Quaternary International 349 (2014) 221–231

Contents lists available at ScienceDirect

Quaternary International

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

Melting and crystallization of andesite from Chilungshan, Northern Taiwan: An experimental Petrological study at atmospheric pressure

Yu-Ming Lai [a], Teh-Ching Liu [b, *], Yu-Ming Chen [c], Yoshiyuki Iizuka [d]

[a] Department of Geosciences, National Taiwan University, 1, Sec 4 Roosevelt Road, Taipei 106, Taiwan, Taiwan, ROC
[b] Department of Earth Sciences, National Taiwan Normal University, 88, Sec 4 Tingchou Road, Taipei 116, Taiwan, Taiwan, ROC
[c] Dun-Hua Elementary School, Taipei, Taiwan, ROC
[d] Institute of Earth Sciences, Academia Sinica, Taipei, Taiwan, Taiwan, ROC

ARTICLE INFO

Article history:
Available online 12 July 2014

Keywords:
Chilungshan
Andesite
Quartz
Experimental petrology

ABSTRACT

To investigate whether quartz can be crystallized from the magma at the Chilungshan andesite in Northern Taiwan, melting experiments involving 17 runs were performed at atmospheric pressure. The liquidus temperature was determined to be 1285 °C, and the melting interval was estimated to be 193 °C. Pagioclase crystallized first at 1285 °C, and iron–titanium oxides subsequently crystallized at 1267 °C. Quartz and orthopyroxene crystallized together at 1174 °C. Finally, clinopyroxene crystallized at 1166 °C, and orthopyroxene disappeared at 1155 °C.

The crystallization of the Chilungshan andesitic melt at atmospheric pressure was successively controlled by plagioclase, iron–titanium oxides, quartz, orthopyroxene, and clinopyroxene. The differentiation trend of the residual melt involved the depletion of aluminum and calcium, but the residual melt became enriched in silicon and potassium. In addition, it became enriched in magnesium, iron, and titanium at the initial stages, which were depleted at the final stages. The study results suggest that quartz grains can be crystallized from the Chilungshan andesitic melt at atmospheric pressure.

1. Introduction

Taiwan is part of an active mountain belt created by the collision between the northern Luzon Volcanic Arc and the Asian continent (Teng, 1990). Taiwan is situated between the Philippine Sea Plate and the Eurasian Plate (Fig. 1). The Northern Taiwan Volcanic Zone (NTVZ) is composed of the Tatun Volcanic Group, Chilung Volcanic Group (CVG), Kuanyinshan, Tsaolingshan, and several volcanic islands (Chen, 1997). The volcanic rocks in the NTVZ are formed by the extensional collapse of this area, which is triggered by the upswelling of the asthenospheric mantle (Wang et al., 2004).

The CVG is separated from the NTVZ by two faults, the Kanchiao Fault in the north and the Chuchih Fault in the south (Fig. 1a) (Chen et al., 1993). The CVG consists of five volcanic bodies, named Chilungshan, Penshan, Tsaoshan, Wutanshan, and Chimuling, and one offshore volcanic island named Chilungtao (Fig. 1b) (Yen, 1949; Wang, 1953; Chen and Huh, 1982; Juang and Chen, 1989; Chen, 1999). The petrology, petrography, geochemistry, and geochronology of the region have been extensively investigated in previous studies (Yen et al., 1979; Chen, 1983, 1999; Hwang and Meyer, 1983; Juang and Chen, 1989; Chen et al., 1993; Li, 1998; Shen and Yang, 2004). In previous studies, the volcanic rocks of the CVG have been categorized into dacite or quartz andesite because of the presence of quartz grains in the andesites (Wang, 1953; Yen et al., 1979; Chen and Huh, 1982; Hwang and Meyer, 1983). Chen (1999) suggested that these quartz grains most likely originated from the sedimentary stratum captured by the andesitic magma. Therefore, andesite might be the correct name for these rocks.

Chilungshan is an intrusive body and was exposed through weathering and erosion (Wang, 1953). Volcanic rocks are categorized as basaltic andesite to andesite depending on their predominant elements. The content of rare earth elements is relatively low, and no Eu anomalies exist. The large ion lithophile elements are enriched, whereas the high field strength elements are depleted (Chen and Huh, 1982; Hwang and Meyer, 1983; Juang and Chen, 1989; Chen, 1990, 1999; Wan et al., 2012). In addition, the Pb, Nd, Hf, and O isotopic ratios have been previously analyzed by Chen (1999) and Wan et al. (2012). The intrusive age of the Chilungshan volcanic rocks is approximately 0.81–1.26 Ma (0.81 ± 0.12 Ma based on K–Ar age dating conducted by Juang (1988); 0.88 to 1.09 Ma based on fission track dating reported by Chen et al. (1993);

* Corresponding author. Earth Sciences, National Taiwan Normal University, F405, No. 88, Sec. 4, Tingzhou Rd., Taipei City 11677, Taiwan, Taiwan, ROC.
E-mail addresses: liutc@ntnu.edu.tw, shiaoteh@gmail.com (T.-C. Liu).

