Pergamon

Journal of Structural Geology, Vol. 18, No. 10, pp. 1265 to 1269, 1996

0191-8141/96 $15.00 + 0.00

PII: S0191-8141(96)00046-6

Clay diapirs in Neogene–Quaternary sediments of central Sicily: evidence for accretionary processes

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(*Received* 21 *December* 1995; *accepted in revised form* 5 *June* 1996)

Abstract—The Neogene–Quaternary sediments infilling the perched basins of the central Sicilian thrust belt are characterized by the occurrence of several lenticular bodies of mud breccia. These bodies, made of a brecciated to cataclastic clayey matrix containing exotic blocks, represent the result of mud diapirism occurring along the frontal part of the central Sicilian accretionary wedge. Copyright © 1996 Elsevier Science Ltd

INTRODUCTION

Recent investigations on modern accretionary complexes show that mud diapirism is one of the processes for producing large volumes of melanges (Brown & Westbrook 1988, Brown 1990, Cita & Camerlenghi 1990, Henry *et al.* 1990, Moore *et al.* 1990, Limonov *et al.* 1994, Cronin *et al.* 1995). Mud diapirs, which have been also recognized in ancient accretionary terranes (Larue & Speed 1984, Torrini *et al.* 1985), are caused by the occurrence of highly overpressured and underconsolidated sediments along the basal detachment of the wedge. Dewatering and degassing of methane-rich overpressured material (Hedberg 1974, Brown & Westbrook 1988) cause the intrusion of mud bodies that, on sampling the entire accretionary prism during their uprising, form mud diapirs and, at the surface, mud volcanoes (Higgins & Saunders 1973, Hedberg 1974). Mud diapirism and/or volcanism in thrust belts suggest, therefore, the occurrence of accretionary processes with the underplating of sediment at the base of the wedge.

The Neogene–Quaternary sediments which occur in the central Sicilian thrust belt (Fig. 1) exhibit, at different stratigraphic horizons, typical levels of chaotic clays, known as brecciated clays (*Argille brecciate*, Ogniben 1954). Five main levels, having a thickness ranging from a few to hundreds of metres, have been distinguished within the Tortonian–Lower Pleistocene sequences. These levels, made up of dark mud breccia containing exotic blocks, have been interpreted (Ogniben 1953, 1954, Rigo De Righi 1957) as large olistostromes related to the gravitational processes occurring on the basin slopes as a result of the rapid erosion of clay-cored anticlines.

Bearing in mind that mud volcano eruptions releasing small amounts of methane are active on land (e.g. Maccalube and Salinelle mud volcanoes, Fig. 1), the significance of mud breccia occurring within the Plio–Pleistocene sequences of the frontal part of the thrust belt can be re-interpreted in the light of new information about mud diapirism. Three case histories have been investigated. The study is mostly based on field relationships between the mud breccia and the Neogene–Quaternary sediments and on the reconstruction of the geometry and the style of the deformation of the chaotic levels.

GEOLOGICAL SETTING

Sicily is part of the south-verging branch of the Apenninian–Maghrebian orogenic belt made up of a pile of nappes derived from the deformation of different Meso–Cenozoic domains as a result of the African–European collision. These units were piled up during Paleogene–Neogene times and, in Pleistocene times, overthrust the carbonate platform of the Pelagian block (Burollet *et al.* 1978) that, exposed in the Hyblean Plateau, presently represents the foreland of the system (Fig. 1).

Besides remnants of Hercynian crystalline nappes forming the southernmost edge of the Calabrian arc (Fig. 1), the backbone of the Maghrebian thrust belt is made of a pile of allochthonous Mesozoic–Eocene pelagic terranes grading upwards into Oligocene–Middle Miocene turbidites (Ogniben 1960, Lentini & Vezzani 1978). The frontal part of the orogenic belt is

