable shale dike injections (DDB1) and mappable Diapirically Disrupted Bodies (DDB2), which show an internal zonation of deformation. This deformation reworked the previously formed chaotic bodies. Although some of these polygenetic mélanges cannot be mapped at a 1:25,000 scale, their careful documentation provides a better understanding of time-progressive, scale-independent mélange-forming processes.

1. Introduction

Accretionary complexes in convergent margins constitute a primary tectonic setting for the formation of chaotic bodies of mixed rocks and mélanges. Comparative studies of modern and ancient accretionary complexes are, therefore, a natural laboratory to investigate the mode and nature of all geological processes involved in mélange formation and their mechanisms and interplay (Ogawa et al., 2011).

Tectonic, sedimentary and diapiric processes that play the most important role in the formation of chaotic bodies and mélanges occur at all scales in convergent margin settings. While it is possible to decipher the internal architecture and large-scale structures in modern accretionary complexes by indirect methods of observations (i.e., seismic imaging), it is difficult to do so when the scale of observation is smaller (mesoscale to outcrop scale). Submersible investigations and drill cores provide *in situ* samples and measurements from accretionary complexes (Anma et al., 2010, 2011; Kawamura et al., 2009; Ogawa et al., 2011), but these methods are usually highly expensive and limited in coverage. The well-preserved on-land examples of ancient accretionary complexes are, therefore, highly important to conduct three-dimensional studies of chaotic bodies of mixed rocks and mélanges at various scales, and to better document different processes and their superposition during progressive evolution of accretionary complexes (Aalto, 1981; Cowan, 1985; Cowan and Pini, 2001; Festa et al., 2010a, 2010b; Ghikas et al., 2010;

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Hashimoto and Kimura, 1999; Hsü, 1968; Ogawa, 1998; Orange, 1990; Pini, 1999; Raymond, 1984; Sample and Moore, 1987; Tankut et al., 1998; Ujiie, 2002; Vannucchi and Bettelli, 2002; Yamamoto et al., 2005, 2009).

The results of comparative studies of active and ancient accretionary complexes demonstrate that their complex evolution in time and space also affects the mode of tectonic, sedimentary and diapiric processes and how they interact during mélange formation. Therefore, the structural architecture preserved in a mélange record may be an artifact of the latest and/or more pervasive process(es) involved (e.g., Dela Pierre et al., 2007; Festa, 2011; Festa et al., 2010a, 2010b; Raymond, 1984; Yamamoto et al., 2005). This is particularly the case for "polygenetic mélanges" whose evolution may have transcended several different tectonic settings with complex spatial and temporal interrelationships and superposition (e.g., Bettelli et al., 2002; Camerlenghi and Pini, 2009; Cowan and Pini, 2001; Dela Pierre et al., 2007; Dilek et al., 2005; Festa, 2011; Festa et al., 2010a, 2010b; Orange, 1990; Pini, 1999; Raymond, 1984; Yamamoto et al., 2009). Clear understanding of the geological processes and their interplay in modern and young accretionary complexes is also highly important in better documenting the structural architecture and evolution of more ancient examples in the Precambrian record (Dilek and Ahmed, 2003; Dilek and Polat, 2008).

In this paper, we report on the occurrence of small-scale mélanges *s.l.* (non-mappable at 1:25,000 or smaller scale according to the definition of mélange of Silver and Beutner, 1980) in the Ligurian accretionary wedge in Italy, and discuss the various processes (particularly shale diapirisim) involved in their formation during subduction–accretion, continental collision, and post-collisional periods of the tectonic evolution of the Northern Apennines. These small-scale mélange occurrences recorded in the "*Argille varicolori*" (Varicolored scaly clays) or "*Argille scagliose*" (Scaly clays) *Auct.* of the Northern Apennines provide an excellent case study to demonstrate the significance of their structures to better understand the time-progressive and scale-independent development of chaotic bodies in evolving orogens with superimposed processes and non-coaxial strain patterns.

