Journal of Volcanology and Geothermal Research 215–216 (2012) 1–7

Contents lists available at SciVerse ScienceDirect

Journal of Volcanology and Geothermal Research

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

Volcanic strain change prior to an earthquake swarm observed by groundwater level sensors in Meakan-dake, Hokkaido, Japan

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ARTICLE INFO

Article history:
Received 13 January 2011
Accepted 11 November 2011
Available online 28 November 2011

Keywords:
Deflation
Earthquake swarm
Groundwater level
Volumetric strain
Deep low frequency earthquakes

ABSTRACT

We installed and operated a low-cost groundwater level observation system at intermittent hot spring wells in order to monitor volcanic strain signals from the active Meakan-dake volcano in eastern Hokkaido, Japan. Data are sampled at 1 Hz and are transmitted to the data center in real time. Evaluation of the water level time series with theoretical predictive tidal strain and coseismic static strain changes has suggested that the wells penetrate to the artesian aquifer and act as a volumetric strain sensor. An active earthquake swarm with more than 400 events occurred at the shallower part of the volcano from January 9 to 11, 2008. Three independent wells recorded pre- to co-swarm groundwater drops simultaneously, which represented a decrease in volumetric strain. The total volumetric strain change during the three active days was estimated to be from 6 to 7×10^{-7}. The observed data, including changes in volumetric strain, absence of deformation in the GPS coordinates, and activation of deep low-frequency earthquakes, might imply possible deflation of a source deeper than 10 km, and these preceding deeper activities might induce an earthquake swarm in a shallower part of the Meakan-dake volcano.

1. Introduction

The Meakan-dake volcano in eastern Hokkaido, Japan, is an active volcano with an elevation of 1,499 m (Fig. 1). The Meakan-dake volcano is a typical island-arc volcano associated with the subducting Pacific plate. Although historical records are limited, several phreatic eruptions have been recorded since 1955. Effusive rock compositions of this volcano are dacite, andesite, and basaltic andesite (Wada, 1991). Three major stages of explosive eruptive activity at 12 ka, 9 ka, and 5 to 6 ka were associated with the generation of pyroclastic flows, and successive lava effusions have continued fitfully over the last few thousand years. The most recent magmatic eruption was estimated to have occurred anywhere from several hundreds of years to thousands of years ago (Wada et al., 1997).

In 1956, the Japan Meteorological Agency (JMA) installed a seismograph, which has been operated routinely since 1973. The number of earthquakes per day sometimes exceeded 400 when an active earthquake swarm occurred (Fig. 2a). However, none of these earthquakes were felt because of their miniscule magnitude. Small phreatic eruptions in 1988, 1996, 2006 and 2008 occurred following an earthquake swarm.

Geothermal fields and hot springs are located on and near the volcanic edifice. Prior to 2004, the average temperature of active fumaroles in the summit crater (Fig. 1) had been approximately 400 °C (Fig. 2b). However, a decrease in temperature was observed over the last decade, and recent data gathered during the spring of 2008 indicated that the temperature was less than 100 °C (Fig. 2b).

Crustal deformation associated with volcanic activity can be used to investigate the magmatic and/or geothermal system beneath the volcanic edifice. However, recent space geodetic techniques such as GPS and InSAR provide high-quality geodetic data, strain observations can provide higher precise signals that cannot be detected by GPS (e.g., Agnew and Wyatt, 2003; Chardot et al., 2010; Ueda et al., 2005). Although high installation cost is one of main difficulties in establishing a new site, Hokkaido University and the Geological Survey of Hokkaido started a low-cost groundwater level change observation at intermittent hot spring wells to monitor the strain activity of the Meakan-dake volcano. We herein report a volcanic strain event determined using the newly proposed groundwater observation system.

