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Character and origin of lithofacies in the conduit of Unzen volcano, Japan

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ABSTRACT

Unzen, western Kyushu, Japan, is an andesitic to dacitic, polygenetic volcano that reaches an elevation of 1486 m above sea level. A 1996-m-long hole has been drilled on a slanted trajectory passing beneath the volcano, penetrating the conduit zone of the volcano at 30–150 m below sea level. Spot drill cores, totalling 75 m in length, were recovered between lengths 1582 to 1996 m of the hole. The principal lithofacies of the cores are polymict volcanic breccia (74 vol.% of total drill cores), coherent dacite (13 vol.%), coherent andesite (6 vol.%), partly brecciated coherent dacite (5 vol.%), and volcaniclastic veins (2 vol.%). The polymict volcanic breccia is poorly sorted, non-graded and made up of various clasts of andesite/dacite composition, 1–120 cm across, in a matrix of andesite/dacite fragments, up to 5 mm across. The clasts are subangular to subrounded, non-vesicular to vesicular, and contain 62–66 wt.% SiO_2. This facies is interpreted as forming the subvertical body of a diatreme, and to have been produced by fragmentation of vent–conduit wall rocks by explosive eruptions and associated gravitational failure. The coherent dacite (SiO_2=66–67 wt.%) is uniform to flow-banded and commonly has chilled margins. The dacite is porphyritic containing phenocrysts of plagioclase, hornblende, biotite and minor quartz in a non-vesicular groundmass. This facies is interpreted as representing dykes that have intruded into the polymict volcanic breccia. The coherent andesite (SiO_2=59 wt.%) and partly brecciated coherent dacite (SiO_2=69 wt.%) are massive to fractured, vesicular and porphyritic. These facies are interpreted to be lavas extruded during the old stage (500–300 ka) of the evolution of the Unzen volcano. The volcaniclastic veins occur within all the lithofacies described and range from 0.1 to 250 mm wide. The veins consist of volcanic lithic and mineral fragments up to several millimetres across, and are inferred to have formed by injection of high-temperature fluid and entrained particles into temporarily opened fractures. Below 30–150 m sea level the conduit zone is at least 350 m wide in the north–south direction, and consists of polymict volcanic breccia and east–west-striking subvertical dykes. Both single dykes, 4–8 m wide, and composite dykes, 26–44 m wide, are present. Numerous volcaniclastic veins intrude both the breccia and dykes.

1. Introduction

Volcanic conduits are pathways for rising magma beneath volcanoes. Recent models of volcanic eruptions suggest that degassing of magma within volcanic conduits plays an important role in controlling eruption styles, whether explosive or effusive (e.g. Eichelberger et al., 1986; Jaupart and Allegre, 1991). Documenting the morphology and other features of volcanic conduits, and describing the physical behaviour of magma ascending through volcanic conduits, are therefore critical for a better understanding of volcanic eruptions. However, the nature of volcanic conduits, such as their geometry, internal structure, temperature, development and degassing systems, is poorly understood. Descriptive studies of volcanic conduits are uncommon (e.g. Eichelberger et al., 1988; Heiken et al., 1988; Kurozumi and Doi, 2003), and previous studies have been largely based on ancient examples of eroded volcanoes (e.g. Sillitoe et al., 1984, 1985; Stasiuk et al., 1996). Drilling of the conduits beneath modern volcanoes has only previously been applied to a small monogenetic lava dome (Inyo dome, California, Eichelberger et al., 1984, 1985; Eichelberger, 1989). Up until now, volcanic conduits beneath large, active, polygenetic volcanoes have never been drilled.

