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Geometry and kinematics of the fault systems controlling the unstable flank of Etna volcano (Sicily)

R. Azzaro *, A. Bonforte, S. Branca, F. Guglielmino

Istituto Nazionale di Geofisica e Vulcanologia, Sezione di Catania, Piazza Roma 2, 95123, Catania, Italy

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ABSTRACT

An updated tectonic framework of Etna's unstable flank has been defined as a result of multidisciplinary analyses carried out by integrating geological and geophysical data. The different typologies of datasets have been analyzed and correlated in order to constrain the geometry and kinematics of the fault systems controlling the unstable flank of Etna volcano and to better understand their complex relationship with the offshore morphostructures of the continental margin. In particular, we have considered as the main structural elements the following four fault systems: Pernicana, Ragalna, Tremestieri–Trecastagni and Timpe. Slip-rates and kinematics have been estimated in both long- and short-terms, respectively, from geological and seismotectonic/geodetic data. Data integration has allowed defining five kinematic domains in the sliding flank of Etna: (1) the NE block, bordered by the Pernicana fault and characterised by the highest deformation velocities; ground velocity progressively diminishes toward South, with a clockwise rotation of the vectors defining (2) the block embracing the central part of the Timpe system; (3) the Giarre wedge; (4) the Medium-East block, bounded by the S. Tecla and Trecastagni faults; and (5) the SE block bordered, by the hidden Belpasso-Ognina tectonic lineament. The dynamics of these blocks takes place through discontinuous movements: sudden short-term accelerations related to the magma intrusion are superimposed to a fairly constant mid-term ESE sliding. The proposed comprehensive model of the unstable flank provides the basic input parameters for applying analytical models to flank dynamics of Etna volcano.

1. Introduction

The geological evolution and volcano-tectonic features of volcanic edifices are strongly conditioned by the structural setting of their basement and by regional tectonics (see the special volume edited by Tibaldi and Lagmay, 2006, and papers therein). In particular, the relationships between volcano dynamics and regional stress regime play an important role in the magma transport from the mantle to the surface and flank instability of volcanic edifices, with important implications for their geologic hazard (Nakamura, 1977; McGuire et al., 1997; Pasquaré and Tibaldi, 2003; Norini and Lagmay, 2005; Tibaldi, 2005; Tibaldi et al., 2005; Acocella, 2006).

Mount Etna is a large polygenetic basaltic volcano built up over the past 500 ka on the eastern coast of Sicily in a geodynamic setting generated during the Neogene convergence between the African and European plates (Lentini et al., 2006; Branca et al., 2011). The structural framework of the Etna edifice is the result of a complex interaction between regional tectonics, flank instability processes and basement geometry (McGuire and Pullen, 1989; Borgia et al., 1992; Lo Giudice and Rasà, 1992; McGuire et al., 1996; Montalto et al., 1996; Rasà et al., 1996; Rust and Neri, 1996; Monaco et al., 1997; Bousquet and Lanzafame, 2004; Neri et al., 2005; Rust et al., 2005; Norini and Acocella, 2011). In particular, recent data obtained from different geophysical techniques (Lundgren et al., 2004; Puglisi and Bonforte, 2004; Rust et al., 2005; Walter et al., 2005; Solaro et al., 2010; Bonforte et al., 2011) have highlighted that the unstable flank of Etna is dismembered into different blocks, characterised by homogeneous kinematics.

An updated structural setting of Etna volcano has recently been defined in the new volcano-tectonic map, at 1:100.000 scale (Azzaro et al., 2012a) and reported by Barreca et al. (2012) in a GIS database. The main structural lineaments of the unstable flanks of Etna, are the following fault systems (Fig. 1): Pernicana, Ragalna, Tremestieri–Trecastagni, Timpe and Ripe della Naca–Piedimonte–Calatabiano.