2. Groundwater level observation

Several studies have shown that, under proper conditions, artesian groundwater acts as a volumetric strain sensor (Akita and Matsumoto, 2004; Gahalaut et al., 2010; Itaba et al., 2010; Matsumoto, 2002; Matsumoto et al., 2003; Quilty and Roeloffs, 1997; Roeloffs, 1988; Shibata et al., 2010; Wakita, 1975). The suggested volcanic strain signals might also be observed as groundwater level changes. In order to monitor volcanic unrest signals using groundwater level data, we

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doi:10.1016/j.jvolgeores.2011.11.006

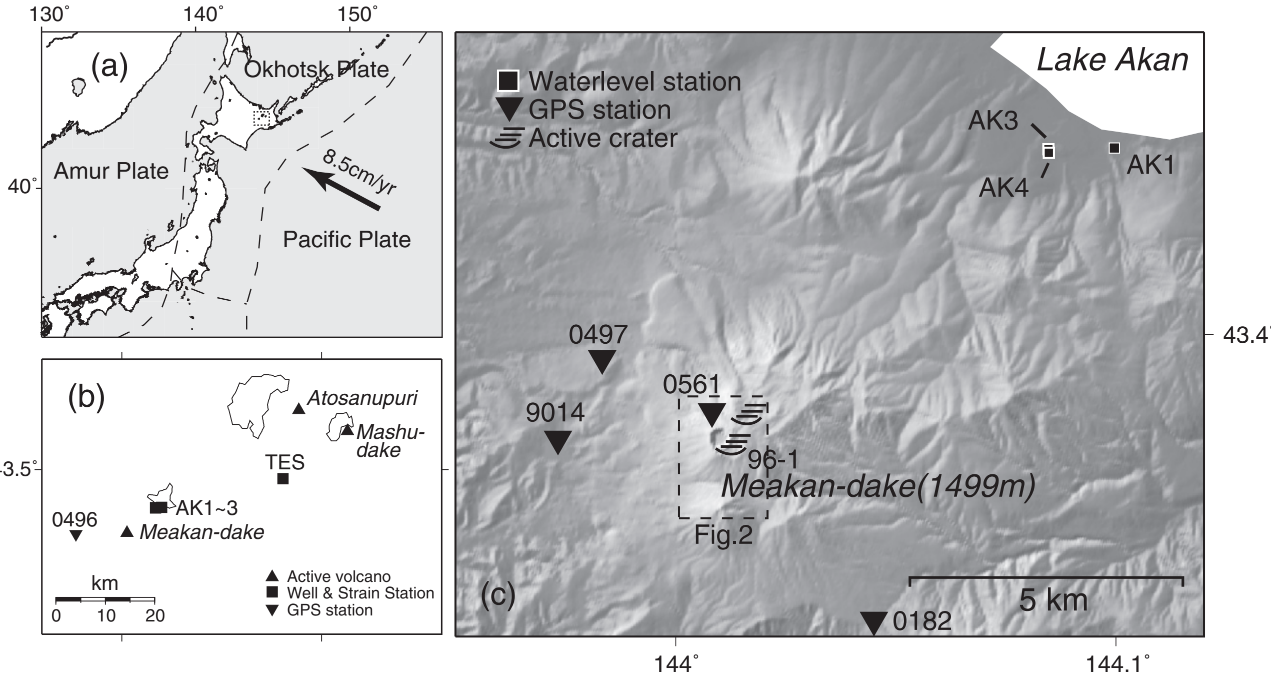

Fig. 1. (a) Map showing the geographical location of the Meakan-dake volcano indicating the tectonic background. The dashed lines show the plate boundaries. (b) Close-up of the rectangular area shown in Fig. 1(a). The nearest TES strain station and GPS station (0496) are also indicated. (c) Location of well stations (AK1, AK3, and AK4), GPS stations (0497, 9014, 0561, and 0182), and active vent 96–1, at which temperature observations were made. An inset rectangular is used in Fig. 2.