In the following, we refer to mélange (*sensu* Silver and Beutner, 1980) in describing chaotic rock bodies, mappable at 1:25,000 or smaller scale, of mixed blocks composed of exotic (with respect to the lithostratigraphic unit of the matrix and/or its depositional environment) and native rocks in a pervasively deformed matrix. We refer, on the contrary, to broken formation (*sensu* Hsü, 1968; see also "broken" and "dismembered units" *sensu* Raymond, 1984) in describing, chaotic rock units in which blocks are only of native nature with respect to the matrix (i.e. not-exotic but of the same original lithostratigraphic unit or depositional environment). The term mélange *s.l.* (*sensu lato*) is used to describe in the wider sense chaotic rock units independently of the nature (exotic or not) of the blocks. Moreover, we define "small-scale" mélanges as the chaotic rock units that, according to the definition of Silver and Beutner (1980), are not mappable at 1:25,000 or smaller scale.

2. Regional geology of the Northern Apennines

The Northern Apennines (Figs. 1A and 2) comprise an E to NE-verging accretionary wedge composed of imbricate thrust sheets

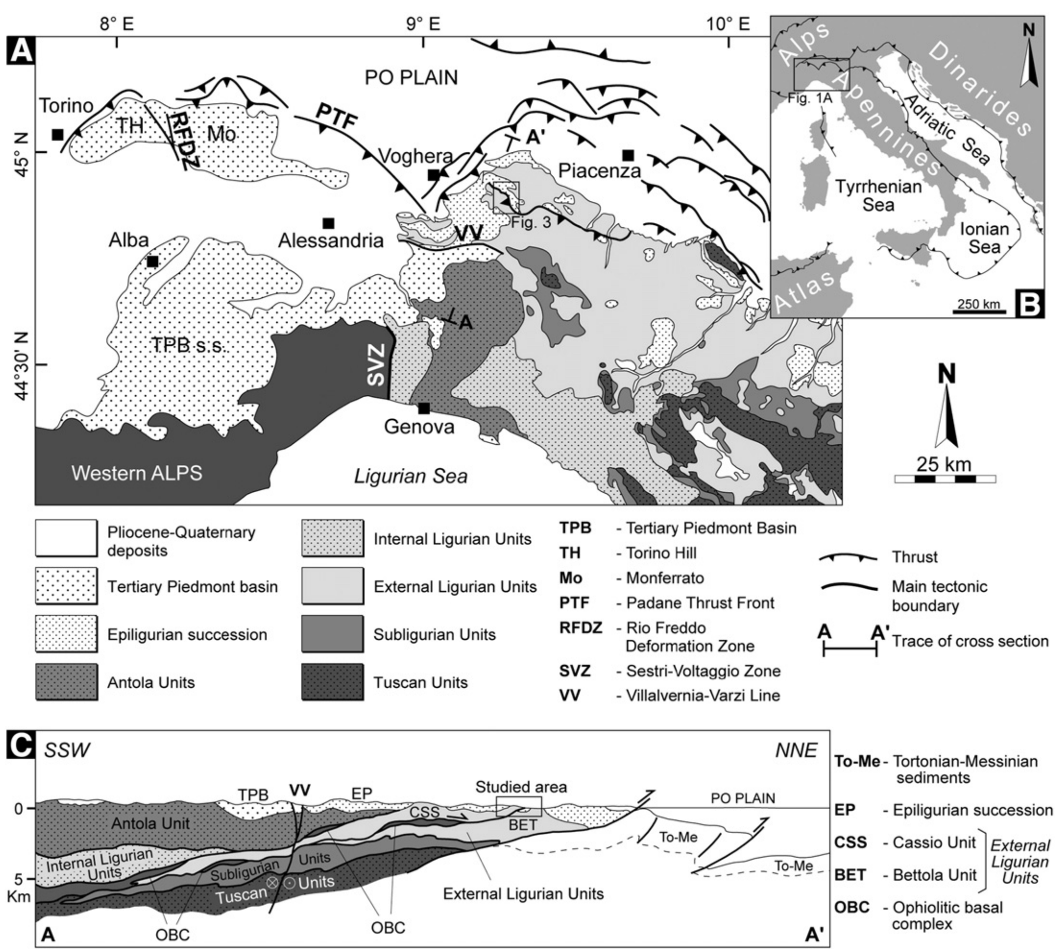

Fig. 1. Structural sketch map (A) of the northwestern Italy (modified from Bigi et al., 1983; Marroni et al., 2010; Vezzani et al., 2010). (B) Location of Fig. 1A. (C) Geological cross section across the Northern Apennines.
Modified from Boccaletti and Coli (1982).