

MORPHOMETRIC, GEODETIC AND GEOPHYSICAL SURVEYS OF MUD VOLCANOES: EVIDENCE OF TECTONIC CONTROL IN THE SICILIAN COLLISIONAL BELT

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Introduction. The Sicilian belt is part of the complex collisional boundary between African and Europe convergent plates. The thrust system is characterized by the underplated African-Pelagian continental crust and by the overlying imbricated tectonic units of the Apenninic-Maghrebien chain, this latter originated by deformation of Meso-Cenozoic sedimentary sequences belonging both to the oceanic crust-type sector (Alpine Tethys and Ionian basin) and to the African paleo-margin. Neogene-Quaternary sedimentary top-thrust sequences have recorded the recent geodynamic evolution of the Sicilian orogeny (Lentini and Carbone, 2014). The surficial landscape of the largest thrust-top basin in central-southern Sicily is influenced by morphostructural evidences of south-southeast foreland-verging fold and thrust belt in which consequent and subsequent drainage patterns dissect and contour the geological structures in relation to their space-time evolution and rheological proprieties. In particular, some features linked to fluvial processes (v-shape section valley, overflowing and trellis patterns) indicate recent derangements of basins evolution characterised by recent variations of base level and suggest recent and active vertical deformation of folds and thrusts. Although NNW-SSE compressive regime in Sicily is mostly accommodated by aseismic folding at the front of the chain, the earthquakes distribution shows a clear trend of the seismic events deepening from very shallow hypocenters down to a depth of about 40÷50 km, towards the NNW, below the chain, where the “Sicilian Basal Thrust” has been previously recognized (De Guidi *et al.*, 2015; Lavecchia *et al.*, 2007). Therefore, we used earthquake focal localizations and local mechanism solutions to relate deep thrusts with surface structures as well as stress directions and geodetic surveying to evaluate surficial horizontal and vertical GNSS velocity (IGMI 92_ networks, discrete UNICT_NET in operation since 2016). The solution and inversion of all data sets allowed us to reconstruct the relations between deeper and surficial orientations of both stress and strain fields. Moreover, the morpho-structural study of mud volcanoes distributed along the frontal sector of the Sicilian collisional belt (San Biagio, Santa Barbara and Aragona villages) (Fig. 1) (Imposa *et al.*, 2016; Madonia *et al.*, 2011) also represents a clue that could be used as a proxy for supplementary stress and strain indicators. In fact, on a regional scale, mud volcanoes in active fold-and-thrust belts may occur over wider areas or may cluster along discrete structures, where the generation of overpressures is expected to establish a positive feedback loop allowing for fault movement and mud volcanism.

Geological framework. The center-south sector of Sicily consists of four groups of terrain, three of which represent tectonic complexes, while the latter consists of piggy-back structures superimposed at rear of the three tectonic complexes.

The three tectonic complexes represent, from the bottom upwards: the Western extension of the Hyblean Foreland, partly deformed, consisting mainly of meso-pliocenic carbonate successions, which in this area fell below the Sicilian chain. A group of tectonic units deriving from the deformation of the sican domain, arranged tectonically according to prevalent duplex geometries. A group of tectonic units, largely outcropping in the study area, consisting of predominantly clayey, conglomerate and arenitic successions, which are indicated by the authors “Falda di Gela”.

The tectonic-stratigraphic succession emerging in the nissena area is made up of tectonic units of the lower Cretaceous-Miocene ages belonging to the outer edges of the Sicilide Tectonic Units. These units are covered by several neogenic-quaternary sedimentary cycles that have

been involved in the latest tectonic phases.

The deeper stratigraphic formations belonging to the Tectonic Unit of the Chain (Tactonic Sicilid Units). Sicilian units occupy the most structurally elevated position in the Apennine-Maghreb System. They originated in the Paleogene as an development wedge following the collapse of sedimentary shells from the neotetical ocean floor due to the convergence that produced alpine orogenesis and subsequently were transported in full on the outer paleodomains. Among the terms of the Sicilian Units, in the nissena area emerge the group of the Argille Variegate and the Numidian Flysch (member of Nicosia).

Deep geology. The study of deep geology has required the literature analysis of various geological sections. All these geological sections were realized through the analysis of seismic profiles and stratigraphies (Catalano *et al.*, 2013; Lentini and Carbone, 2014; Bello *et al.*, 2000; Accaino *et al.*, 2011; Bianchi *et al.*, 1987; Lavecchia *et al.*, 2007). According to Lavecchia *et al.* (2007) it was possible to extrapolate the depth of the Moho and of the Sicilian Basal Thrust (SBT). From the sections realized by Catalano R. *et al.* (2013), structures and geological formations present in the Sicilian subsoil have been extrapolated. The seismic profiles of the SI.RI.PRO project were also re-interpreted.