Unzen in the Shimabara Peninsula, western Kyushu, Japan (Fig. 1) is an andesitic to dacitic, polygenetic volcano that reaches an elevation of 1486 m above sea level with a base diameter of 10 km. It has erupted in 1657, 1792 and 1990–1995, with the 1990–1995 eruptions forming a dacitic lava dome on the summit of the volcano (the 1991–1995 lava dome, Fig. 1B, Sato et al., 1992; Nakada and Fujii, 1993; Nakada et al., 1999). In 2003–2004, eight years after the 1990–1995 eruptions, we

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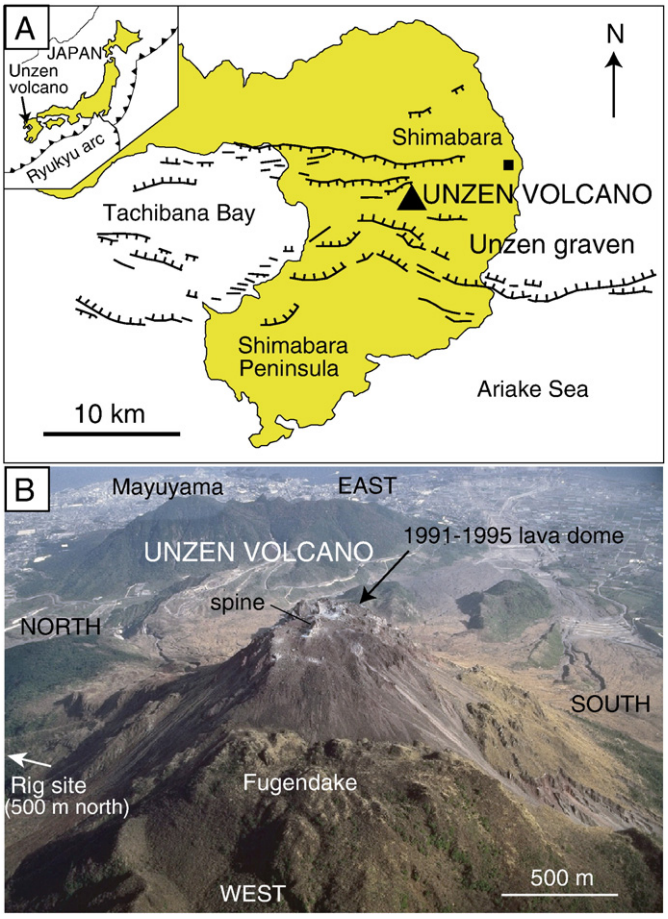

Fig. 1. (A) Location and tectonic setting of Unzen volcano in the Shimabara Peninsula, Kyushu, Japan. The volcano has grown in a tectonically active, volcanic graben (Unzen graben), which is 7–10 km wide (north–south) and extends for 40 km in the east–west direction. Modified from Tsukuda (1993) and Nakada et al. (1999). (B) Western view of Unzen volcano (elevation 1486 m above sea level), with the 1991–1995 lava dome at the summit. Also showing Fugendake and Mayuyama lava domes. An east–west striking spine occurs at the top of the lava dome. The rig for the conduit drilling was positioned at 840 m above sea level on the northern slope of the volcano (out of view of this photograph). Photograph taken by Y. Miyabuchi of the Forestry and Forest Products Research Institute.

drilled the conduit zone beneath the volcano, targeting the feeder conduit of the 1991–1995 lava dome. In July 2004, the drilling succeeded in penetrating the conduit zone at 30–150 m below sea level and recovering a total of 75 m of spot drill cores. The drilling of the conduit provided an excellent opportunity to study the nature of volcanic conduits and to explore various mechanisms of volcanic eruption. Because the drill core is discontinuous and gives only a one-dimensional perspective, the inferred facies architecture, particularly the contact relationship of lithofacies and their three-dimensional extent, has limitations. We have minimised such limitations by comparing the drill cores with data from physical logging and well cuttings. The objectives of this paper are to describe and interpret the lithofacies of the drill cores, and to infer the geometry, internal structure and formation of the conduit zone.

