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Growth processes, dimensional parameters and scaling relationships of two conjugate sets of compactive shear bands in porous carbonate grainstones, Favignana Island, Italy

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ABSTRACT

Three main sets of deformation bands are identified in the Lower Pleistocene carbonate grainstones of Favignana Island (Italy). A bedding-parallel set is interpreted to contain compaction bands, based on the lack of evidence for shear. The other two sets are oriented at a high-angle to bedding, forming a conjugate pair comprised of compactive strike-slip shear bands. In this study, we focus on the compactive shear bands documenting their development, as well as analyzing their dimensional parameters and scaling relationships.

Single compactive shear bands are thin, tabular zones with porosity less than the surrounding host rocks, and have thicknesses and displacements on the order of a few mm. The growth process for these structures involves localizing further deformation within zones of closely-spaced compactive shear bands and, possibly, along continuous slip surfaces within fault rocks overprinting older zones of bands. During growth, single bands, zones of bands and faults can interact and link, producing larger structures. The transitions from one growth step to another, which are controlled by changes in the deformation behavior (i.e. banding vs. faulting), are recorded by different values of the dimensional parameters for the structures (i.e. length, thickness and displacement). These transitions are also reflected by the ratios and distributions of the dimensional parameters. Considering the lesser porosity values of the structures with respect to the host rock, the results of this contribution could be helpful for mapping, assessing, and simulating carbonate grainstone reservoirs with similar structures.

1. Introduction

Deformation bands are tabular zones mm- to-cm thick, which accommodate shear and/or volumetric strain in porous rocks and sediments (Engelder, 1974; Aydin, 1978; Aydin and Johnson, 1978; Antonellini and Aydin, 1994; Aydin et al., 2006; Eichhubl et al., 2010; Fossen et al., 2011). Many natural examples of deformation bands are reported from siliciclastic sediments (Fossen et al., 2007; and references therein). In contrast, only a few field examples of deformation bands are described in porous limestones (Micarelli et al., 2006; Tondi et al., 2006a; Tondi, 2007; Rath et al., 2011). Deformation bands are easily recognizable because of their lighter-colour and positive relief with respect to the parent rocks. These field characteristics are strictly related to the deformation mechanisms that modify the grain sizes and porosity values within the bands. Microscopic observations of natural deformation bands, as well as those obtained from experiments on high-porosity limestones (Vajdova et al., 2004; Baxevanis et al., 2006; Baud et al., 2009; Vajdova et al., 2010; Zhu et al., 2010; Cilona et al., Submitted for publication; Vajdova et al., submitted for publication), show a variety of mechanisms responsible for their nucleation and development: (i) grain sliding with rotation and pore collapse; (ii) grain fracturing; and (iii) pressure solution. The first two mechanisms are responsible for the formation of narrow tabular deformation bands with volumetric and shear strain. If the volumetric component of this deformation is negative, the product is known as a compactive (or compactional) shear band (Aydin et al., 2006; Tondi et al., 2006a; Fossen et al., 2007; Tondi, 2007), granulation seams (Pittman, 1981) or disaggregation bands (Fossen et al., 2007). At more advanced stages of deformation, within the

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already compacted bands, pressure solution is the main process responsible for grain-size reduction (Tondi, 2007), which could be also defined dissolution/cementation bands sensu Fossen et al. (2007). Eventually, further deformation facilitates slip along pre-existing stylolites and enhances the accumulation of a larger displacement along discrete shear planes (Aydin et al., 2006; Tondi et al., 2006a). Mechanical twinning of calcite crystals (Ferrill and Groshong, 1993) and precipitation of dissolved solids in the nearby pores are processes also documented within deformation bands in porous limestones (Tondi et al., 2006a; Tondi, 2007; Baud et al., 2009; Vajdova et al., 2010; Rath et al., 2011).

The transition from one deformation behavior to another (i.e. banding vs. faulting) is likely controlled by changes of the material properties within the bands; the resulting mechanical instability is often accompanied by progressive evolution of the tectonic structures (Aydin and Johnson, 1983; Shipton et al., 2005). In porous rocks, deformation first occurs in the form of single compactive shear bands, evolves continuously forming zones of multiple compactive shear bands and, eventually, faults composed of discrete, sharp, more or less planar discontinuities and fault rocks (i.e. breccia and gouge).

The aim of this study is to investigate both dimensional parameters and scaling relationships of single compactive shear bands, zones of compactive shear bands and strike-slip faults in porous carbonate grainstones. Many excellent outcrops of Favignana Island (Egadi Islands, western Sicily) expose a 21–23 m-thick Lower-Pleistocene porous carbonate grainstones crosscut by the aforementioned tectonic structures. There, we collected detailed data related to length, thickness and amount of slip along structures as well as to investigate their detailed geometries, kinematics and growth processes. Previous works on fault scaling relationships provide a window into the mechanics of brittle strain localization in compact and porous rocks (Cowie and Scholz, 1992; Dawers et al., 1993; Willemse et al., 1996; Scholz, 2002; de Joussineau and Aydin, 2007; Fossen et al., 2007; Schultz et al., 2008). In particular, the previous data from porous rocks pertain primarily to displacement–length (D–L) and displacement-damage zone thickness (D–T) scaling relations of deformation bands in sandstones (Fossen and Hesthammer, 1997; Shipton and Cowie, 2001; Wibberley et al., 2000; Shipton et al., 2005; and Fossen et al., 2007 and the references therein). Data presented in this paper provide a new insight into the evolution of statistical parameters of shear bands, which may be useful for an improved understanding of faults in porous carbonate rocks and characterization of carbonate reservoirs (cf. Agosta et al., 2010).