Geodetic characterization of the area. Normally the phenomenon of “*Maccalube*” shows distinct warning signs that in the past have never been detected through monitoring systems. The geodetic-topographic monitoring network consists of a GNSS benchmarks network in order to record the vertical and horizontal movements of this area. With the Working Group of the Catania University of Geodesy, a series of GNSS field measurement have been conducted since October 10, 2016. Two GNSS receivers (TOPCON HiPerV (L1 + L2)) have been used.

For the post-processing phase of the data, the Magnet Tools software provided by the University of Catania, was used. For better estimation of parameters for each daily solution, calculated precise ephemeris IGS and IGL and ground rotation parameters provided by the International Earth Rotation Service have been used. In addition, during processing, the data of the RESU permanent station belonging to the RING network was included in the data process.

Morphometric analysis and morphometric elements. The study area has been identified in a geological structural domain affected by fold and thrust deformations characterized by south verging NE-SW trending structures, according to a roughly N-S oriented regional contractional stress regime.

The geometry of the main hydrological basin (Imera river) develops on a regional scale from N to S for 114 km and about 40 km towards E-O; affecting an area of 2000 km².

For the morphometric analysis, we elaborated all the DEM (Digital Elevation Modell) mask using the MICRODEM software and calculate the respective Strahler's curves. The pattern of the hydrographic network can be ascribed to dendritic and trellis pattern; because the tributaries of southern Imera river are orthogonal both to the main and to the tectonic structures.

It is possible to find out from the observation and interpretation of every single Strahler



Fig. 1 - Geographic overview of mud vulcano in Sicily (red point) and of the Sicilian Basal Thrust (red line).

