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Micro-scale heterogeneity of andesite from Chilungshan, northern Taiwan: Evidence from melt inclusions, geochronology and Hf–O isotopes of zircons

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ABSTRACT

The Chilungshan andesite belongs to the Chilung Volcano Group in northern Taiwan and constitutes the western end of the island chains of the Ryukyu arc. Chemically it is a normal, medium-K calc-alkaline andesite. SHRIMP dating of magmatic zircons yielded an emplacement $^{206}Pb/^{238}U$ age of 1.04 ± 0.06 Ma with $\varepsilon_{Hf}(t)$ of 6.1 to 13.4 and $\delta^{18}O$ of 5.02 to 6.28‰. The zircons contain inherited cores and felsic to andesitic silicate-melt (glass) inclusions besides apatite, quartz, K-feldspar, biotite, garnet, Fe-Mg minerals (pyroxene or hornblende) and plagioclase with variable An values. Plagioclase phenocrysts also contain quartz, K-feldspar and felsic melt inclusions. This study confirms the presence of micro-scale heterogeneity in the andesite as a result of mixing between mantle-derived and continental material. Contamination of continental crust occurs either within the magma chamber at a medium to deep crustal level and/or during dehydration and melting of a subducted oceanic slab and overlying sediments in an island-arc environment.

1. Introduction

Several opinions have been advanced on andesite origins: 1) crystal fractionation of basaltic magma, 2) partial melting of lower crust, 3) contamination of basaltic magma by crustal material, 4) partial melting of subducted oceanic crust, and 5) partial melting of upper mantle under water-rich conditions (Gill, 1981; Grove and Kinzler, 1986; Straub et al., 2011). For most calc-alkaline andesites and other island arc magmas, dehydration and melting of a subducted oceanic slab and overlying sediments are considered to play an important role, because dewatering of these rocks during subduction provides aqueous fluids and melt phases with incompatible components to the depleted mantle wedge, therefore causing chemical and physical changes in the latter, including partial melting and magma mixing (Keken, 2003). However, the evidence is mainly from andesite distribution in arc terranes and the geochemical composition of andesite (Chen et al., 1993; Chen, 1999; Chung et al., 2001; Elburg et al., 2002), whereas there is only little information from silicate-melt inclusions trapped in magmatic minerals of the rocks (Thomas et al., 2003). Fluid and silicate-melt inclusions are important because they provide evidence for specific chemical composition and physio-chemical conditions of a magma at a specific stage of its formation and late evolution (Schiano and Clocchiatti, 1994; Wulff-Pedersen et al., 1996; Thomas, 2000; Frezzotti, 2001; Thomas et al., 2003; Schiano et al., 2004). The study of inclusions in eclogite–facies rocks suggests that with increasing mineral solubility into the fluid, silicate-rich aqueous solutions are similar in geochemical behaviour and transport capacity to a melt phase (Scambelluri and Philippot, 2001). This is supported by experimental work showing a high solubility of silicate components in fluids at high pressures (Massonne, 1992; Domanik and Holloway, 1998).

We report on a petrographic and geochemical study and zircon U–Pb geochronological and Hf and O isotopic data on a very young andesite from the Chilung Volcano Group in northern Taiwan. The discovery of silicate-melt inclusion in magmatic zircon and plagioclase phenocryst provide direct evidence for the micro-scale heterogeneity in andesite.

2. Geological background

The northern Taiwan volcanic province constitutes the western end of the island chains of the Ryukyu arc and is mainly composed of the Tatun, Kuanyinshan, Chilung groups of volcanoes, on which

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petrographical, petrological, geochronological and geochemical studies were carried out (Chen, 1983, 1999; Huang and Meyer, 1983; Juang and Chen, 1989; Shinjo et al., 2000). The Chilung Volcano Group is composed mainly of andesite and can be subdivided into five separate bodies, namely Chilungshan, Penshan, Wutanshan, Tsaoshan and Chimuling (Fig. 1) (Juang and Chen, 1989; Chen et al., 1993; Chen, 1999). The Chilungshan volcanic body, from which sample CL was taken for this study, is located in the northern part of the Chilung Volcano Group. The andesite is homogeneous on a macro-scale, and no felsic magma exists in the Chilung Volcano Group. In the early literature, these rocks were denoted as "dacite" or "quartz andesite". However, Chen (1999) suggested that the quartz grains are remnants of near-surface sediments and originated through magmatic assimilation, therefore andesite should be the correct name for these rocks. Apart from quartz grains, the andesite commonly contains plagioclase, amphibole, biotite and pyroxene phenocrysts, which crystallized from the magma. K–Ar dating of five biotite samples and one whole-rock sample from the Chilung Volcano Group yielded ages ranging from 0.81 to 1.7 Ma (Juang and Chen, 1989). Fission track dating (FTD) of zircons from the same volcano group yielded ages ranging from 0.88 to 1.09 Ma (n = 44, Chen et al., 1993). Gao et al. (2010) reported a zircon U–Pb age of 1.17 ± 0.02 Ma for the Chilungshan andesite (Chinkuashi dacite in Gao et al. (2010)). Geochemically, the volcanic rocks are uniform, with SiO_2 contents of 55.5 — 58.5%, and are regarded as medium-K calc-alkaline andesites in an orogenic belt (Chen, 1999). The formation of these volcanic rocks is believed to be related to the subduction of the Philippine Sea plate under the Asian continent, with some younger high-Mg potassic alkaline basalts being formed in a post-collision extensional environment owing to orogenic collapse (Chung et al., 2001 and references therein). Based on spatial and temporal geochemical variation of the volcanic rocks from the Northern Taiwan Volcanic Zone (NTVZ, 2.8–0.2 Ma), Wang et al. (2004) indicated that they resulted from the upwelling of asthenosphere in response to post-collisional extension, and the NTVZ is not part of the Ryukyu Arc.

