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Research paper

What controls sheet intrusion in volcanoes? Structure and petrology of the Stromboli sheet complex, Italy

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Abstract

A multidisciplinary study has been conducted on 109 intrusive sheets of Stromboli. The relation between sheet injection conditions with the magmatic and structural variations of the volcano, and the parameters governing the preferential intrusion geometry inside the volcano in a time perspective have been determined.

During its subaerial activity (the last 100 ka) Stromboli experienced periods of extrusive growth and sheet intrusions, alternated to caldera and lateral collapses of the NW Sciara del Fuoco flank. The sheet intrusions, similar to the extrusive rocks, span a large compositional range from calc-alkaline to potassic, through high-K calc-alkaline and shoshonitic series. The most evolved compositions of the effusive rocks, however, have not been found as intrusions, whereas some mafic and basic magmas of sheets were never erupted.

The repeated time change of location of the intrusions from Strombolicchio to the NE–SW trend passing trough the inferred Paleostromboli summit cone and the southern flank could represent the expression of the shift of the magma chamber towards the southeast, and the subsequent onset of a clear NE–SW-elongated magma chamber located along the main Stromboli weakness zone. The Stromboli evolution in the last 100 ka has been characterized by the persistent N 10–55° E intrusion direction, which reflects the influence of the edifice's state of stress on the magma feeding paths. After 13 ka ago, sheets mainly intruded along to the sector collapse scarps in a circum-amphitheatre geometry, which has been demonstrated to be influenced by the new cone morphostructure and not by different magma rheological characters.

Keywords: Stromboli; dykes; intrusive sheets; stratovolcano; volcanic stress; petrochemistry

1. Introduction

Intrusive sheets represent the magma path towards the surface and are classically studied by means of structural approaches and/or petrochemical analyses. Structural studies of deeply eroded magmatic complexes show that, in the vicinity of a magma reservoir, sheet geometry is controlled by the local stress field linked to the depth, shape and internal excess magma pressure of the reservoir (e.g. Chadwick and Dieterich, 1995; Gudmundsson, 1998; Marti and Gudmundsson, 2000; Gudmundsson, 2006). The propagation pattern of the intrusions at shallower levels within the volcanic edifice, instead, depends upon the geological, structural and geomorphological evolution of the volcano and related stresses (Nakamura, 1977; Tibaldi, 1996, 2003; Gautneb and Gudmundsson, 1989; Gautneb and Gudmundsson, 1992; Marti and Gudmundsson, 2000; Walter and Troll, 2003; Acocella and Tibaldi, 2005; Gudmundsson,

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2006; Gudmundsson and Philipp, 2006) that in turn might be related to the substrate tectonics (Tibaldi et al., 2005). Once intrusions occur, they can have a feedback effect on the structural stability of the cone (Voight and Elsworth, 1997; Donnadieu et al., 2001; Corazzato, 2004; Apuani et al., 2005; Apuani and Corazzato, in press). The relevance of structural studies of sheets within volcanoes of basic-intermediate magma compositions is thus the possibility of assessing the location and geometry of magmatic feeding systems producing eruptions, endogenous growth (Francis et al., 1993; Allard et al., 1994; Locke et al., 2003) and deformation of the volcano flanks. On the other hand, petrographic and geochemical analyses of sheets can give clues to the evolution of the magmatic system. A combined analysis of the structural and petrochemical evolution of the sheet system of a volcano will therefore reveal the complete history of a volcano in terms of the relationships between deep and surface processes, and will provide us with data on the geometry and location of the conduits within the edifice.

At active volcanoes, the reconstruction of the geometry of magma paths is of paramount importance for the assessment of geological hazards such as the localization of areas prone to: i) the potential opening of new vents; ii) slope collapses triggered by magma pressure; and iii) related tsunami-generation at coastal/island volcanoes. These assessments can benefit from the comprehension of the past and recent history of the geometry of magma feeding structures. Since intrusive sheets are sensitive to the evolution of both magma reservoir and volcanic edifice, it follows that the individuation of the various phases of sheet emplacement is fundamental.

