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Dependence of volcanic systems on tectonic stress conditions as revealed by features of volcanoes near Izu peninsula, Japan

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ABSTRACT

Five volcanoes, Asama, Fuji, Izu-Tobu, Izu-Oshima and Miyakejima, which are aligned along the same volcanic chain in central Japan, are subjected to different degrees to the stress conditions associated with the continental collision and subduction along wedge shaped trenches near Izu peninsula. At a great distance from the collision boundary, Asama is characterized by an axially symmetric edifice with a unique summit crater for magma effusion and Miyakejima has a similar symmetric structure accompanied by radial eruptive fissures. At the opposite extreme Izu-Tobu, which is the closest to the collision boundary, consists of many small monogenetic volcanoes that lack a central vent. In intermediate locations, Fuji and Izu-Oshima exhibit elongated volcanic edifices with both summit vents and parallel fissures on their flanks for magma effusion. To understand this systematic trend of volcanic features, growth of volcanic systems is analyzed based on magma transport in cylindrical conduits and planar fissures available in individual stress conditions. It is assumed in this analysis that fissures are produced with extensional stresses or high magma pressures enough to overcome compressive stresses and that cylindrical conduits that have arisen from localization of fissures can be persistently used for repeated magma supply. The analysis predicts that volcanoes are classified into the following three types that represent their growth processes in different stress conditions. (1) A polygenetic volcano having an axially symmetric edifice grows with unique magma supply through the central conduit under compressive or neutral stresses, (2) a polygenetic volcano having an elongated edifice grows with a summit crater and eruptive fissures parallel to the elongation under weak extensions, and (3) a group of small monogenetic volcanoes is constructed along many parallel fissures under strong extensions. This classification is examined for the five volcanoes and some other volcanoes in the world. The alternate occurrences of summit and flank eruptions observed at some polygenetic volcanoes are interpreted to be controlled by the summit height, magma densities and stress conditions that influence the pressure of a common magma source.

1. Introduction

How volcanoes and their magma plumbing systems are constructed in various tectonic conditions is one of the most fundamental questions in volcanology. The concept of plate tectonics gives a basic background but does not directly answer this problem (Canon-Tapia and Walker, 2004; Tibaldi and Lagmay, 2006). The problem is related to the structures, growth histories and eruptive features of volcanoes that have been extensively studied for many volcanoes in the world.

The gravitational force is surely a basic factor that may control growth of volcanoes (Eaton and Murata, 1960) but actual magmatic processes are more complex than determined by a simple gravitational balance (Wilson et al., 1992). A central issue of the problem would be the effect of stress conditions on magma transport (Nakamura, 1977; Takada, 1994; Ida, 1999; Gudmundsson, 1998; Canon-Tapia and Walker, 2004; Tibardi, 2005). In principle the stress condition influences volcanic processes through magma transport in fissures. In fact the vent alignment and the elongation of volcanoes normally reflect the orientation of the regional extension (Nakamura, 1977) even if they occasionally reflect pre-existing tectonic faults (Acocella et al., 2002). Gravitational forces also can influence magmatic processes and volcanic structures through the change of local stress conditions (Tibaldi and Groppelli, 2002).

It is generally accepted that volcanic systems grow more easily under extensional stress conditions. In fact eruptions often occur when the maximum tensile stress component is enhanced (Diez et al., 2005; La Femita et al., 2004; Monaco et al., 2005). It is also true, however, that some volcanoes including huge stratovolcanoes can be constructed with contradictional tectonics (Tibardi, 2005). Furthermore, the tectonic stress condition may give different influences on magma transport depending on compositions and viscosities of magmas (Petrinovic et al., 2006).

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Actual features of volcanoes are somewhat more variable. Magma disperses to small monogenetic volcanoes in some places and concentrates into a polygenetic volcano in others as is well compared for volcanoes in mid-ocean ridges (Takada, 1994). Where a central volcano is constructed regional dike intrusion can simultaneously take place outside the central vent (Gudmundsson, 1995, 1998). Many stratovolcanoes erupt only at the summit while eruptions of shield volcanoes often occur from fissures on their flanks or nearby fields (Simkin and Siebert, 1994). Furthermore, some volcanoes involve both summit and flank eruptions that are triggered by each other within the same eruptive episode having a common magma source (Acocella and Neri, 2003). The alternation between summit and flank eruptions may be controlled by balance of the tectonic stress and magma supply (Takada, 1997, 1999).

We believe that all these problems can be described more comprehensively with a good common framework of volcanic systems. To approach this goal systematic studies of magmatic activities are important and five volcanoes, Asama, Fuji, Izu-Tobu, Izu-Oshima and Miyakejima in central Japan (Fig. 1) could provide a good set of examples for the studies. These volcanoes are aligned along the same volcanic chain parallel to the Japan and Izu-Ogasawara trenches and thus have common magma sources associated with the sinking Pacific plate. Their volcanic features including the shape of volcanic edifices and the distribution of eruptive vents are, however, quite different and easily distinguished from one another (Fig. 2). In particular Izu-Tobu is a group of monogenetic volcanoes while the other four are polygenetic volcanoes involving eruptions from summit vents and/or flank fissures.