3. Analytical methods

Mineral and glass inclusions in zircon and plagioclase were identified using a Jasco nitrogen Raman spectroscope with a Renishaw 1000 laser and using the 514.5 nm line at the Institute of Geology, Chinese Academy of Geological Sciences (CAGS), Beijing. Mineral and glass compositions were determined using a Jeol JXA 8800R electron microprobe analyzer with 20 kV accelerating voltage and a 21 nA beam current at the Institute of Mineral Resources, CAGS, and a CAMECA SX-51 electron microprobe with 15 kV acceleration potential and 20 nA beam current at the Institute of Geology and Geophysics, Chinese Academy of Sciences (CAS), Beijing. For minerals, the analysis total is commonly close to 100%. For glass, however, it is much lower, generally between 90 and 95% partly because of an uneven surface of the mount.

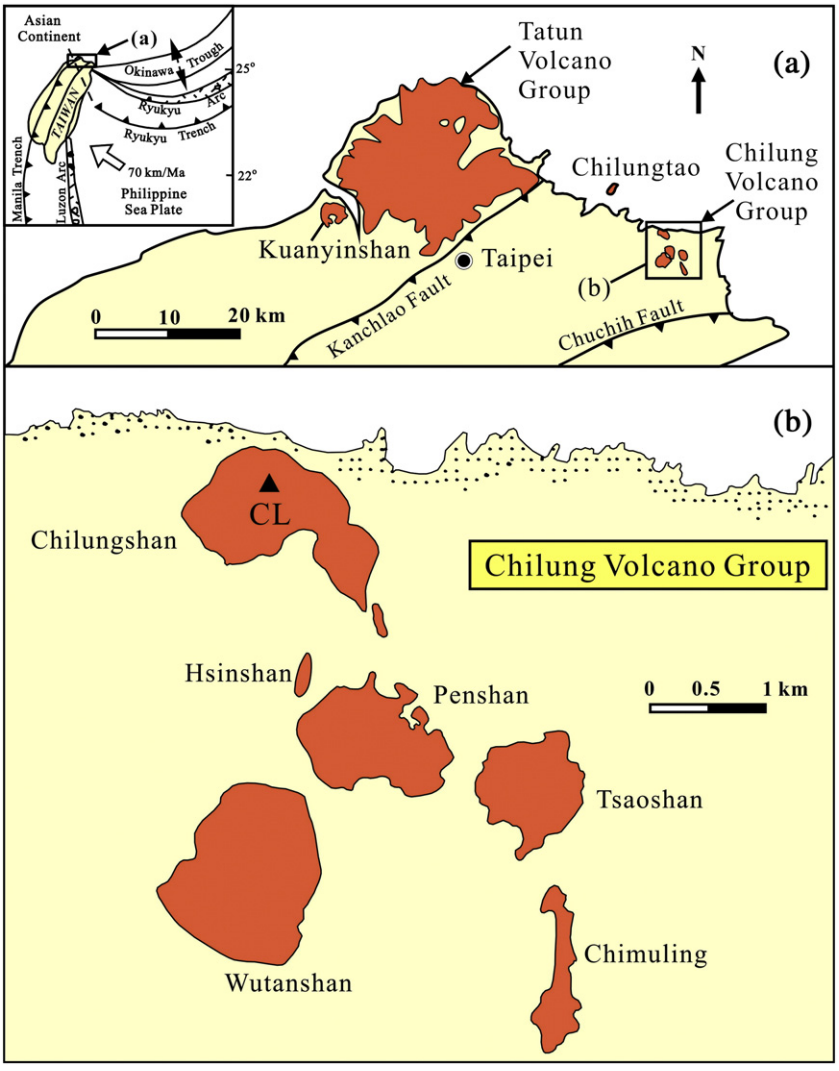

Fig. 1. Distribution of Neogene volcanoes in northern Taiwan (after Chen et al., 1993). Also shown is the location of andesite sample CL of this study.