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Detection of microwave emission due to rock fracture as a new tool for geophysics: A field test at a volcano in Miyake Island, Japan

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ABSTRACT

This paper describes a field test to verify a newly discovered phenomenon of microwave emission due to rock fracture in a volcano. The field test was carried out on Miyake Island, 150 km south of Tokyo. The main objective of the test was to investigate the applicability of the phenomenon to the study of geophysics, volcanology, and seismology by extending observations of this phenomenological occurrence from the laboratory to the natural field.

We installed measuring systems for 300 MHz, 2 GHz, and 18 GHz-bands on the mountain top and mountain foot in order to discriminate local events from regional and global events. The systems include deliberate data subsystems that store slowly sampled data in the long term, and fast sampled data when triggered. We successfully obtained data from January to February 2008. During this period, characteristic microwave pulses were intermittently detected at 300 MHz. Two photographs taken before and after this period revealed that a considerably large-scale collapse occurred on the crater cliff. Moreover, seismograms obtained by nearby observatories strongly suggest that the crater subsidence occurred simultaneously with microwave signals on the same day during the observation period.

For confirmation of the microwave emission caused by rock fracture, these microwave signals must be clearly discriminated from noise, interferences, and other disturbances. We carefully discriminated the microwave data taken at the mountaintop and foot, checked the lightning strike data around the island, and consequently concluded that these microwave signals could not be attributed to lightning. Artificial interferences were discriminated by the nature of their waveforms. Thus, we inferred that the signals detected at 300 MHz were due to rock fractures during cliff collapses. This result may provide a useful new tool for geoscientists and for the mitigation of natural hazards.

1. Introduction

Japan has suffered several huge earthquakes in recent history. In particular, the Great East Japan Earthquake in March 2011 resulted in the death of about 20,000 people and caused heavy damage to houses and social infrastructure including the Fukushima nuclear power station (Cyranoski and Brumfiel, 2011). In light of such events, a greater demand than ever is placed on seismologists to clarify the mechanism of great earthquakes and to predict their occurrence (Sagiya, 2012).

These requirements are currently not realistic (Uyeda et al., 2012). One reason may be the lack of knowledge and experience. In addition, study tools are limited to monitoring data from mechanical vibration sensors (Fujinawa and Noda, 2007) and remote sensing measurements of ground deformation (Massonnet et al., 1993). Therefore, new tools are required, such as those in the field of electro-magnetic measurements, measurements of the Earth's atmosphere and ionosphere, and hydrological instruments. Among these approaches, however, the VAN method of ground potential measurement (Varotsos et al., 1993) lacks an understandable explanation of the causes of the signals, and it is difficult to discriminate the signal from the noise. The correlation between the ionospheric disturbances and earthquakes needs a physical explanation, which could be provided by laboratory experiments (Molchanov and Hayakawa, 1998).

Meanwhile, Maki et al. (2006) recently found that electromagnetic emissions at 300 MHz, 2 GHz, and 22 GHz as well as at lower frequency already reported by former works (Cress et al., 1987; Nitsan, 1977) are caused by fracturing rock for the first time ever in laboratory experiments. Generally, measurements of electromagnetic emissions at microwave bands are particularly difficult because the emitted signal's

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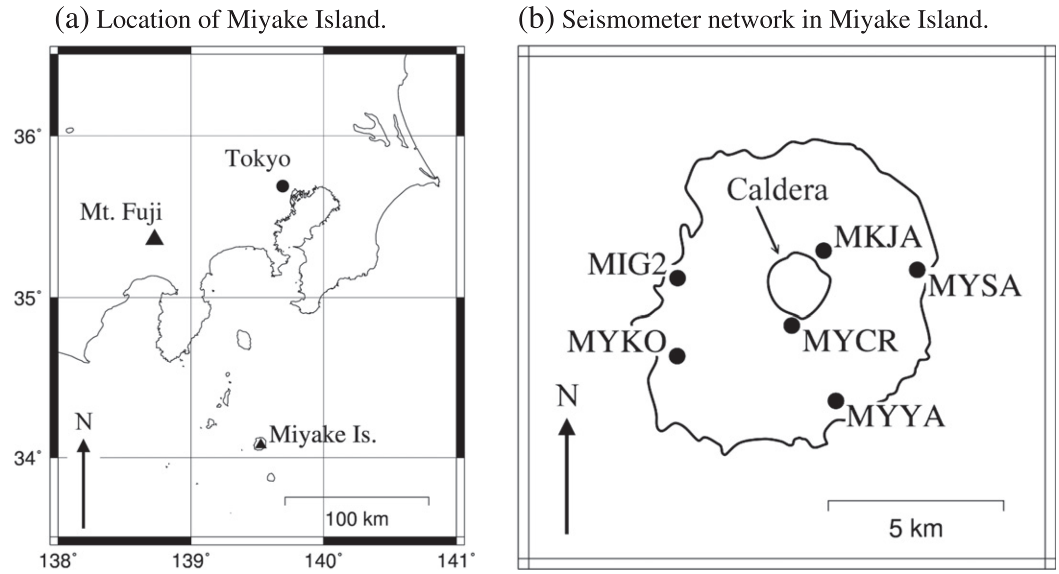