1.1. Terminology

We use 'vent' to refer to the opening through which volcanic materials are extruded (Davidson and Silva, 2000; Rosi et al., 2003). The term 'volcanic conduit' or 'conduit' is used to describe a subterranean passage through which magma rises towards the surface of a volcano (Carrigan, 2000; Rosi et al., 2003; Schmincke, 2004). A volcanic conduit grades upward into a vent. A pipe-like volcanic conduit filled with volcanic breccia is termed a 'diatreme' (Cas and Wright, 1987; Schmincke, 2004). Conduits of monogenetic volcanoes may be simple and consist of a dyke or a diatreme (Lorenz, 1986; Eichelberger et al., 1988). On the other hand, polygenetic volcanoes may have more complicated conduits that have been repeatedly used, and/or multiple conduits. At Unzen volcano (this study), the conduit consists of a complex of several dykes and volcanic breccia. We therefore use the term 'conduit zone' to describe the complex feeder zone beneath the vent of the polygenetic Unzen volcano.

2. Geological setting

Unzen volcano consists of andesitic to dacitic lavas, lava domes, pyroclastic flow deposits, debris avalanche deposits, and debris-flow deposits (Watanabe and Hoshizumi, 1995; Hoshizumi et al., 1999). The volcano has grown since ca. 500 ka within a tectonic graben, which is 7–10 km wide (north–south) and extends in an east–west direction for 40 km (Fig. 1A, Unzen graben, Ohta, 1973; Chida, 1979; Hoshizumi et al., 1999). Geodetic surveys suggest that the graben is spreading in a north–south direction at the rate of 1.4 cm/year, and subsiding at the rate of 2.5 mm/year (Tada, 1984; Tsukuda, 1993). The basement of the Unzen volcano consists of Pliocene to Pleistocene sedimentary rocks, basaltic to andesitic lavas and volcaniclastic rocks (Hoshizumi et al., 1999).

The eruptive history of Unzen volcano is divided into three stages (Hoshizumi et al., 2004). The old stage (500–300 ka) was characterised by explosive eruptions that produced andesitic to dacitic pumice fall/flow deposits. Effusive eruptions also occurred and

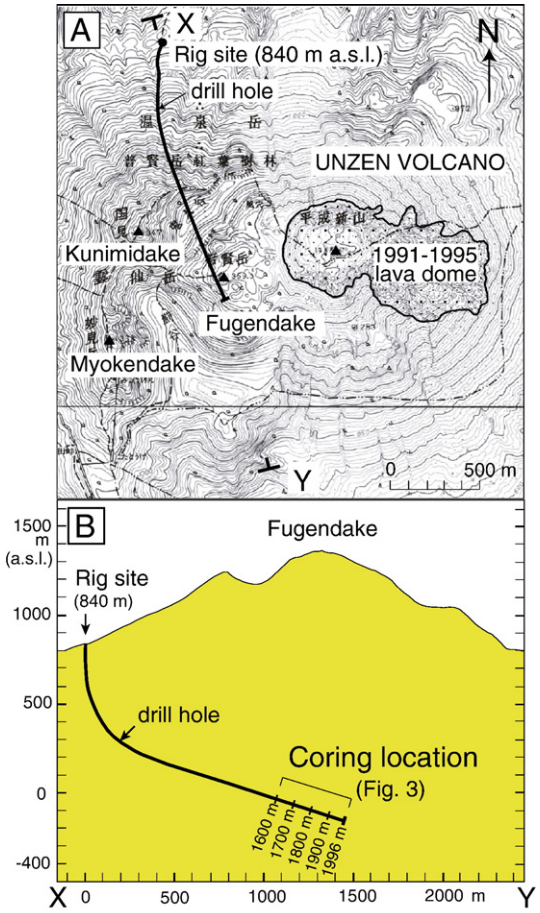

Fig. 2. Location and trace of USDP-4 drill hole. (A) Plan view. Rig site (solid circle) is located at 840 m above sea level on the northern slope of Unzen volcano. The drill hole is directed south-southeast toward the western core of Unzen volcano. Locations of X and Y for Fig. 2B are also shown. (B) Cross section (X–Y). The drill hole curves from initially being vertical at the rig site, to a plunge of 27°. The coring location (Fig. 3) is also shown. a.s.l. = above sea level.