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Geological and geophysical evidences for mud diapirism in south-eastern Sicily (Italy) and geodynamic implications

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ABSTRACT

A recent investigation on the northern margin of the Hyblean Plateau in south-eastern Sicily highlights the occurrence of a clayey diapiric intrusion into the foreland carbonate series. The piercing body, exposed along a ~270 long and ~30 m deep NE-SW elongated quarry, consists of serpentinite-bearing clayey material. As suggested by the internal contractional features and by its geometric relations with the adjacent rocks, the clayey body intruded in the foreland series producing on its flanks a set of domino-arranged normal faults which nucleated as a result of gravitative collapse. Taking into account previous petrological studies, which provided information about the origin of the mud, a deep geodynamic model for the northern part of the Hyblean Plateau is here presented. The mud diapirs originated from the uprising of pre-existing serpentinite bodies and others products of alteration probably developed along an ancient ridge-transform intersection where a hydrothermally altered mantle wedge occurred. This interpretation is supported by seismic, magnetic and gravimetric anomalies beneath the analyzed area and has implications on its geodynamic evolution.

1. Introduction

Mud diapirism and mud volcanism are peculiar geological phenomena that have been widely recognized all over the globe. They occur in various tectonic settings and typically predominate at converging plate boundaries, such as the Mediterranean Ridge (Limonov et al., 1997; Camerlenghi et al., 1995; Cita et al., 1996; Robertson and Shipboard Scientific Party, 1996; Fusi and Kenyon, 1996; Kopf et al., 1998, among others), Sicily (Monaco and Tortorici, 1996), Eastern Indonesia (Barber et al., 1986), Barbados (Martin et al., 1996), and Makran (Wiedicke et al., 2001). Diapirs commonly intrude vertically upward along fractures or zones of structural weakness through denser overlying rocks because of density contrast between a less dense, lower rock mass and overlying denser rocks (e.g. Bishop, 1978). Tectonic processes are the main driving mechanism invoked for the development of mud diapirism and volcanism (e.g. Higgins and Saunders, 1974; Barber et al., 1986; Vendeville and Jackson, 1992; Limonov et al., 1996), in addition to high overpressure in sediments due to rapid sedimentation and gas generation (Hedberg, 1974; Brown, 1990; Hovland et al., 1997).

Many types of diapirs have been documented by abundant literature including those consisting of salt (e.g. Jackson and Talbot, 1986), mud (Orange, 1990), and serpentinite (e.g. Carlson, 1984).

Serpentinite diapirs mainly occur at ocean-continent boundaries (e.g. Galicia Bank in the Western Iberian Margin, see Boillot et al., 1980), at ridge–transform intersections (RTIs) (Blackmann et al., 1998; Cann et al., 2001; Ildefonse et al., 2007) and along subduction zones (e.g. Mariana Forearc, see Oakley et al., 2007 and reference therein). Serpentinite originates from the interaction of seawater and peridotites during which the variable degree of serpentinization usually causes differential expansion that may provoke vertical movements along fracture zones (Skelton and Jakobsson, 2007). Locally, the contrast of density among serpentinized ultramafic bodies and denser overlying rocks, may give rise to intrusion of serpentinite muds that can reach the surface or seafloor forming volcano-like dome-shaped reliefs and oceanic core complexes (OCCs) (e.g. Escartin et al., 2003; Tucholke et al., 2008), respectively.

Many examples of mud diapirism along the Sicilian collision zone have been documented by previous authors (e.g. Monaco and Tortorici, 1996; Bonini, 2009). In particular, Late Miocene to Pleistocene brecciated clays outcropping in the central part of the Sicilian chain have been attributed to mud volcanism related to overpressured fluids in clayey thrust fault zones (Monaco and Tortorici, 1996). Active mud diapirism currently occurs onshore, at the Paternó "Salinelle" mud field in eastern Sicily, at the Aragona

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"Maccalube" mud field in Western Sicily and at the Caltanissetta "S. Barbara village" mud field in central Sicily (Madonia et al., 2011), and offshore, along the external Calabrian arc sedimentary wedge (Polonia et al., 2011) or along fracture zones in the Hyblean-Malta shelf (Holland et al., 2003).

New field evidences from recent deep excavations at the S. Demetrio high in the NE sector of the Hyblean Plateau suggest a diapiric intrusion of unusually chaotic clayey material in the foreland domain of Sicily. Intrusion mechanisms have been highlighted through the analysis of structural pattern into the clayey body and of the associated flank deformation in the host rocks. The comparison between field and available offshore seismic sections, has allowed to better interpret the deep geometry of the outcropping piercing bodies. Moreover, previous petrological studies (e.g. Manuella et al., 2012), gravity and magnetic anomalies (e.g. Chiappini et al., 2000) and available industry drill-hole data (e.g. the S. Demetrio 1 Agip well) have also been examined with the aim of understanding origin and triggering mechanism of diapirism in south-eastern Sicily and of imaging a possible crustal model of the northern margin of the Hyblean Foreland.

2. Geological framework

South-eastern Sicily is constituted by the emergent portion of a larger foreland domain, the Pelagian Block (Ben-Avraham and Grasso, 1991). This is a 25–30 km thick continental crustal portion of the north-Africa margin (Cassinis, 1983; Scarascia et al., 1994; Dewey et al., 1989) which extends from the Sahel region of Tunisia to Sicily (Finetti, 1982; Burollet et al., 1978; Argnani, 1990) (Fig. 1A).

