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Volcaniclastic dykes tell on fracturing, explosive eruption and lateral collapse at Stromboli volcano (Italy)

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A B S T R A C T

In the upper part of the Stromboli volcano, in the Le Croci and Bastimento areas, two dyke-like bodies of volcanic breccia up to two-metre thick crosscut and intrude the products of Vancori and Neostromboli volcanoes. We describe the lithofacies association of these unusual volcaniclastic dykes, interpret the setting of dyke-forming fractures and the emplacement mechanism of internal deposits, and discuss their probable relationships with the explosive eruption and major lateral collapse events that occurred at the end of the Neostromboli period.

The dyke volcaniclastic deposits contain juvenile magmatic fragments (pyroclasts) suggesting a primary volcanic origin. Their petrographic characteristics are coincident with the Neostromboli products. The architecture of the infilling deposits comprises symmetrically-nested volcaniclastic units, separated by sub-vertical boundaries, which are parallel to the dyke margins. The volcanic units are composed of distinctive lithofacies. The more external facies is composed of fine and coarse ash showing sub-vertical laminations, parallel to the contact wall. The central facies comprises stratified, lithic-rich breccia and lapilli-tuff, whose stratification is sub-horizontal and convolute, discordant to the dyke margins. Only at Le Croci dyke, the final unit shows a massive tuff-breccia facies.

The volcaniclastic dykes experienced a polyphasic geological evolution comprising three stages. The first phase consisted in fracturing, explosive intrusion related to magma rising and upward injection of magmatic fluids and pyroclasts. The second phase recorded the dilation of fractures and their role as pyroclastic conduits in an explosive eruption possibly coeval with the lateral collapse of the Neostromboli lava cone. Finally, in the third phase, the immediately post-eruption mass-flow remobilization of pyroclastic deposits took place on the volcano slopes.

1. Introduction

Lateral volcano collapses are regarded as catastrophic processes occurring during the evolution of several stratovolcanoes (Beget and Kienle, 1992; McGuire, 1996; Voight and Elsworth, 1997) and they resemble a primary type of volcanic hazard. They are the indirect cause of consequent explosive eruptions, landslides, floods, lahars, and tsunamis. Studies on the debris avalanche deposit emplaced during a volcano collapse are well advanced, on the sedimentary characteristics of the deposit (i.e.; Voight et al., 1981; Clavero et al, 2002; Shea et al., 2008), and on analogue (Merle et al., 2001; Acocella, 2005, and references therein) and numerical (i.e.; Voight, 2000; Apuani et al., 2005; Kelfoun and Druitt, 2005; Apuani and Corazzato, 2009) modelling of the process. Indeed, we know comparatively little about the behaviour of the shallow magmatic system exposed to syn-collapse stresses and deformations. During collapse processes, the volcanic cone suffers structural changes that can cause bulging or subsidence (Donnadieu et al., 2001) and fracturing along regional and/or local magma-related trends (Ventura et al., 1999). The magma can be stimulated to a quick uprising (Manconi et al., 2009; Cassidy et al., 2015), in a physical-chemical state different respect to the normal state, with involvement of ground and geothermal fluids (Lopez and Williams, 1993), and to feed collapse-related volcanic activity (Rowley et al., 1981; Druitt, 1992).

Stromboli (Southern Tyrrhenian Sea, Aeolian Arc, Italy; Fig. 1) is an active composite volcano famous for its persistent low-energy explosive activity. In the last 13 ka, multiple lateral collapses formed the horseshoe-shaped Sciara del Fuoco depression along the NW side of the Stromboli cone (Fig. 1; Tibaldi, 2001). The latest lateral collapse event at the Sciara del Fuoco occurred during the 2002-03 eruption and triggered a tsunami causing damages on the eastern coast of the island with effects on the entire Aeolian archipelago and also on the nearby coasts of southern Italy (Bonaccorso et al., 2003; Maramai et al., 2005; Tinti et al., 2006). The results of the multi-disciplinary monitoring system of the Stromboli 2002-03 events (Bonaccorso et al., 2003; Baldi et al., 2008; Carapezza et al., 2004; Brusca et al., 2004; Ripepe et al., 2007) suggest that the volcano collapse formed part of a complex set of associated phenomena involving the entire magmatic system. Understanding the interconnected relationships between the structural behaviour of the volcano and the collapse events is important to define