The aim of this study is to give a comprehensive structural, petrographic and geochemical description of the sheets emplaced during the last 100 ka in the active Stromboli stratovolcano (Aeolian Islands, southern Tyrrhenian Sea, Italy, Fig. 1), and analyzing them in a time perspective. Apart from the relevance for the contribution to assessing the local hazards linked to the individuation of preferential magma path, this work provides an example of an approach useful to understand the interplaying behaviour of the magmatic system and structure of an active stratovolcano, through the reconstruction in detail of the sheet emplacement evolution. The petrochemical characters of each sheet have been compared with those of the lithostratigraphic succession of the volcano, enabling correlation with dated lithostratigraphic units. This provides to be a very useful method when crosscutting relationships between sheets and host rocks are not enough for dating the intrusive events. The entire history of sheet intrusions has then been compared with the geological, structural, geomorphological and petrochemical evolution of the volcano, enabling the reconstruction of the reciprocal feedback effects.

2. Geological framework

2.1. Tectonic setting

Stromboli volcano is the northeasternmost island of the Aeolian archipelago in the southern Tyrrhenian Sea (Fig. 1), and is worldwide famous for its continuous activity throughout historic times. Subaerial Aeolian volcanism started at ~0.22 Ma BP (De Rosa et al., 2003) and is still active at Lipari (580 AD), Vulcano (1888–1890 AD), and Stromboli (persistent activity).

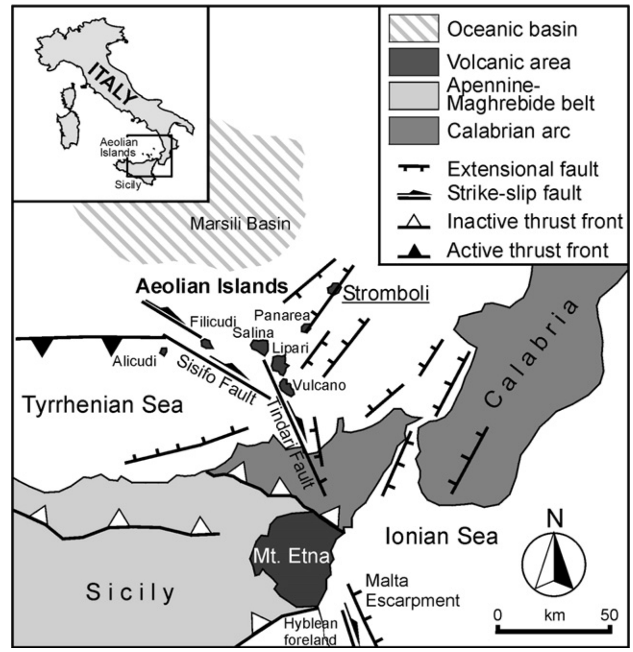

Fig. 1. Location of the Stromboli volcano within the Aeolian archipelago in the southern Tyrrhenian Sea, and main tectonic features of the area (adapted from Neri et al., 2003; Goes et al. 2004; Billi et al., 2006).

The Neogene–Quaternary tectonics of the Aeolian region has been controlled by a complex interplay of contractional and extensional domains within the overall NW–SE-directed plate convergence regime between Africa and Europe (Goes et al., 2004). Geological, seismological, and geochemical data allow dividing the Aeolian region into three sectors that correspond to different structural domains (Fig. 1). The western sector, comprising the Alicudi and Filicudi islands, is characterized by ongoing compressional dynamics related to the relatively slow northwestward motion of the Africa–Sicily block. In this Aeolian sector, epicentre alignments and fault-plane solutions mainly show reverse to strike-slip mechanisms on E–W- to NW-striking faults (Neri et al., 2005). The eastern sector, represented by Panarea and Stromboli islands, is characterized by extensional dynamics related to the rapidly extending Marsili oceanic basin and the southeastward migration of the Calabrian arc. Focal mechanisms in this part of the southern Tyrrhenian basin show NNE- and NE-striking normal faulting (Neri et al., 2003). The central sector, including the islands of Vulcano, Lipari and Salina, corresponds to the transfer zone between the above described compressional and extensional domains accommodated by NW- and NNW-striking dextral strike-slip and normal faults system (Tindari fault system; Billi et al., 2006) at the northern tip of the regional-scale structure of the Malta escarpment fault system.

The island of Stromboli (924 m above sea level — asl) is the apex of a composite volcano rising from a depth of ~2000 m below sea level. Together with the eroded Strombolicchio edifice and the submerged Cavoni volcano (Gabbianelli