The five volcanoes actually have grown in different circumstances (Fig. 1). They are located on either the Philippine Sea plate or the landward plate that may be separated into the Eurasian and North-American plates whose relative motion is insignificant around this area (Seno and Sakurai, 1996). The Philippine Sea plate is moving northwestward and subducting below the other landward plate (Seno, 1977, 1993) and the Izu peninsula on the former is colliding with central Honshu on the latter (Matsuda, 1978) forming a wedge shaped plate boundary. The volcanic chain containing the five volcanoes crosses this continental collision boundary and volcanic features change systematically with relative locations to the collision boundary.

In this paper we analyze features of these five volcanoes and propose a new physical picture that could explain growth of volcanic systems in various tectonic circumstances. For this analysis we mainly use volcanic landforms because volcanoes are generally constructed rapidly compared with other slow processes like uplift and erosion (Thouret, 1999) and geomorphic features are strongly controlled by the local tectonic structure (FavalliM et al., 2005). Although there are some other volcanoes along the volcanic chain the five volcanoes are significantly more active and have much more detailed records of magmatic eruptions than other volcanoes. Presence of frequent new activities is important to our study because it assures of clear shapes of volcanic edifice and clear traces of craters that have not been destroyed by erosion. Underground volcanic structures can give more direct information for magma plumbing systems but our analysis does not rely on this information because detailed underground structures are still in debate for the five target volcanoes.

2. Volcanic features

We first describe some basic features of the five volcanoes, Asama, Fuji, Izu-Tobu, Izu-Oshima and Miyakejima, which are aligned along the same volcanic chain (Fig. 1). The topographies and vent distributions of these volcanoes are shown in Fig. 2. The volcanoes are marked with letters from A to E, based on their volcanic features and the probable

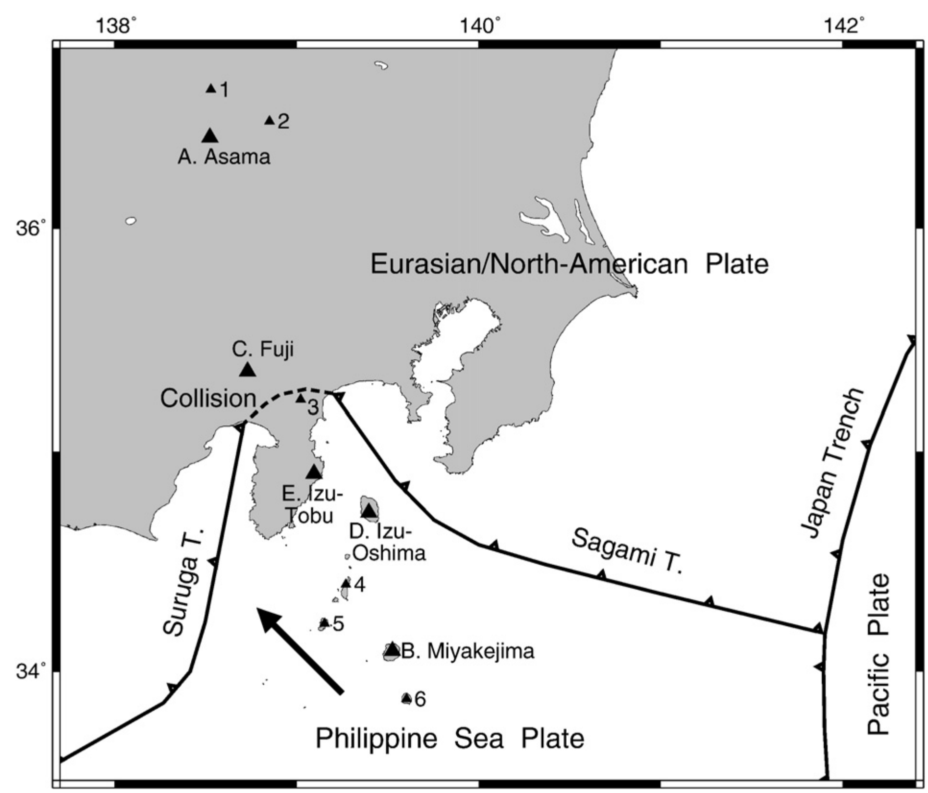

Fig. 1. The five active volcanoes, A) Asama, B) Miyakejima, C) Fuji, D) Izu-Oshima, and E) Izu-Tobu, selected for the analysis. These volcanoes are aligned along the same volcanic chain that runs parallel to the Japan and Izu-Ogasawara trenches where the Pacific plate is sinking. The volcanoes exist under different stress conditions that are influenced to different degrees by the subduction and continental collision of the Philippine Sea plate along the wedge shaped plate boundary. The collision started early Quaternary. Locations of 1) Kusatsu-Shirane, 2) Haruna, 3) Hakone, 4) Niijima, 5) Kozushima and 6) Mikurajima on which some remarks are given in the text are also shown.