The Pernicana fault system (PF) is a transtensive structure with left strike-slip extending from Piano Provenzana in the upper northeast flank down to the Ionian coast. This complex transtensive structure is formed by a main E–W striking segment showing a south-facing scarp, which in the eastern portion is characterised by a purely left-lateral displacement rate of 2.8 cm/a in the last decade (Groppelli and Tibaldi, 1999; Azzaro et al., 2001) and about 2 cm/a reconstructed over the past 150 years by Rasà et al. (1996). The eastward propagation of the PF consists of a set of en-échelon right-stepping, ESE-striking segments extending down to the coastline where the fault segments strike toward NNE. This fault system also includes the Fiumefreddo fault, an E–W trending normal fault with left-lateral strike-slip localized close to the Ionian coast (Azzaro et al., 1998; Tibaldi and Groppelli, 2002). The offshore continuation of the PF is a set of small NNE–SSW scarps, with

* Corresponding author.
E-mail address: azzaro@ct.ingv.it (R. Azzaro).

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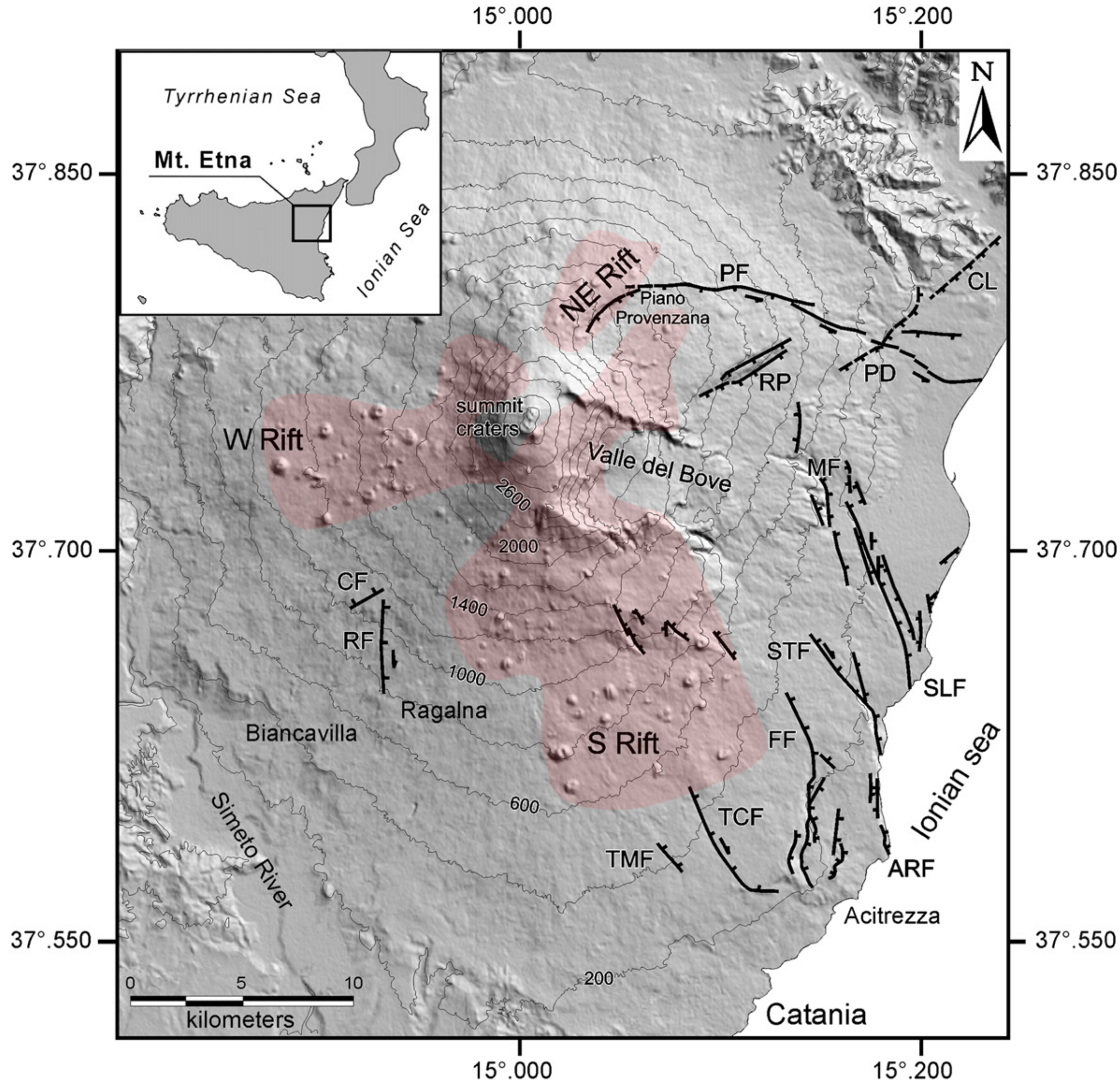