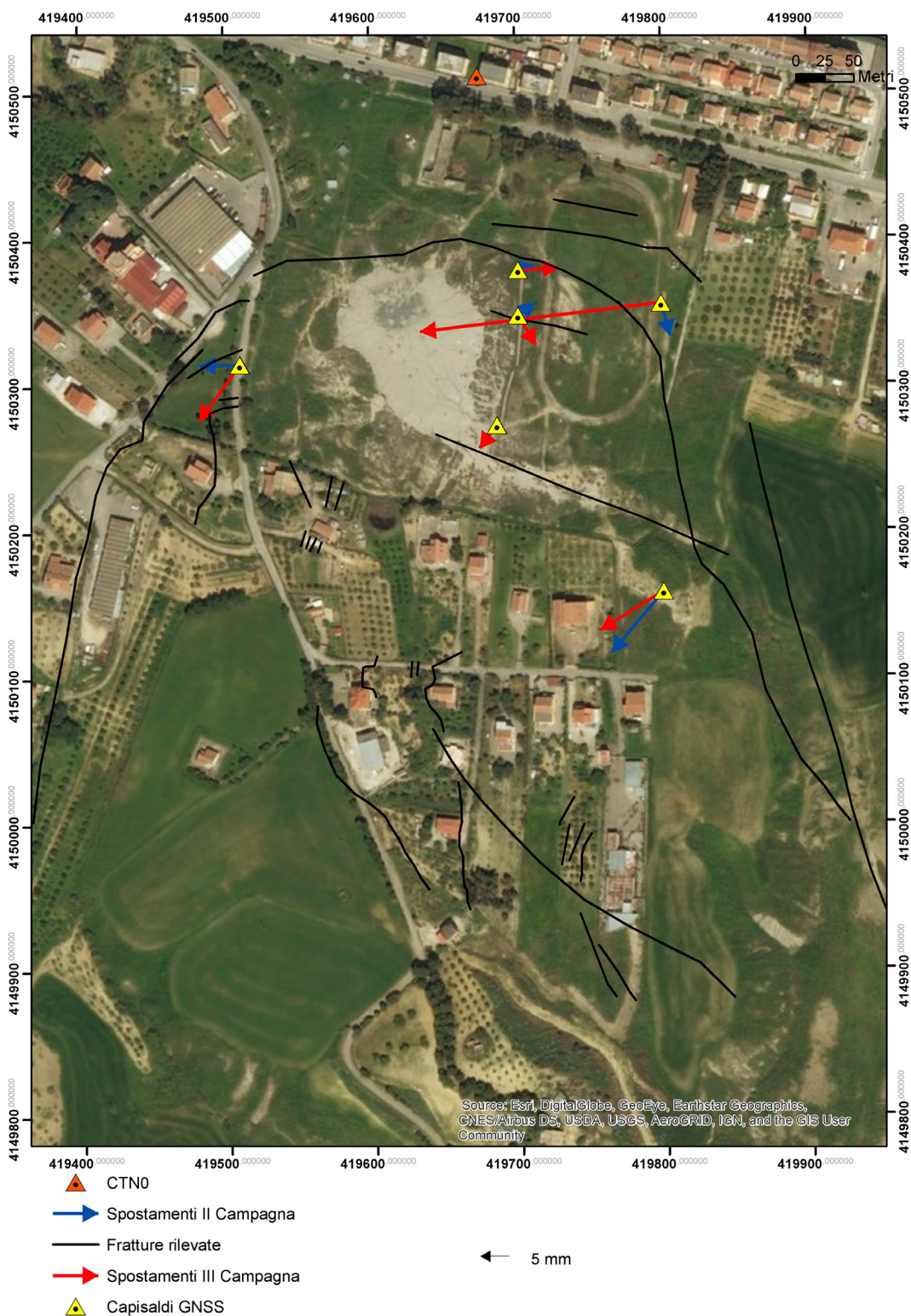


Fig. 2 - Map of movement in the Maccalube area.

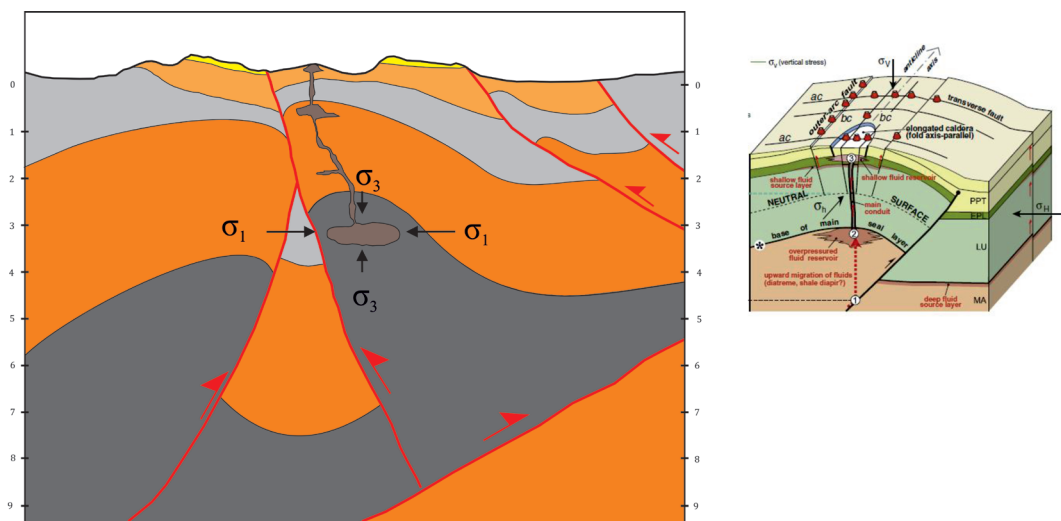


Fig. 3 - Synthetic model of the Santa Barbara mud volcano on the left and the schematic model of mud volcano created by Bonini *et al.* (2012)

ipsometric curve that about 10 basins are in a rejuvenation stage, while 3 basins have reached their balance between erosion and deposition. Finally, the remaining 9 basins show a multiform pattern, both a juvenile and a senile stage. These results can be influenced by the erosion resistance of the outcropping lithologies, creating disequilibria on the Strahler curve.

Conclusions. GNSS measurements started in October 2016 and establish the “point 0” of the geodetic evolution of the area. The aim of these measures is to detect any surface movements in the Maccalube area (Fig. 2), and by GIS analysis to understand the relative horizontal movements of the soil portions by comparing the structures detected by the Civil Protection technicians immediately after the event Of 2008 (Report DPC UOB XXX, 2008). In relation to the measured displacement rates, it is not yet possible indicate what are the geometric parameters and modular displacement because it is a function of the order of magnitude of the instrument error which for this measure is in the order of 1.5 centimetres.

However, the vectors indicate a homogeneous trend, but the module still falls into the error, so we can confirm this deformation only in subsequent surveys.

According to Bonini (2012) a model for this specific area was carried out (Fig 3) which show the relationship between sedimentary vulcanism and compressive tectonics.

In conclusion both the hydrographic pattern analysis and slope variations show the existence of a transient state of the landscape.

All the data confirm the recent activity of the Sicilian Basal Thrust (Lavecchia *et al.*, 2007) in the study area, show by the presence of deep and surface earthquakes along this structure, by lifting of the area along the anticline folds and thrust, by the deepening of river basins in the uplifting areas and by the sedimentary volcanism of the Maccalube of Santa Barbara that is presumably linked to the recent activity of the compressive tectonic.

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