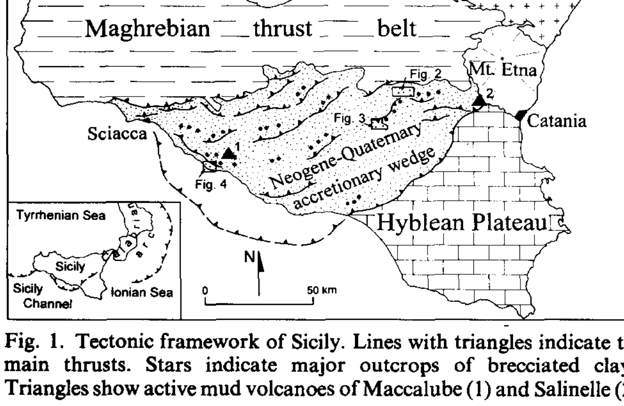

Fig. 1. Tectonic framework of Sicily. Lines with triangles indicate the main thrusts. Stars indicate major outcrops of brecciated clays. Triangles show active mud volcanoes of Maccalube (1) and Salinelle (2).

represented by a Neogene–Quaternary accretionary wedge which has developed since Tortonian times to form a prism up to 6000 m thick (e.g. the Caltanissetta basin and the Gela nappe), involving the entire sedimentary cover of the African continental margin (Roure *et al.* 1990). This succession is represented by Triassic to Paleogene platform and basinal carbonates, including several levels of volcanics, covered by Neogene to Pleistocene glauconitic and quartz-rich sandstones, evaporites, marls and calcarenites (Catalano & D'Argenio 1978, Patacca *et al.* 1979). From Tortonian to Pleistocene times, during the progressive southward thrust imbrication, different syntectonic perched basins developed above the wedge (Butler & Grasso 1993, Butler *et al.* 1995). The infilling of these basins is represented by Upper Tortonian–Lower Messinian marly clays and sandstones, by Messinian evaporitic sequences, by Lower Pliocene marls and marly limestones and finally by Upper Pliocene–Lower Pleistocene sediments. Discontinuous levels of mud breccia are embedded at different stratigraphic intervals.

FIELD OBSERVATIONS

In order to define the geometry of the bodies of mud breccia and their relationships with the Plio–Pleistocene sequences, three representative areas characterized by the occurrence of these chaotic levels have been examined along the Neogene–Quaternary accretionary wedge of central Sicily (Fig. 1). From the north-east to the south-west, the areas investigated are located near the Zimbalio and Grottacalda mines and around the village of Realmonte.

The Zimbalio mine (Fig. 2) is located on the southern border of an Upper Pliocene perched basin which developed above different thrust sheets of the Maghrebian orogenic belt, mainly represented by the clays and quartzarenites of the Numidian Flysch. This unit is unconformably covered by Upper Tortonian–Lower Messinian marly clays and sandstones, Upper Messinian evaporitic limestones and gypsum and by Lower Pliocene marly limestones. These sequences, involved in thrust deformation during the Middle Pliocene, are unconformably covered by Upper Pliocene marls, sands and calcarenites (Di Grande *et al.* 1976) which form, as a whole, a wide syncline representing a remnant of the perched basin. Along the southern border of this basin, a 5 km-long, NE–SW trending body made of mud breccia outcrops in front of an overturned south-verging fault propagation fold (cross-section in Fig. 2). This body, which truncates the contacts between the different rock units of the whole succession, is made of brownish clayey breccias containing blocks of Messinian evaporites, Lower Pliocene marly limestones and quartz-arenites belonging to the Numidian Flysch unit. These clays, interpreted as an olistostrome interlayered in the Upper Pliocene sequence (Di Grande *et al.* 1976), are characterized by a brecciated to cataclastic texture. In this area, mud breccias have developed along a regional thrust fault, over which the whole Upper Pliocene basin was carried southwards.

The Grottacalda mine is located within a large Upper Pliocene–Lower Pleistocene perched basin (Fig. 3) filled