http://dx.doi.org/10.1016/j.quaint.2014.06.037
1040-6182/

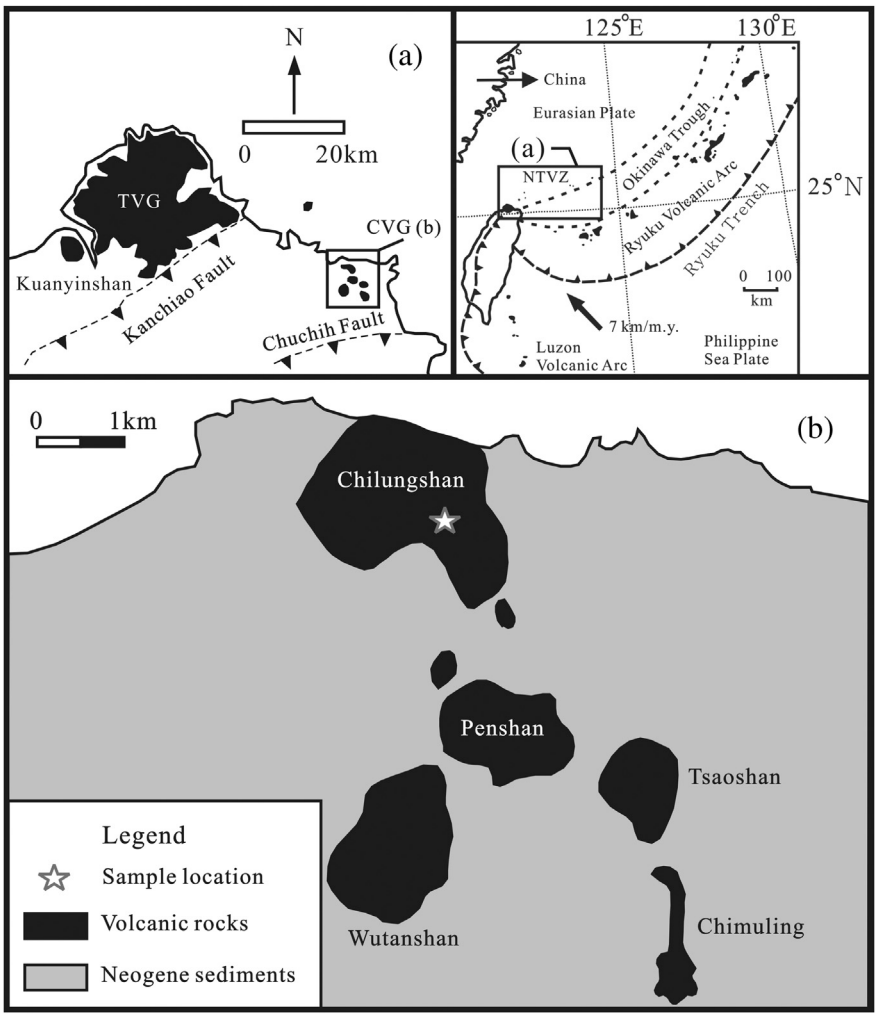

Fig. 1. Regional tectonic setting of Taiwan (after Teng, 1990). Rectangular area shows the volcanic fields of the Northern Taiwan Volcanic Zone (NTVZ). (a) Distribution of Neogene volcanoes in northern Taiwan. Kuanyinshan in the west, Tatun Volcanic Groups (TVG) in the center and the Chilung Volcanic Groups (CVG) in the east. (b) the star marked the sample location of this study.

1.26 ± 0.01 Ma according to Ar–Ar age dating performed by Li (1998); and 1.04 ± 0.06 Ma based on zircon U–Pb age dating conducted by Wan et al. (2012)).

The origin of the quartz grains with irregular, rounded, or embayment textures in the Chilungshan andesite is considered to be xenoliths from the Neogene sediments that were captured by the andesitic magma as it traveled to the surface (Chen, 1999). Chung (2006) proposed that magma mixing generated the andesite. Oxygen isotope analyses of the essential minerals in the andesite revealed that the quartz in the Chilungshan andesite could not be assimilated from sedimentary rocks (Kuo, 2002). In this study, melting experiments were conducted on the Chilungshan andesite at atmospheric pressure to investigate its crystallization process. According to the crystallization trend, quartz can be formed by the Chilungshan andesitic melt.

2. Experimental method

2.1. Starting material

Approximately 2.0 kg of natural andesite samples were collected from Chilungshan (Fig. 1b). The color, texture, and size of the crystals comprising the rock samples were determined. The weathered portion of the andesite was removed, and the remaining andesite were crushed and ground into powder that was able to pass through a 200-mesh sieve. The powder was placed in a desiccator, and used as the starting material for the melting experiments. In the melting experiments, the andesitic melt was assumed to be the parental magma.

2.2. Apparatus, procedures, identification, and phase analyses

The andesite samples were cut into thin sections; their textures were observed, and the minerals were identified using a polarizing microscope (Axioplan 7082). The percentage of phenocrysts was determined by performing point counting.

The major elements of the Chilungshan andesites were determined at National Taiwan University (NTU) by using X-ray fluorescence (XRF) spectrometry (Rigaku RIX-2000). The detection limits and the analytical uncertainty were the same as those described by Lee et al. (1996). The CIPW norm of the andesite was calculated using the IGPET 06 computer program, which was supplied by Terra Softa Inc., New Jersey, USA. The whole rock composition of the Chilungshan andesite is listed in Table 1.