Earth-Science Reviews 167 (2017) 1–26

Contents lists available at ScienceDirect

Earth-Science Reviews

journal homepage: www.elsevier.com/locate/earscirev

Invited review

Intra-arc and back-arc volcano-tectonics: Magma pathways at Holocene Alaska-Aleutian volcanoes

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ARTICLE INFO

Article history:
Received 20 September 2016
Received in revised form 1 February 2017
Accepted 13 February 2017
Available online 16 February 2017

Keywords:
Magma pathway
Dyke
Stress
Earthquake
Volcanic hazard

ABSTRACT

The reconstruction of magma pathways at active volcanoes is of paramount importance for the comprehension of their structure and for geohazard assessment. Magma plumbing systems at volcanic arcs may be particularly complicated since the magma rises along fractures that can be consistent with the coeval regional state of stress, the local state of stress, or can form dykes that instead follow pre-existing structures. Magma path orientation can be stable over time or can vary as the consequence of external events like large earthquakes or important modifications in volcano morphology. In order to advance understanding of these issues, we reviewed all available information on the Holocene volcano-tectonics of the Alaska-Aleutian arc and back-arc zones, based on published seismological, interferometric and geological-structural data, geological maps, and official reports. We completed our review with some new measurements of Holocene eruptive fissures, faults, dykes, and morphometric characteristics of pyroclastic cones and volcanic domes aimed at better defining the possible shallow magma paths of the recent-active volcanoes. Finally, we reviewed the possible parameters and models that explain the path configurations. At 32 volcanoes, magma paths strike NW-SE, perpendicular or oblique to the arc but parallel to the regional greatest principal stress. At 20 volcanoes magma paths are parallel to the arc, and 19 volcanoes form rows of coalescent cones that also suggest ascent of magma parallel to the arc. Eight volcanoes display both directions (normal and parallel to the arc), and seismological data indicate that at some volcanoes there has been a rotation of the magma pathway over time. Integration of all data shows that the regional ambient tectonic stress field promotes dyke intrusions normal to the trench. Dykes can also intrude parallel to the trench following stress unclamping from large earthquakes. Trench-parallel dykes and rows of volcanoes can be generated by magma batches that are aligned parallel to the trend of the subduction zone. Once a dyke or a sill is intruded, it locally perturbs the stress field facilitating successive intrusion along a perpendicular direction.

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http://dx.doi.org/10.1016/j.earscirev.2017.02.004

1. Introduction

Within the crust, magma rises to the surface through networks of planar structures (intrusive sheets) that form a magma plumbing system. There has been growing consensus on this concept during the last tens of years with increasing field evidence and modelling at various structural levels (see reviews in: Acocella and Neri, 2009; Rivalta et al., 2015; Tibaldi, 2015). Although some debate is still alive for the deepest structural levels, all data indicate that in the shallowest portions of the crust and within volcanic edifices, magma moves along planar fractures: Ground deformation measures, direct observations of eruptions, and the seismicity associated with magma intrusions, provide evidence for the role of tabular sheets (Pollard et al., 1983; Rubin and Pollard, 1987; Peltier et al., 2005; Yamaoka et al., 2005; Aloisi et al., 2006; Mattia et al., 2007). Also field evidence at several eroded volcanoes shows that magma movement takes place along sheets (Tibaldi et al., 2013), both for basic magma and for more felsic magmas (Gudmundsson, 1987, 1988, 1990, 2002; Tibaldi, 2001; Corazzato and Tibaldi, 2006; Pasquarè and Tibaldi, 2007; Tibaldi et al., 2008a,b, 2009a,b). Locally, intrusive sheets may have planar, curved, en-échelon, or more complex geometries, but they invariably have a very high length/thickness ratio. Based on the sheet attitude and the relations with the country rocks, magma can move along vertical to steeply-dipping dykes, or inclined sheets and sills, the latter formed when magma is injected between rock layers forming a horizontal or gently-dipping sheet.

Volcanic hazard assessment also depends on understanding the structure of magma plumbing systems. Processes occurring at open conduit volcanoes, among which paroxysmal explosions, have been addressed considering the structure of the shallower conduits. For example, Chouet et al. (1997, 2008), at Stromboli Volcano (Italy), studied the wave fields of tremors and explosions showing that the source of these phenomena is located within a planar conduit at a depth < 200 m beneath the summit crater. The modelling of this process along a NE-striking dyke-like conduit is also fully consistent with field observations carried out on outcropping portions of Stromboli's plumbing system (Pasquarè et al., 1993; Tibaldi, 1996, 2001, 2003; Corazzato et al., 2008). Similarly, the assessment of areas most prone to vent and