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Multiple Vent-forming Phreatic Eruptions after AD 1663 in the Noboribetsu Geothermal Field, Kuttara Volcano, Hokkaido, Japan

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The Noboribetsu geothermal field (area 1×1.5 km) is located in the western part of Kuttara volcano, southwestern Hokkaido, Japan. Seventy-one shallow trenches (<90 cm deep) were systematically dug within the geothermal field, in order to study the stratigraphy and distribution of the most recent phreatic fall deposit (the Nb-a deposit) erupted from the field. The Nb-a deposit (<68 cm thick) consists of altered dacitic lithic clasts in a fine-grained clay-rich matrix. The deposit overlies the Us-b tephra that was emplaced in AD 1663. Stratigraphic sections constructed from the 71 trenches indicate that the deposit is distributed within an elliptical area measuring 850×1250 m across and extending NNW-SSE. Isopach and maximum-grain-size isopleth maps indicate that the deposit increases in thickness and maximum-grain-size toward several explosion craters. These data suggest that phreatic eruptions, through multiple vents, occurred in the Noboribetsu geothermal field after AD 1663.

Key words: phreatic eruption, deposit, trench survey, Noboribetsu geothermal field, Kuttara volcano

1. Introduction

The Noboribetsu geothermal field at Kuttara volcano, southwestern Hokkaido is one of major geothermal fields in Japan (Fig. 1). Geological and geochronological studies (Goto *et al*., 2011a, b, 2013; Katsui *et al*., 1988; Yamazaki, 1986) indicate that at least 12 episodes of phreatic eruptions (here, the term 'phreatic eruptions' is used for steam-driven explosions that do not involve fresh magma, following Barberi *et al*., 1992 and McPhie *et al*., 1993) have occurred in this field within the past 8500 years. However, the details of each episode, such as the mode and magnitude of eruptions, remain unclear. We performed a stratigraphic survey of the most recent phreatic fall deposit erupted in this field (the Nb-a deposit; Goto *et al*., 2013) in order to clarify the style of the most recent phreatic eruptions in this field. As this field is generally covered with thick vegetation, we excavated and examined 71 shallow trenches throughout the field. This paper reports the results of the stratigraphic survey and discusses the style of the most recent eruptions.

2. Noboribetsu geothermal field

The Noboribetsu geothermal field lies in the western part of Kuttara volcano (Fig. 1) and is approximately 1 km wide (ENE-WSW) and 1.5 km long (NNW-SSE) (Katsui *et al*., 1988; Moriizumi, 1998). This field is inferred to have formed at *ca.* 15 ka (Goto and Danhara, 2011; Goto *et al*., 2013), and is characterized by a dacitic cryptodome (Hiyoriyama cryptodome), a volcanic lake (Oyunuma Lake), and a fumarolic valley (Jigokudani Valley) (Figs. 2 and 3). The Hiyoriyama cryptodome, in the northern part of the geothermal field, is 350−550 m in diameter and rises 130 m above the surrounding areas (Fig. 2A; Goto and Johmori, 2013). Oyunuma Lake (115×210 m in area), located in the central part of the geothermal field, is the largest explosion crater in the field and is filled with hot acidic water (Fig. 2A). The Jigokudani Valley, in the southern part of the geothermal field, extends for 500 m in an ENE-WSW orientation and hosts active fumaroles (Fig. 2B). The geothermal manifestations of the geothermal field (active fumaroles, hot springs, and hydrothermal alteration zones) are distributed in a zone extending NNW-SSE from the Hiyoriyama cryptodome to the Jigokudani Valley (Goto and Johmori, 2011). A number of small explosion craters (diameter 25−210 m) occur in this zone (Goto *et al*., 2011a).

3. Trench survey

The Noboribetsu geothermal field is generally covered by forests consisting of tall trees and short bamboo, except in areas where geothermal manifestations occur (Fig. 2A). Stratigraphic and descriptive studies of the Nb-a deposit are thus hampered by limited exposures caused by a thick cover of vegetation. To address this issue, 71 shallow trenches were systematically dug throughout the Noboribetsu geothermal field (Fig. 3). The trenches were excavated using a hand shovel. Each trench had a horizontal area of

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