Fig. 1. Tectonic sketch map of Etna volcano defined by structures with morphological expression (modified by Branca et al., 2011). Fault abbreviations: PF, Pernicana; RF, Ragalna; CF, Calcerana; TMF, Tremestieri; TCF, Trecastagni; FF, Fiandaca; ARF, Acireale; STF, S. Tecla; MF, Moscarello; SLF, S. Leonardello; RF, Ragalna; RP, Ripe della Naca; PD, Piedimonte; CL, Calatabiano. The arrows indicate the strike-slip component, the contour of the rift zones is in red; inset map shows the location of the study area.

few meters of vertical displacement, whose morphological evidence is confined within 2 km from the coastline (Chiocci et al., 2011; Argnani et al., 2012).

The Ragalna fault system (RF) is a dextral transtensive structure, located in the lower western flank of Etna (Fig. 1). This fault system, interpreted as the western boundary of the unstable south flank (Neri et al., 2007), is formed by a main segment, N–S striking, showing an east-facing scarp with slip-rates of 3.4 and 3.7 mm/a calculated for left-lateral and dip-slip components of movement (Neri et al., 2007).

The Tremestieri (TMF)–Trecastagni (TCF) is a normal fault system (Fig. 1) formed by two faults with right-lateral component representing the southern boundary of the unstable east flank (Lo Giudice and Rasà, 1992; Solaro et al., 2010). TMF is the longer NNW–SSE oriented segment. Conversely, the TCF is a short segment, NW–SE oriented. According to Chiocci et al. (2011) the TMF–TCF system is linked with a main transcurrent fault located in the offshore of Acitrezza village dissecting the laccolith of Ciclopi Islands.

The Timpe is a normal fault system with a right-lateral component dissecting the lower eastern flank (Fig. 1). This fault system is formed by several main master segments named Fiandaca, Acireale, S. Tecla, Moscarello and S. Leonardello faults, showing slip-rates ranging from 1.0 to 2.7 mm/a (Azzaro, 2004). In particular, the Fiandaca fault (FF) is roughly N–S oriented and rotates toward SE near Acitrezza. The Acireale fault (ARF), roughly N–S trending, forms a scarp up to 120 m high along the coast while the S. Tecla fault (STF) is NW–SE oriented, forming a scarp up to 180 m high and in the south tip it is linked with ARF. The Moscarello fault (MF), NNW–SSE trending, is the most prominent scarp of the Timpe system; finally, the S. Leonardello fault (SLF) forms a NNW trending graben as a consequence of the eastward extension of this fault system. The offshore continuation of the Timpe system is characterised by well-developed morphological scarps, up to 60–80 m of vertical displacement, that gradually rotate towards SE (Fig. 1, cfr. Chiocci et al., 2011).

The Ripe della Naca–Piedimonte–Calatabiano system is formed of normal structures located along the northeast flank formed by several main segments. The Ripe della Naca faults (RP) consist of a couple of WSW–ENE oriented scarps from 80 to 120 m high. The Piedimonte fault (PD), WSW–ENE oriented, and the Calatabiano fault (CL), NE–SW striking, are interpreted as regional tectonic lineaments (Finetti et al., 2005; Lentini et al., 2006). RP–PD are buried by Holocene lava flows and truncated by the Pernicana fault segments (Azzaro et al., 2012a). Short normal faults showing a similar NE–SW trend are present along the Ionian coast. The continuation in the offshore of these small fault segments is given by several well-developed morphological scarps, NE