2. Geological framework

Favignana is the largest of the Egadi Islands, and is located in NW Sicily along the southern edge of the Tyrrhenian Sea (Fig. 1a). This area represents the westernmost, and most external, sector of the Sicilian orogenic belt, which is mainly comprised of south-verging, Neogene fold-thrust tectonic elements (Fig. 1a; Scandone et al., 1974; Giunta et al., 2000).

The most recent faults of NW Sicily (Nigro et al., 2000; Renda et al., 2000; Gueguen et al., 2002; Giunta et al., 2009) form a grid of high-angle strike-slip structures roughly oriented either W-NW (right-lateral) or N-NE (left-lateral). The kinematics of these two sets of strike-slip faults is compatible to the current regional stress field, which is characterized by a NW-SE oriented, greatest horizontal compression direction (Giunta et al., 2004; Tondi et al., 2006b).

At Favignana Island (Fig. 1b), deformed Triassic to Miocene platform carbonates, which pass upwards into deep-water marls and limestones, are the basement units underlying Plio-Pleistocene marine deposits (Abate et al., 1995, 1997; Incandela, 1995; Tavarnelli et al., 2003). These marine deposits are comprised of Upper Pliocene shales overlain by 20–25 m thick, Lower Pleistocene carbonate grainstones (Fig. 1b).

2.1. Lower Pleistocene carbonate grainstones

The yellowish carbonate grainstones of Favignana are Lower Pleistocenic in age. The grainstones are characterized by beds dipping: 5°–10° ESE, and a bed thickness ranging between 20 cm and 100 cm. The mean thickness of the whole Lower Pleistocene succession is nearly 21 m at Cala San Nicola and 23 m at Cala Rossa (Fig. 1b and Fig. 2). The maximum burial depth experienced by the carbonate grainstones is estimated to be between 0 and 30 m (Abate et al., 1995, 1997).

Based upon their grain size, sorting, sedimentary/biogenic structures and amount of matrix and cement, as well as the widespread erosional flooding surfaces, we distinguish up to seven different lithofacies (Fig. 2). In general, the carbonate grainstones are mainly comprised of bioclasts (i.e. *Vermetus*, *Serpula*, lamellibanches, echinoids, algae and corals) ranging in size from sub-millimeter to centimeter (Fig. 2b). The amount of matrix and calcite cement vary significantly among the different lithofacies.

Thin-section observations are consistent with presence of intergranular and intragranular porosity within the carbonate grainstones. Generally, well-developed intergranular pores form

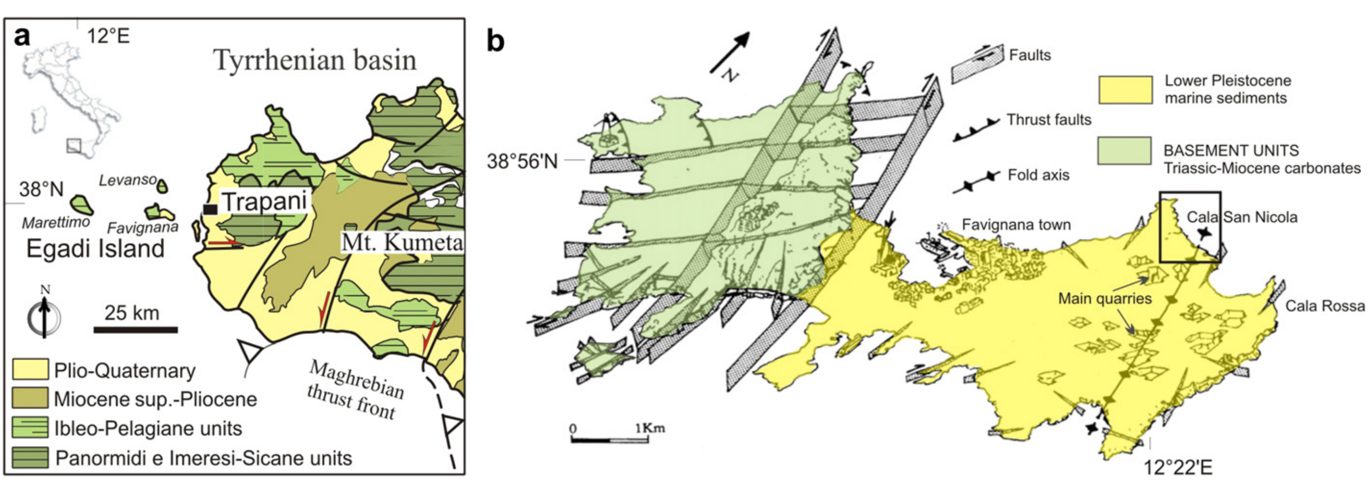

Fig. 1. (a) Geological setting of western Sicily and (b) of Favignana Island. The location of the study area is marked with a black rectangle.