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Recognition of trigger mechanisms for soft-sediment deformation in the Pleistocene lacustrine deposits of the Sant'Arcangelo Basin (Southern Italy): Seismic shock vs. overloading

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Abstract

The lacustrine deposits of the San Lorenzo Cycle belong to the infill succession of the Sant'Arcangelo Basin, a Pliocene to Pleistocene satellite basin, developed close to the front of the south-Apennines thrust belt. The lower to middle Pleistocene lacustrine succession is made up of siltstone and claystone interbedded with sandstone, carbonate and volcaniclastic beds, arranged in fining-upward sequences. The upper to middle part (about 50 m thick) of the succession (about 200 m thick), has been investigated in detail in the depocentral sector of the lacustrine basin. Here, soft-sediment deformation structures occur in fine-grained sandstone and claystone alternations and show a wide morphological variability (deformed laminations, slumps, load structures, large vertical water-escape structures and neptunian dykes). Their formation occurred during and after sedimentation, with different mechanisms of deformation: some structures are related to liquefaction and fluidization processes (viscous fluid behaviour) while others occurred when sediment had already undergone lithification and its behaviour was plastic and/or brittle.

Facies analysis and detailed morphologic study of the soft-sediment deformation structures indicate that the main trigger agents for deformation were seismic shocks and overloading induced by sudden deposition of coarser sediments on clays due to the arrival of density currents. Thus, the soft-sediment deformation structures provide a continuous record of the tectonic and sedimentary processes that acted in the lacustrine basin from sedimentation until diagenesis.

Keywords: Soft-sediment deformation structures; Seismites; Overloading; Lacustrine deposits; Early Pleistocene; Southern Italy

1. Introduction

Most soft-sediment deformation is related to a drastic decrease in shear resistance in water-saturated and unconsolidated sediments. Liquefaction and fluidization are the main processes that allow a temporary change from solid-like to liquid-like behaviour in sand and silt (Allen, 1982). Liquefaction and fluidization can be induced by many natural processes, including overloading, unequal loading, wave-induced cyclical and/or impulsive stresses, sudden changes in groundwater level, and earthquakes (Owen, 1987, 1996). Soft-sediment deformation structures related to seismically-induced liquefaction or fluidization (seismites, *sensu* Seilacher, 1969, 1984, 1991) have been analysed by many authors and reported from all sedimentary environments, but they seem to be particularly common in lacustrine successions (Sims, 1973, 1975, 1976; Ben-Menahem, 1976; Hesse and Reading, 1978;

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Hempton and Dewey, 1983; Seilacher, 1984; Plint, 1985; El-Isa and Mustafa, 1986; Anand and Jain, 1987; Davenport and Ringrose, 1987; Scott and Price, 1988; Ringrose, 1989; Beck et al., 1992; Karlin and Abella, 1992; Van Loon et al., 1995; Beck et al., 1996; Alfaro et al., 1997; Lignier et al., 1998; Malkawi and Alawneh, 2000; Rodríguez Pascua et al., 2000; Becker et al., 2002; Leroy et al., 2002; Bowman et al., 2004; Migowski et al., 2004; Weidlich and Bernecker, 2004; Schnellmann et al., 2005). Moreover, some homogeneous silty beds in lacustrine environments have been interpreted as seismites (Doig, 1986, 1990; Shilts and Clague, 1992).The relative abundance of seismites in lacustrine successions is explained by Sims (1973) in terms of: (1) the presence of water-saturated sediments; (2) the presence of sediments with high susceptibility to liquefaction; and (3) the absence of hydrodynamic and sedimentary processes able to obliterate the products of seismically-induced deformation.

In this paper we describe and analyse deformed beds observed in a Pleistocene lacustrine succession of the Sant'Arcangelo Basin (Southern Italy). Our analyses focused on the detailed description of the morphology of different kinds of soft-sediment deformation structures, interpretation of the timing and mechanism of deformation, and the interpretation of trigger mechanisms.

The detailed study of these soft-sediment deformation structures allows us to demonstrate that not all deformed beds are related to a seismic trigger mechanism. A major outcome of the study is to contribute to the establishment of general criteria to distinguish seismically induced soft-sediment deformation structures from non-seismically induced ones in lacustrine successions.

2. Geological setting

2.1. The Sant'Arcangelo Basin

The studied lacustrine deposits (San Lorenzo Cycle in Pieri et al., 1993, 1994) are located in the northern part of the Sant'Arcangelo Basin, a Pliocene to Pleistocene satellite basin, developed close to the front of the south Apennines chain (Fig. 1A,B). Sediment infill of the Sant'Ar cangelo Basin reaches more than 5 km in thickness (Mostardini and Merlini, 1986; Merlini and Cippitelli, 2001). Initially, during the Pliocene and early Pleistocene, the Sant'Arcangelo Basin was a shallow-sea area onto a large moving sheet overthrusting the Apulia units. During late early and middle Pleistocene, when the thrust front began to undergo uplift, marine sedimentation was progressively followed by continental deposits (Vezzani, 1967; Caldara et al., 1988; Pieri et al., 1996). Uplift was caused by thrusting and transpression in the buried Apulia units (Roure et al., 1991; Hippolyte et al., 1994; Bonini and Sani, 2000; Patacca and Scandone, 2001). During the middle Pleistocene, these tectonic features caused the emergence of a ridge (ridge 2 in Fig. 1B), leading to the complete isolation of the Sant'Arcangelo Basin from the foredeep (the Bradanic Trough, Fig. 1B) and the end of deposition within the basin.

The Sant'Arcangelo Basin infill is represented by four depositional sequences (Pieri et al., 1996) characterized by the occurrence of syndepositional tectonics recorded both by progressive unconformities and by growth faults or folds (Caldara et al., 1988; Pieri et al., 1994; Vitale, 1996; Zavala, 2000). Palaeomagnetic data from claystones, showing ultrarapid vertical-axis rotations (Mattei et al., 2004), confirm the presence of tectonics during sedimentation.

The lower two sequences are mainly composed of deltaic to shelf systems. The third sequence developed in two different and adjacent sectors of the basin and comprises deltaic to shelf systems (Sauro Cycle) in the eastern sector of the Sant'Arcangelo Basin and fluvio-lacustrine systems (San Lorenzo Cycle) in the western sector (Fig. 1C); the fourth sequence, the only one comprising undeformed strata, unconformably overlies the older sequences and is composed of alluvial sediments.

2.2. The San Lorenzo Cycle

The San Lorenzo Cycle is composed of three units (from the bottom upwards it is made up of conglomerates, then silty claystones and then conglomerates again), and reaches a thickness of over 500 m. The middle unit, the subject of this work, is represented by lacustrine deposits cropping out over an area of 5 km × 2 km, in a NW–SE trending synclinal basin (Fig. 1C). The depocentre is located at Serre, where the unit thickness is over 200 m; outward from this area, the thickness decreases by tens of metres. In the southern area, bedding dips about 10° towards the syncline axis and the angle decreases upwards until strata become subhorizontal. The San Lorenzo Cycle developed during the growth of the Alianello anticline (Fig. 1C,D), which induced the progressive unconformity that is characterised by the onlap of the lacustrine deposits onto the flank of the fold and the progressive decrease in thickness both of some guidebeds and of the whole succession toward the hinge region of the fold (Fig. 1D – Sabato, 2000).

In the depocentre and along the eastern side of the lacustrine unit, the sediments are generally claystones and silty claystones interbedded with sandstones. Calcareous and volcaniclastic interlayers were also found. Along the western side of the lacustrine succession, sandstones and