used three preexisting intermittent hot spring water wells, AK1, AK3, and AK4, which are situated approximately 8 km NNE from the volcano summit (Fig. 1). The parameters of each well are listed in Table 1 (Kawamori et al., 1987). Well AK1 had a borehole depth of 1,061 m with a strainer located at a depth of between 518 and 1,061 m, whereas wells AK3 and AK4 had shallower boreholes (92 and 57 m) with strainers located at depths of between 24 and 55 m and between 41 and 57 m, respectively. These facts indicate that AK1 and AK3-4 penetrate different aquifers. In order to measure the groundwater levels, in April of 2006, we installed a water pressure measurement sensor (Druck PTX1830) approximately 5 m below the water surface. The hydraulic heads from the ground surface are 1 m for AK1 and 0.5 m for AK3 and AK4. The sensor resolution is less than 1 mm. A barometric pressure sensor was also deployed at the same location in order to eliminate barometric pressure effects on the water levels. The obtained data are converted to digital signals using a 24-bit AD converter at a sampling rate of 1 Hz and are transmitted in real time to the data center at Hokkaido University via IP protocol. A precise time calibration is accomplished by on-site GPS receivers every 2 h. All data are stored in a crustal deformation database system (Yamaguchi et al., 2010) and are distributed to concerned institutions in pseudo-real time.

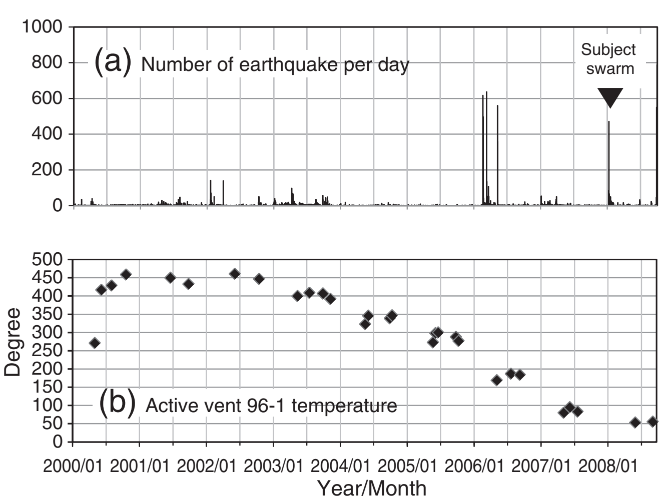

Fig. 2. (a) Number of volcano earthquakes per day, and (b) temperature recorded at active vent 96–1 crater shown in Fig. 1(c), from January 2000 to October 2008.

The proportion of the groundwater level to crustal strain was evaluated by Saito (2008). He analyzed raw water level data for a period of one month using BAYTAP-G tidal analysis software (Ishiguro et al., 1981; Tamura et al., 1991). The time series of the tidal response, the barometric pressure response, and the irregular and trend components were deconvoluted. The barometric component was obtained using barometric pressure data observed at the observation site. Clear responses to tidal components were observed at AK1 and AK4, suggesting that these wells are under artesian influence. In contrast, a less clear response was observed at AK3, indicating that this well is not under artesian influence. Based on these observations, Saito (2008) concluded that the sensitivity coefficients of the M2 tidal component (period: 12.42 hours) were dominant and had a smaller phase difference. The coefficients of volumetric strain to the groundwater level were estimated by comparing the theoretical volumetric tidal strains of earth and ocean loading calculated using GOTIC2 tidal loading computation software (Matsumoto et al., 2001), and the observed tidal components were decomposed by BAYTAP-G software. The strain sensitivities to the M2 tidal constituent, W_s, were calculated as follows:

$$W_s = T_w / T_t,$$

where T_w and T_t are the water level and theoretical amplitude of the M2 tidal component, respectively (Table 1).

In order to validate the above procedure, a suitability test of the response coefficient was conducted by comparing coseismic water level changes with theoretical values observed at AK1. The result also indicated properness of the water level coefficients to volumetric strain. In addition, a suitability test by Saito (2008) revealed that the