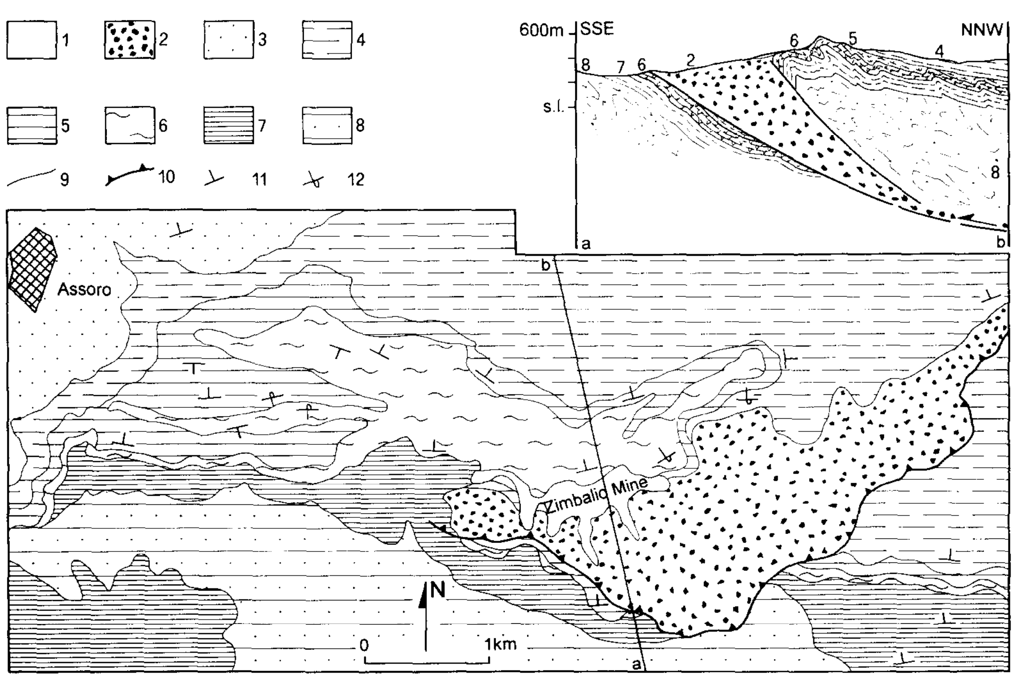

Fig. 2. Geological map (location in Fig. 1) of the Zimbalio Mine area (after Di Grande *et al.* 1976, modified). Key: 1, detritus; 2, mud breccia; 3, sands and calcarenites (Late Pliocene); 4, blue marly clays (Late Pliocene); 5, marls and marly limestones (Early Pliocene); 6, diatomites, evaporitic limestones and gypsum (Messinian); 7, marly clays and sandstones (Late Tortonian–Early Messinian); 8, Maghrebian units (Cretaceous–Middle Miocene); 9, stratigraphic boundaries; 10, thrusts; 11, bedding (strike and dip); 12, overturned bedding.

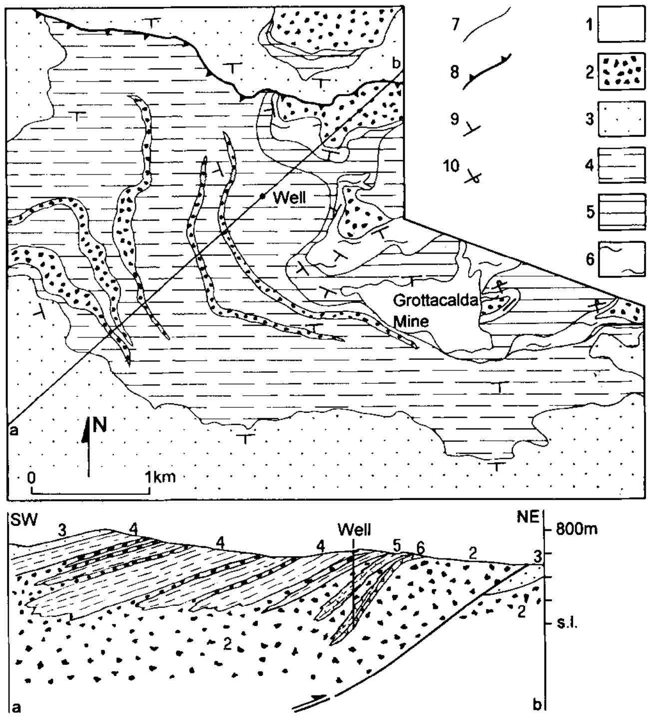

Fig. 3. Geological map (location in Fig. 1) of the Grottacalda Mine area (after Ogniben 1954, modified). Key: 1, detritus; 2, mud breccia; 3, sands and calcarenites (Late Pliocene); 4, blue marly clays (Late Pliocene); 5, marls and marly limestones (Early Pliocene); 6, diatomites, evaporitic limestones and gypsum (Messinian); 7, stratigraphic boundaries; 8, thrusts; 9, bedding (strike and dip); 10, overturned bedding.