In the central Mediterranean, rocks pertaining to the Pelagian Block outcrop both in the Sicily Channel (Finetti and Morelli, 1972; Finetti, 1984; Reuther and Eisbacher, 1985), where they form the Lampedusa and Malta islands, and extensively in the south-eastern Sicily mainland where they form the Hyblean Plateau (Fig. 1A and B). This is composed of a ~10 km thick carbonate succession, whose upper 5–6 km have been drilled by commercial boreholes. Carbonate sequences consist of shallow to deep-water Mesozoic-Cenozoic rocks (Patacca et al., 1979; Bianchi et al., 1987) with repeated intercalations of volcanic products (Late Cretaceous, Late Miocene and Plio-Pleistocene cycles, Patacca et al., 1979), while there is no direct evidence of the Permo-Triassic intervals which were inferred only by seismic lines (Bianchi et al., 1987). The Pelagian Block crystalline basement was drilled in mainland Tunisia (Burollet, 1991) where it is made up of Precambrian granites and metamorphic rocks. Conversely, in the Hyblean Plateau the only direct evidence of the nature of the basement derives from xenoliths in volcanic products (Scribano, 1986), whose composition suggests that in this sector the lower crust is formed by an ultramafic core-complex tectonically exposed on the seafloor of an ancient oceanic domain (Scribano et al., 2006). Hydrothermal modification of xenoliths also suggests that a serpentinite-hosted hydrothermal system (Scribano et al., 2006), typical of slow and ultra-slow spreading ridges, was active since the Middle Triassic, as deduced by U/Pb analyses of hydrothermal zircons (Sapienza et al., 2007).

From a tectonic point of view, the Hyblean Plateau is a fault-controlled morphological high limited by major extensional fault systems on its margins. In particular, along its western border the Hyblean succession is dislocated about 4000 m by a roughly

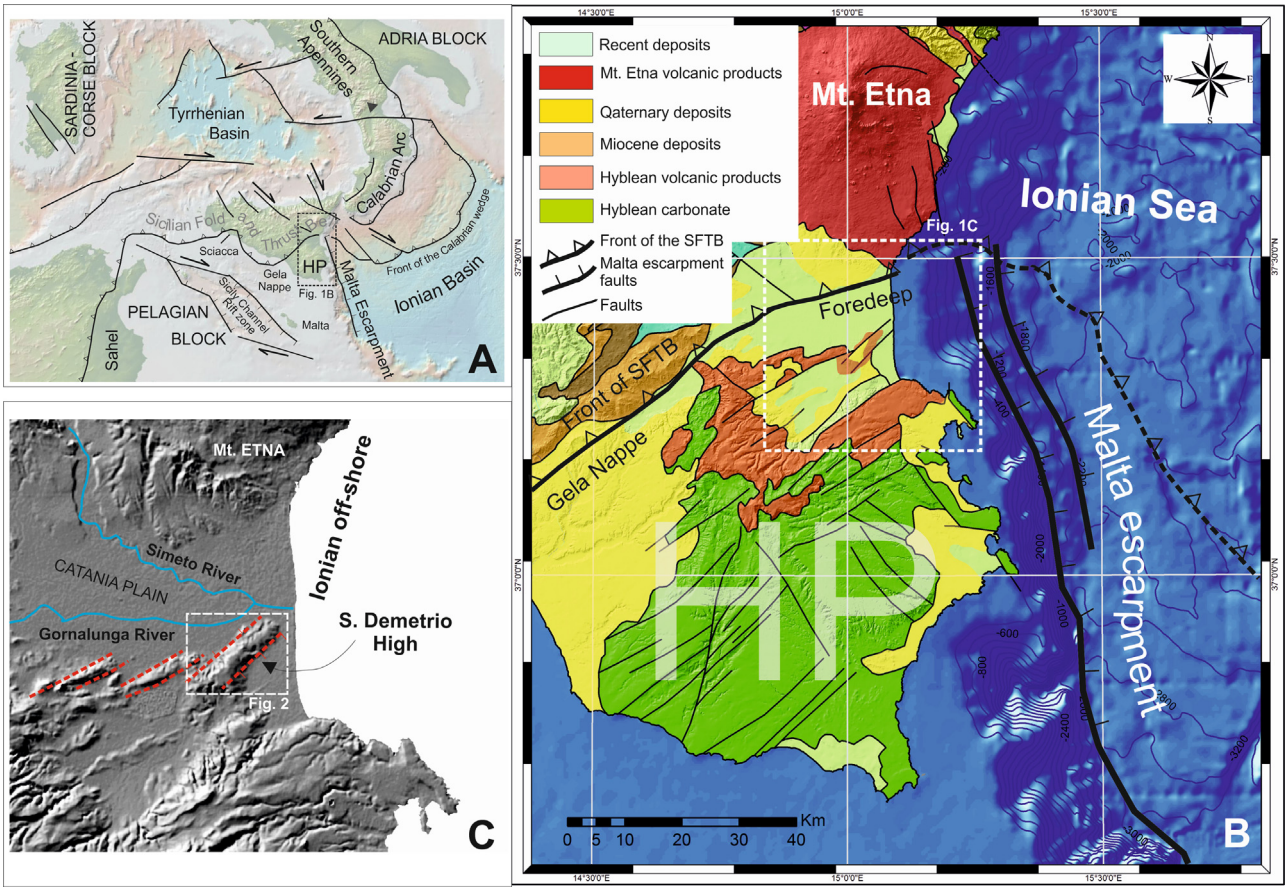

Fig. 1. (a) Structural setting of the central Mediterranean region with evidenced the main tectonic features; (b) geological sketch map of south-eastern Sicily. Mud diapirism develops in the northern margin of the Hyblean Plateau along; (c) a narrow NE-SW oriented horst, the S. Demetrio High, the easternmost of a series of en-echelon arranged fault-controlled blocks.