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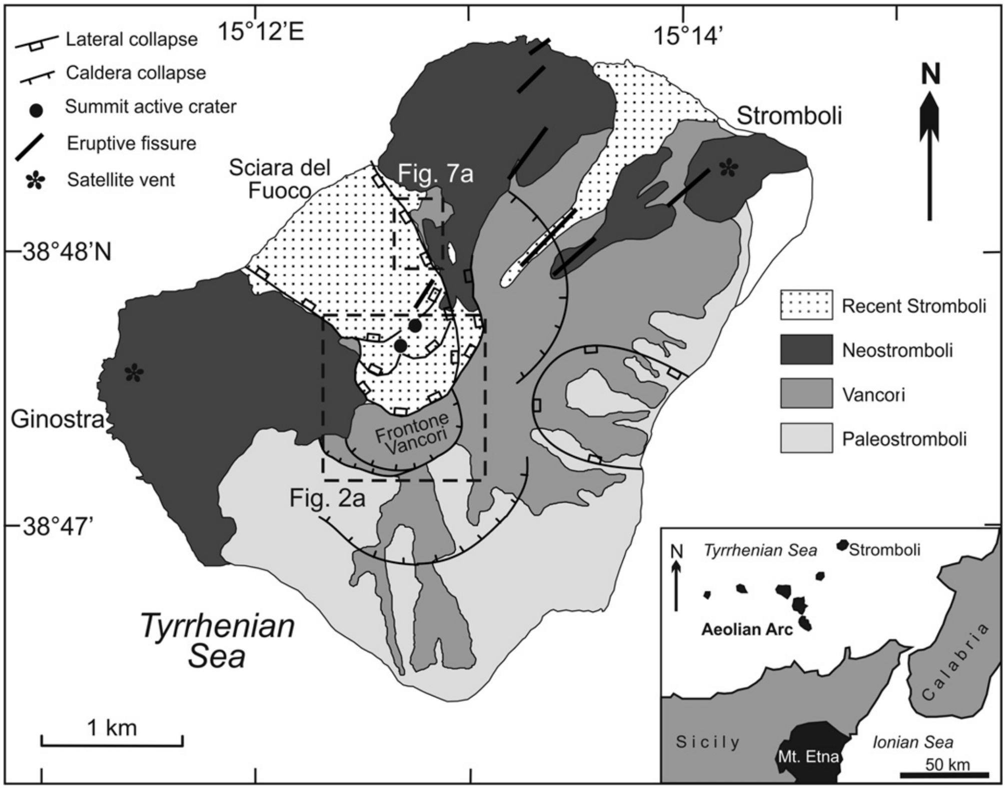

Fig. 1. Simplified geological map of the Stromboli island, based on major periods of activity defined by Hornig-Kjarsgaard et al. (1993). Caldera and lateral collapse traces, eruptive fissures, and vents (after Tibaldi, 2001; Vezzoli et al., 2014) are also shown. Boxes locate the two studied areas shown in Figures 2a and 7a. Inset shows the location of Stromboli in the Aeolian Arc, southern Tyrrhenian Sea.

the type, distribution and dynamics of the developing fracture system. Indeed, the volcanic cone fracturing will influence the future magma path, slide surface location, and ground and hydrothermal fluid circulation.

This paper provides a detailed description of unusual volcaniclastic dykes and related structures cropping out in the upper sides of the Stromboli volcano, interprets the emplacement mechanism of the dykes on the basis of sedimentological, petrological, and structural observations, and discusses the probable relationship of these dykes with a major lateral collapse event and associated hydromagmatic eruption.

Defining the mechanisms of opening and infilling of volcaniclastic dykes in such a structural context may highlight the relative role of extensional tectonics, slope stability, magma rising, and hydrothermal fluids occurrence during lateral volcano collapses.

2. Geological background

2.1. Stromboli structure

Stromboli (924 m above sea level; asl) is a composite stratovolcano constructed with the superposition of at least four edifices in the last 100 ka: Paleostromboli, Vancori, Neostromboli, and Recent Stromboli (Fig. 1; Rosi, 1980; Gillot and Keller, 1993; Hornig-Kjarsgaard et al., 1993; Pasquarè et al., 1993; Tibaldi, 2010; Francalanci et al., 2013). The constructive activity of the Paleostromboli and Vancori volcanoes where intercalated with the vertical collapse of summit calderas. The Vancori activity ended at about 13 ka with the first major lateral collapse that formed a wide depression in the NW flank of the edifice, the paleo-Sciara del Fuoco. The Neostromboli edifice grew within this depression (Vezzoli et al., 2014) and collapsed about 5 ka ago. The Neostromboli collapse surface was nested and, in the summit sector, broadly coincident with the surface of the Vancori collapse. During the last 5 ka, the flank instability episodes of the growing new cones of the Recent Stromboli have increased in frequency, but decreased in magnitude of the mobilized rock mass. In fact, at least three main collapse events formed the present Sciara del Fuoco (Fig. 1), and several other minor collapse events, as the latest in 2002-03 (Bonaccorso et al., 2003; Calvari et al., 2005), repeatedly reactivated this depression. Stromboli collapses are associated with complex volcanic and volcano-tectonic phenomena as explosive eruptions, lava flow eruptions, intrusive sheeting, and ground deformations. Numerous sheets intruded the Stromboli edifice and outlined the structure of the volcano during its magmatic activity and collapse events (Corazzato et al., 2008; Tibaldi et al., 2009). The fracture system active during the present magmatic activity and instability events appears confined to the interior of the Sciara del Fuoco, and the active feeding system is strongly controlled by the NE-SW regional tectonic trend (Acocella et al., 2006).

2.2. Volcaniclastic dykes

Clastic dykes are sheet-like bodies of fragmental materials filling cracks or fissures that cut conformably or unconformably the preexisting adjacent rocks. Clastic dykes are mainly present in a wide variety of submarine and continental sedimentary settings as glacial, fluvial, lacustrine, shallow marine, deltaic, shelf, and deep water environments. In sedimentary clastic dykes, we can distinguish from neptunian dykes, in which the sediments are derived from above by simple infilling, and injection dykes, in which the filling sediments are injected or intruded from below, above, or laterally (Winterer et al., 1991). During forceful emplacement, fluid overpressure generates hydraulic fracturing (Gudmundsson, 2011a), sediments are fluidized and injected (Cosgrove, 2001). The dyke materials often exhibit massive or chaotic textures, but well-defined internal stratification is also present. Triggering processes of clastic dykes of sedimentary origin are: seismic activity,