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Recharge Zone of the Ogiri Geothermal Field, Analyzed the Microearthquake Data

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ABSTRACT

The Ogiri geothermal field is located on the western slope of Kirishima volcano, one of the largest Quaternary volcanoes in Japan. Based on the hypocenter distribution of microearthquakes, geothermal fluid seemed to recharge the reservoir from the east side of the Ogiri field. The image, however, was not clear due to insufficient seismic data in the east side region. Microearthquake swarms have been observed around the Kirishima volcano since August 2024 by the three seismic observation networks, whose data are available through internet. Few events occurred in the Ogiri field, but ray paths of P and S waves from the swarms covered the east side region, thus velocity model was revised. The new velocity model, which showed vertical and lateral changes in the region, resulted in lower uncertainty for locations of the microearthquakes. The relocated hypocenters as well as the new velocity model imply that geothermal fluid source charging the area lie to the east of the Ogiri field.

1. INTRODUCTION

The Ogiri geothermal field is located on the western slope of Kirishima volcano, one of the largest Quaternary volcanoes in Japan (Figure 1). Figure 2 shows the geological structure of the Ogiri field along the NW-SE line. The geothermal field is situated in a volcano-tectonic depressions. A thick pile of Pleistocene volcanic rocks overlies the Pre-Neogene basement rock of the Shimanto Group (Goko, 2000). In the Ogiri geothermal field, the microearthquake activity was observed by a local seismic network before 2002 (Nishi et al., 2003). Based on the hypocentral distribution of microearthquakes, geothermal fluid was recharging the reservoir from the east side, where it was topographically low (Horikoshi et al., 2005). In this study we tried a few methods to infer the recharge zone of the Ogiri field using publicly available microearthquake data.

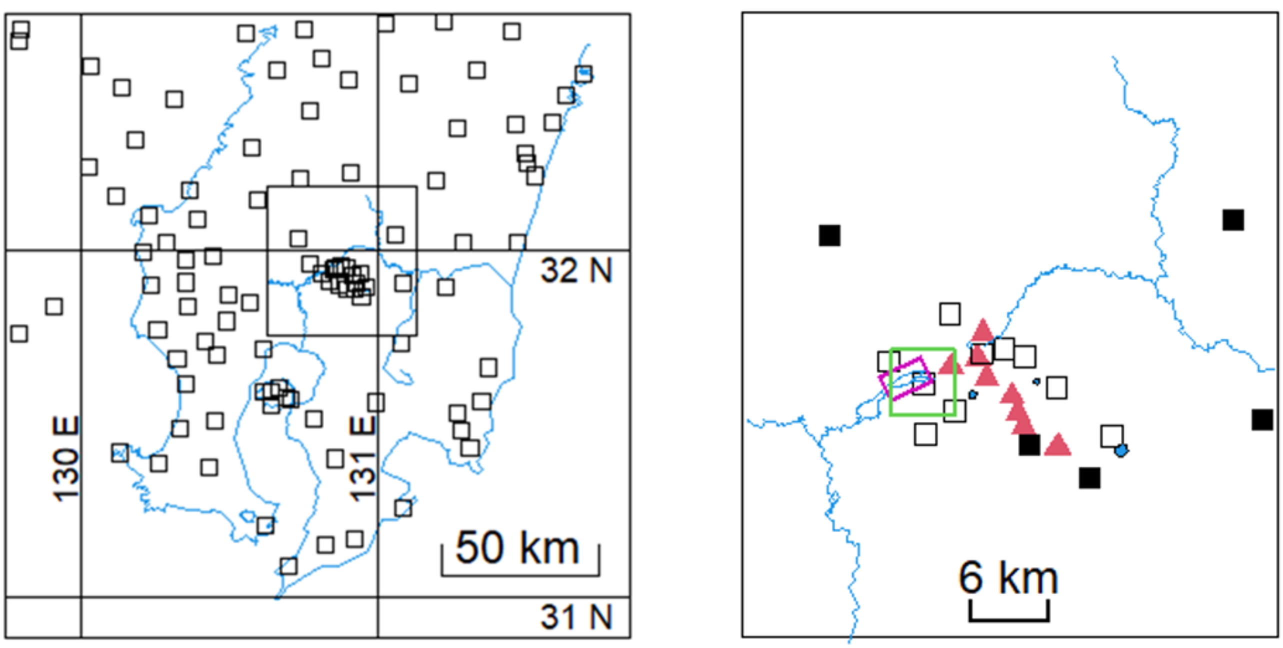

Figure 1: (left) The seismic stations in the southern part of the Kyusyu, Japan. The black rectangle indicates the area of the right map. (right) Seismic stations around the Kirishima volcanic complex, Red solid triangles denote active volcanos. Solid black squares are the seismic stations whose data are used for routinely processing by JMA. Open black squares are other seismic stations. The green rectangle indicates the area of Figure 2 left.