by a sequence of marly clays, sands and calcarenites that, as a whole, rest unconformably above Messinian evaporites and Lower Pliocene marly limestones (Ogniben 1954). In this area, bodies of mud breccia crop out extensively both in the core of WSW–ENE trending anticlines and along WNW–ESE striking back-thrusts involving the whole sedimentary sequence. Lenses, having lengths up to 3 km and thicknesses ranging between 0 and 50 m, are also found within the Upper Pliocene marly clays. Mud breccia levels interlayered within the whole succession (cross-section in Fig. 3) have been found in bore-holes drilled around the mine area (Ogniben 1954). These bodies consist of a matrix of brecciated clays represented by millimetre- to centimetre-sized angular clasts of white, brown, red and green clays and marls containing Cretaceous to Upper Miocene foraminifera (Ogniben 1954). Several decimetre- to metre-sized blocks and fragments of lithics are embedded within the brecciated clay matrix. Exotics are made of Messinian evaporitic limestones, Oligo–Miocene quartz-rich sandstones and Paleogene marly limestones and platform carbonates. The different levels of mud breccia, previously interpreted as repeated events of basinal landslides (Ogniben 1954), show well developed injection structures (observed in a recent trench for a gas pipeline).

The village of Realmonte is located along the southern coast of Sicily, at the frontal part of the thrust belt where a remnant of a frontal Upper Pliocene–Lower Pleistocene perched basin is present (Fig. 4). The Upper Pliocene–Lower Pleistocene sediments consist of clays and calcarenites which lie unconformably on the Messinian evaporites and the Lower Pliocene marly limestones (Magné *et al.* 1972). Middle Pleistocene marine terraces overlie the Lower Pleistocene calcarenites. In this area, the mud breccias crop out as a large body (up to 100 m thick), well exposed in the Capo Rossello cliff (Fig. 4), intruding into the Upper Pliocene–Lower Pleistocene sequence by a conduit that cuts across the whole sediment (cross-section in Fig. 4). Around the main body, sill-like intrusions of mud breccia are also embedded within the calcarenites which are disrupted along the boundaries with mud levels. The brecciated material, which along the conduit walls show subvertical injection structures, comprises dark-brown clay breccias, Cretaceous to Late Miocene in age, including several sedimentary and volcanic blocks belonging to the Meso–Cenozoic successions involved in the accretionary wedge. Blocks include Mesozoic reef limestones, Cretaceous marly limestones and varicoloured clays and marls, Lower–Middle Miocene quartz-rich and glauconitic sandstones and calcarenites belonging to the sedimentary successions of the African paleomargin. Blocks of the Messinian sequence (diatomites, evaporitic limestones and gypsum) and of the Lower Pliocene marly limestones have also been found. Volcanics are alkaline to transitional basalts which have petrochemical features (Lucido *et al.* 1978)