Fig. 1. Overview of Miyake Island. (a) Location of Miyake Island. (b) Seismometer network in Miyake Island.

frequency is extremely high, and it has instantaneous properties with a considerably small time constant. Maki et al. exploited a novel measuring system that includes an antenna and a low noise amplifier for each of three frequency bands, and a large memory with excellent triggering. They used rock samples of quartzite, granite, gabbro, and basalt for experiments. Electromagnetic emissions at 300 MHz and 2 GHz were detected as for all rock samples. That at 22 GHz was detected only in the case of quartzite due to the measurement difficulty. These emissions were not thermally excited and were discriminated from thermal noises. At 300 MHz and 2 GHz, the received power was largest for quartzite and gabbro, the second largest for granite, and the smallest for basalt. It is important that gabbro emits more power than granite though gabbro includes less quartz than granite. Accordingly, this phenomenon is related to not only piezoelectricity but also other rock properties such as stiffness and hardness, but has not yet been explained completely (Takano et al., 2010a,b, 2011). Therefore, the detection of microwave emission may offer a new tool to geosciences and seismic geophysics.

Before the above-mentioned finding, Geng et al. (1999) reported microwave emission from rock fractures, but could not confirm the waveform, spectrum, or power level. There have also been reports of electromagnetic emissions at lower frequencies (Cress et al., 1987; Nitsan, 1977). In addition, it is known that volcanic plumes are electrically charged because of the ejection of ions and atoms, vaporization of water, and wind effects, and that the electromagnetic energy in volcanic plumes can be emitted at lower frequencies (James et al., 2008). A proposed mechanism for the electromagnetic emissions at lower frequencies is the polarization effect due to piezoelectricity and charge movement when piezoelectric rocks fracture. However, this model cannot explain the strong emission from gabbro, which has been confirmed experimentally (Maki et al., 2006). A model of current flow along the surface due to electrical charging was proposed, based on friction and crack generation during fracture (O'Keefe and Thiel, 1995). However, the time constant in this case is about 130 μs, so the high frequency cannot be explained with polarization due to piezoelectricity or the movement of charges, which were adopted in Yoshida and Ogawa (2004). A model that includes discharge across a microcrack could explain the experimental results of the waveforms (Maki and Takano, 2004). Charge arising from bond dislocation between atoms or thermally excited electrons may cause relatively high voltages in some materials (Ohnishi et al., 2007). Kinetic excitation of the inner electrons and the nucleus,

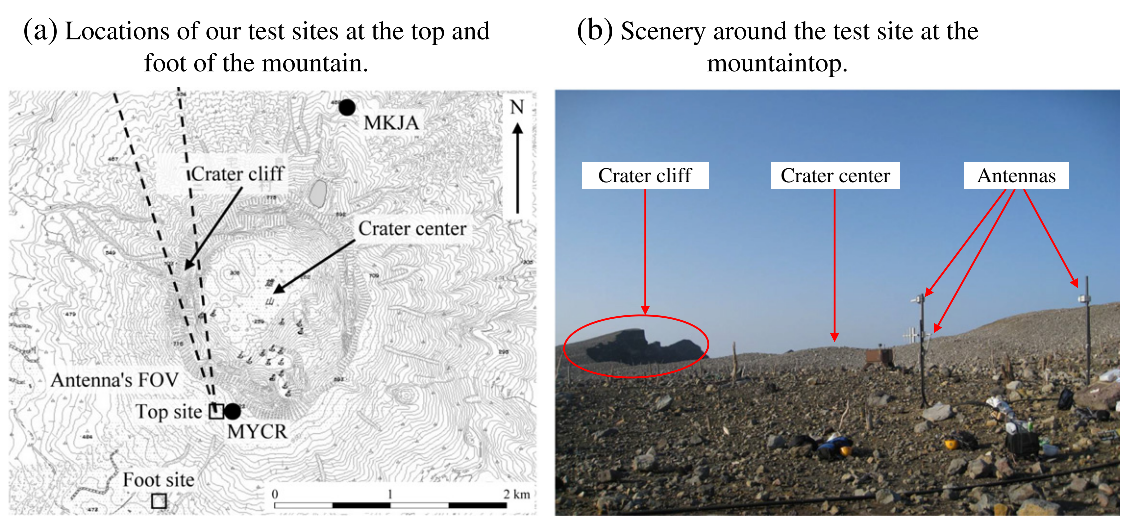

Fig. 2. Overview of our test sites at the top and foot of the mountain at Miyake Island. (a) Locations of our test sites at the top and foot of the mountain. (b) Scenery around the test site at the mountaintop.