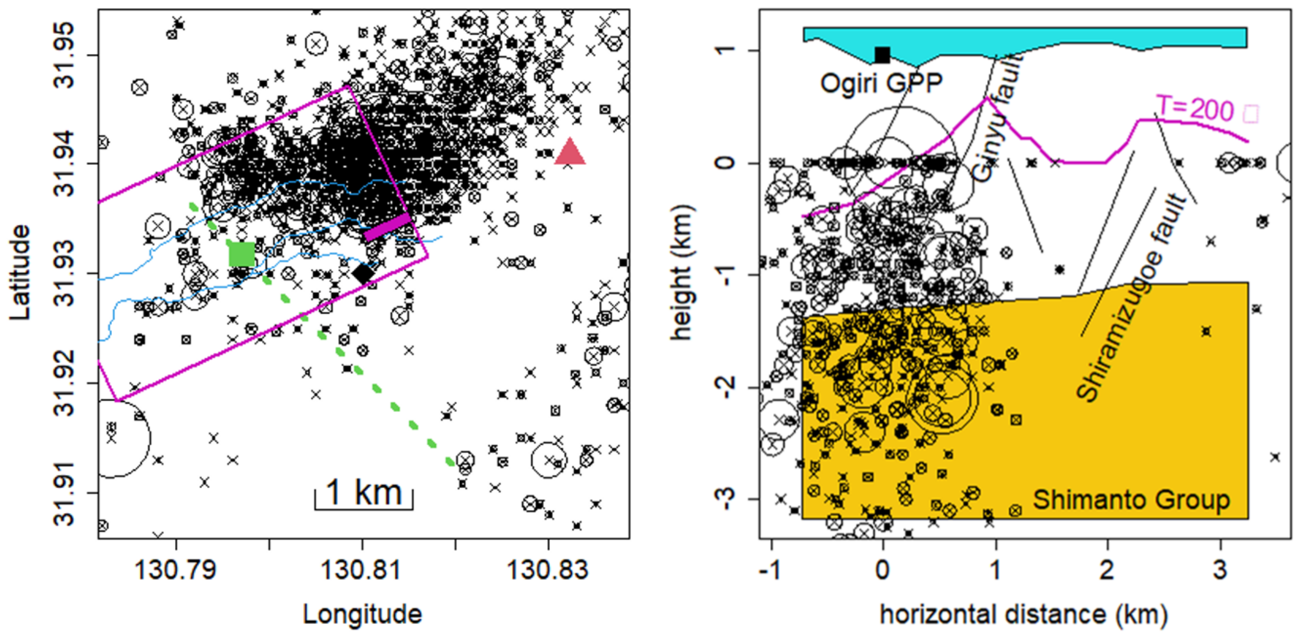

Figure 2: (left) Epicenter distribution of the earthquakes which have occurred since June 3, 2002. Each x shows the epicenter of a microearthquake. Each circle indicates the fault whose size inferred from the empirical relation between magnitude and the fault area scale (Lay and Wallace, 1995). Magenta colored rectangle indicates the outline of the reservoir simulation model (Sugihara and Ishido, 2008). The solid magenta colored rectangle shows the recharge zone of the model. The black diamond is the seismic station whose seismogram is used for the relocation. The green solid square shows the Ogiri GPP. The green dotted line is the cross-section line of the right figure. (right) Cross-section of NW-SE showing the geology and hypocenters.

2. DATA AND METHOD

2.1 Microearthquake data

More than two thousand permanent stations are included in seismic observation networks in Japan. Those observation stations belong to one of the two nation-wide networks, several subregional networks or several tens of local volcanic networks. The networks are basically independent of one another, but they carry out on-line exchange of observation data to some extent. Currently, several hundreds of hypocenters per day are located by the Japan Meteorological Agency (JMA). All digital data from these networks and earthquake catalogs are available through internet for all researchers. Sugihara (2023) studied the fracture structure of the Kakkonda geothermal field using the data. Hypocenters of earthquakes with magnitude greater than 1.0 are routinely determined to the third decimal place in degree both in latitude and in longitude by JMA. Hypocenter depths of some earthquakes are not determined but given to be assumed initial value (0 km in Figure 2 right) due to insufficient data set.