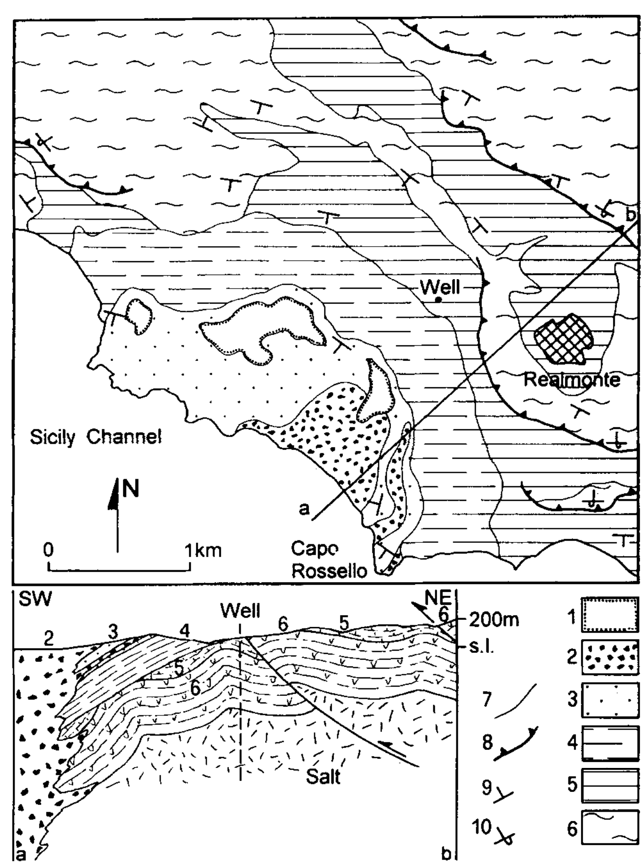

Fig. 4. Geological map of the Realmonte area (location in Fig. 1). Key: 1, marine terraces; 2, mud breccia; 3, sands and calcarenites (Early Pleistocene); 4, blue marly clays (Late Pliocene–Early Pleistocene); 5, marls and marly limestones (Early Pliocene); 6, gypsum and gypsyferous clays (Messinian); 7, stratigraphic boundaries; 8, thrusts; 9, bedding (strike and dip); 10, overturned bedding.

similar to those of the basalts occurring within the Mesozoic carbonates of the African continental paleomargin involved in the thrust belt.

DISCUSSION AND CONCLUSIONS

The Plio–Pleistocene sediments infilling the perched basins developed above the frontal part of the Maghrebian orogenic belt are characterized by the occurrence of bodies of mud breccia. This material, which shows common features in all three key studied areas, occurs as kilometre-long lenticular bodies, developing along the major thrusts (Zimbalio Mine and Grottacalda Mine) or forming large intrusions (Realmonte area) that truncate the contacts between the different Neogene–Quaternary formations. These bodies are basically made of a clayey matrix, containing several exotic blocks. The matrix breccia is made up of clasts and fragments of white, brown, red and green clays and marls derived from Cretaceous to Upper Miocene pelitic sequences. It shows a distinctive brecciated to cataclastic texture with typical injection structures suggesting remobilisation of breccia material related to fluid expulsion. Exotics include several blocks represented by sediments and volcanics belonging to either the Meso–Cenozoic successions of the African continental paleomargin involved in the thrust belt (Grottacalda Mine and Realmonte) or to the Maghrebian units (Zimbalio Mine).

These characteristics suggest that the brecciated material may be the result of mud diapirism. The geometry of these bodies is, in fact, comparable to that documented in several seismic profiles carried out along active accretionary complexes (Brown & Westbrook 1988, Moore *et al.* 1990, Henry *et al.* 1990, Cita & Camerlenghi 1990, Limonov *et al.* 1994). In these regions, mud diapirism has been related to the underplating of underconsolidated material at the base of the accretionary wedge along a basal detachment. Fluids and mud are extruded from the basal detachment and reach the surface of the wedge via major thrust faults and fractures giving rise to mud volcanos, mud ridges and mud diapirs that, during their emplacement, rip up different rock-units of the wedge and the overlying slope sediments (cf. fig. 14 in Brown & Westbrook 1988).

Within this framework the brecciated clays that occur in the areas studied, are interpreted as different manifestations of mud diapirism. In the Zimbalio Mine (cross-section in Fig. 2) and Grottacalda Mine (cross-section in Fig. 3) areas, the brecciated clays are interpreted as mud ridges developing along major thrust faults. The thin mud levels interlayered in the Upper Pliocene clays that occur in the thrust hanging-wall (Grottacalda Mine area) might be the result of fluid venting along permeable layers, related to thrusting (cf. figs. 9 and 11 in Moore *et al.* 1990). The mud breccia body occurring in the Realmonte area (cross-section in Fig. 4) is interpreted as a mud diapir. This mud body truncates the contacts between the different rock units, which are disrupted near the conduit, and gives rise to sill-like intrusions of diapiric material in the upper portion of the Upper Pliocene–Lower Pleistocene sequence (cf. fig. 3 in Brown & Westbrook 1988).

The occurrence of mud diapirism at the frontal part of the central Sicilian thrust and fold belt (the Caltanissetta basin and the Gela nappe) supports the idea that this portion of the Neogene–Quaternary orogenic belt may represent, according to Roure *et al.* (1990), an accretionary wedge related to subduction of a sector of the Pelagian block probably characterized by a very thinned continental to oceanic crust.

Acknowledgements—This work was supported by M.U.R.S.T. (grant 40% 1992) and by C.N.R. (grant no. 94.00184.05).

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