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論　文　内　容　要　旨

(NO.　1)

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学位論文の題　　名	Spatio-temporal changes in seismic velocity of Miyakejima volcano associated with the 2000 activity as inferred from ambient seismic noise analyses (雑微動解析による 2000 年三宅島火山活動にともなう火山体構造の時空間変化)		

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Abstract

Temporal variations in seismic velocity of the solid earth have been extensively studied to deepen our knowledge on the behavior of the medium and also to give some indications of precursor of imminent large earthquakes or volcanic eruptions. The use of repeating earthquakes and active seismic experiments have enabled us to precisely determine seismic velocity changes in the medium associated with earthquake occurrences, volcanic eruptions, or magma intrusions. However, repeating earthquakes are not so often observed generally and are limited to occur at active tectonic or volcanic regions. Also, active seismic experiments need

expensive operational costs that may result inadequate temporal sampling for observations. Instead of using these sources, a new method called seismic interferometry has enabled us to measure seismic velocity changes. Seismic interferometry technique is to retrieve the Green function between two stations by stacking cross-correlation functions (CCFs) of the seismic coda waves or ambient seismic noise signals recorded at the two stations, and no repeating earthquake or artificial source are necessary for monitoring the structure. By comparing the retrieved CCFs for one-day, a week or more for periods of before and after the target phenomena, we can evaluate the difference of travel time of seismic waves propagating between the two stations. Recent studies have succeeded in detecting small temporal changes in the medium by using ambient seismic noise records, and discussed the mechanisms that cause the changes in the structure. However, quantitative discussions are limited, because there have been few other geophysical observations at the same regions.

In this study, we analyze ambient seismic noise records at Miyakejima volcano, Japan, where significant volcanic activity occurred in 2000. We investigate spatio-temporal changes in seismic velocity structure of Miyakejima volcano by analyzing continuous ambient seismic noises recorded by five NIED seismic stations from July 1999 to December 2002. We compare the estimated seismic velocity changes before and after the 2000 activity with the seismic velocity changes predicted from the results of previous studies, which are based on the observed geophysical data and field observation, to examine the mechanisms that introduce seismic velocity changes.

In Chapter 1, we introduce the theoretical background of seismic interferometry, previous studies on detecting temporal changes in the structure, purpose of the study, and structure of this thesis.

In Chapter 2, we introduce the procedures how we calculate CCFs, and measure travel time differences from the calculated CCFs to obtain seismic velocity changes between two stations. We calculate CCFs at frequency bands of 0.4 – 0.8 Hz and 0.8 – 1.6 Hz, and stack them for one day data (one-day CCF). The obtained CCFs show wave packets with large amplitudes, which are Rayleigh waves, propagating with a group velocity of about 1 km/s. We further stack the CCFs for about 2 to 10 months to obtain a reference CCF (RCCF) for each station pair. To improve the accuracy of measurements of travel time differences, we select good quality one-day CCFs that have a large cross-correlation coefficient and a small time delay with the RCCF. We measure lag times of the maximum amplitude of the wave packets, which corresponds to the travel times of Rayleigh waves between two stations, from one-day CCF and RCCF.

In Chapter 3, we show the results of the measurements of travel time differences from one-day CCFs and RCCF. We observe that at frequency band of 0.4 – 0.8 Hz, seismic paths located in the eastern and northern flank of the volcano indicate seismic velocity increases up to 1.9 ±0.1%. On the contrary, seismic paths that are located close to or crossing the collapsed caldera show seismic velocity decreases down to 2.2±1.3 %. At frequency band of 0.8 – 1.6 Hz, similar changes are observed: seismic velocity increases up to 2.8±0.1 % at seismic paths located in the volcanic flank, while seismic velocity decreases down to 0.3±0.0 % at seismic path close to the collapsed caldera. Statistical tests indicate that most of these changes are significant at the 99 % confidence level.

In Chapter 4, we examine several possible mechanisms to explain the observed seismic velocity increases and decreases at Miyakejima volcano. We investigate the observed volcano deformation at Miyakejima due to deflation volcanic pressure sources determined from GPS data [*Nishimura et al.*, 2002]. We calculate strain field by using the two deflation sources, and observe that the volcanic edifices at shallow part (< 1 km) are subject to compression, which may make cracks in the volcanic edifice close and cause seismic velocity increase. The seismic velocity increases in the volcanic flank are well matched with the predicted compression region. Stress sensitivities are estimated to be about 1.8×10^{-3} to 1.5×10^{-2} MPa^{-1} and 4.6×10^{-3} to 2.4×10^{-2} MPa^{-1} at frequency bands of 0.4 – 0.8 Hz and 0.8 – 1.6 Hz, respectively, which are within the range reported in previous studies [e.g., *Yamamura et al.*, 2003; *Nishimura et al.*, 2005]. We further investigate the volcano deformation obtained by InSAR data, which can detect ground motions around the caldera rim where GPS stations were not deployed. Measuring the deformation around the caldera for the period from June 2006 to June 2010 [*Ozawa*, *personal communication*, 2010], we estimate the strain changes to be about $\sim10^{-5}$ for the period from June 2000 to March 2002 (about two years). Using the stress sensitivities we obtained, we predict a seismic velocity decrease of 1.2 % after the 2000 activity around the caldera rim. The predicted seismic velocity decrease is fairly well matched with the observation. We also examine the effect of topographical changes caused by the caldera formation by simulating seismic wave propagations based on a three-dimensional finite difference method. The results show that a caldera having a diameter of 1.6 km and a depth of 500 m causes travel time delays at seismic paths crossing the caldera. The delays correspond to apparent seismic velocity decrease of a few percent compared to the flat structure. The seismic velocity decreases recognized in the simulations are consistent with our observations of seismic velocity decreases at seismic paths crossing the collapse caldera.

In Chapter 5, we discuss the observed travel time difference from one-day CCFs and RCCF just before and during the 2000 activity, the auto-correlation functions (ACFs), and problems that have not been solved in this study. We apply Student's t-test to the data of travel time differences before the 2000 activity. The results show that no significant change is recognized for the seismic velocity changes about one month before the eruption. During the 2000 activity, a gradual increase of seismic velocity seems to be observed for the seismic path in the northeastern flank during the 2000 activity, which shows similar trend with the deflations detected by GPS network. By comparing the ACFs before and after the 2000 activity, we observe that the ACFs obtained at most stations show phase advance of the phases at lag time around 2 s after the 2000 activity. This may indicate that seismic velocity increases occur in the structure below the seismic stations located on the flank. This is consistent with our interpretations that the two deflation volcanic pressure sources cause compression in the edifice and cause seismic velocity increase. We further find that a new phase appears at lag time about 2.5 s in the ACFs for most of the stations from May 2000, which is about two months before the 2000 activity. This may be a precursor of the 2000 activity because elastic properties in some regions in the volcanic edifices may change due to, for examples, gas intrusions, stress accumulation that should be investigated in the future.

In this study, we have observed and explained the occurrence of seismic velocity increase and decrease at the same period associated with a volcanic activity from correlation analyses of ambient seismic noise. It is shown that the structure changes due to volcanic activity can be monitored by analyzing the seismic wavefields recorded at stations deployed at a volcano. We conclude that correlation analyses using continuous ambient seismic noise records can give us good foundations and reliable methods for monitoring active volcanoes.