The resolution of the hypocentral location is too low to delineate fracture structure (Figure 2). Regarding to the stations shown in Figure 1 right, not all but the only five stations shown as solid square are used for the routine work. We, however, can relocate microearthquake hypocenters accurately using all the stations. At the Kirishima volcanic area accurate hypocenters were relocated (e.g. Tsukamoto et al., 2018). We relocate microearthquake hypocenters accurately enough to delineate fracture structure using other stations. First, however, the velocity structure will be introduced.

2.2 Velocity structure

Tomographic inversion of P-wave velocity and Q structures beneath the Kirishima volcanic complex was made based on finite difference calculation of complex travel-times (Tomatsu et al., 2001). The P-wave and S-wave seismic tomography for whole Japanese Islands are given by Matsubara et al. (2022). Microearthquake swarms have been observed around the Kirishima volcano since August 2024. Adding the swarm data we revised the P-wave and S-wave velocity structure at the Ogiri field. Few events occurred in the Ogiri field, but ray paths of P and S waves from the swarms covered the east side region, thus velocity model was revised. The new velocity model, which showed vertical and lateral changes in the region (Figure 3), resulted in lower uncertainty for locations of the microearthquakes.

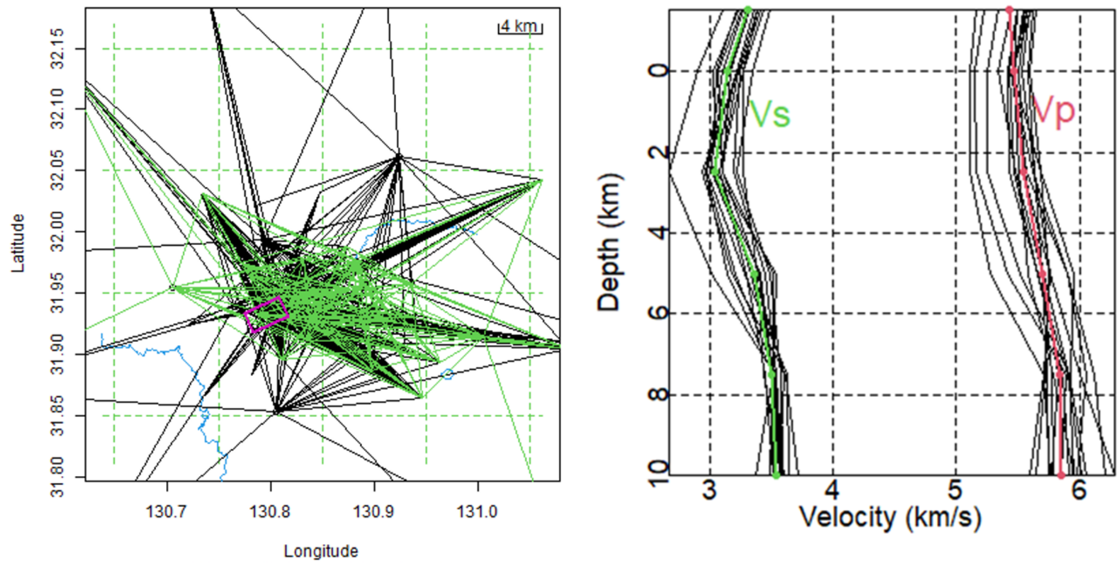

Figure 3: (left) Distribution of seismic ray paths. Green lines indicate the paths of the microearthquakes occurred in 2024. Green dotted lines show the 3d grid of the velocity structure model (4x3x3). The magenta-colored rectangle indicates the outline of the grid in which a reservoir simulation was made. (right) Vp and Vs profiles at each column of the 3d velocity model. Red line and green line indicate Vp and Vs profile of the column which contain the Ogiri field.

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2.3 Method

There are 15 seismic stations in and around the Kirishima volcanic complex (Fig 1 right). Each station provides 26-bit 3 component seismograms. Only one station is in the Ogiri geothermal area (Figure 2 left). The station belongs to the Kirishima volcano network operated by the National Research Institute for Earth Science and Disaster Prevention (NIED). The triaxial hodogram method makes it possible to determine source locations by a single station data (e.g. Moriya et al., 1994). Measuring the P-wave arrival direction and the P and S arrival times, then we can infer the origin time and the source location of the microearthquake (Figure 4). In the situation of the Ogiri area, two 3-component seismometers are installed at different depths; One is at the surface and another is at the depth of 200m. Therefore, we estimate the source parameters by the least square regression method. We can locate microearthquake hypocenters accurately enough to delineate fracture structure.

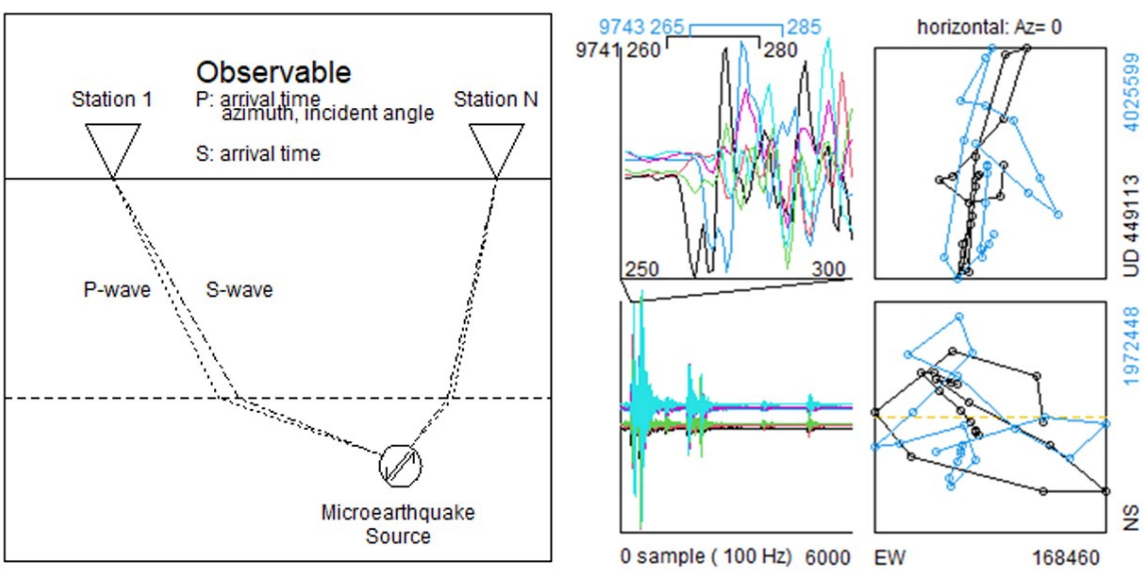


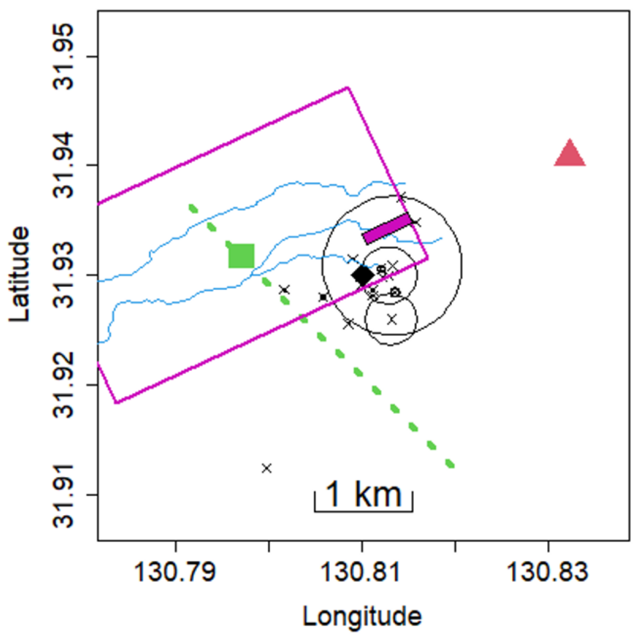
Figure 4: (left) Schematic diagram of the triaxial hodogram method. (right) An example of particle motion plot and waveforms. 3-component seismograms of two seismometers are plotted in each figure.

3. RESULTS AND DISCUSSION

Observed gravity changes and their spatial distributions at the Ogiri area are reproduced fairly well in the reservoir simulation, which incorporates fluid recharge from reservoir boundaries (Sugihara and Ishido, 2008). Numerical models of geothermal reservoirs are, however, never precise because of the problem of non-uniqueness. If only a few facts are known about the reservoir, many reservoir models might explain these known facts equally well but yield very different predictions of potential. As the amount of field data available increases, these uncertainties diminish.

Now we check the model with the microearthquake data. At first the microearthquakes which located near the inferred recharge zone were picked up from the catalogue of JMA. Two microearthquake swarms were selected: the 2014Sep09-10 swarm and the 2021Nov29 swarm. Figure 5 shows the relocated hypocenter distribution. The magnitude range of the 17 events is -4.9 to +3.3. Each circle indicates the fault whose size inferred from the empirical relation between magnitude and the fault area scale (Lay and Wallace, 1995). The sources distribute in the extension of the Shiramizugoe fault. Goko (2000) discussed that the subsurface temperature clearly indicate that the hottest zone is in the southeast part of the Shiramizugoe area, whereas the deep temperature in the Ginyu fault in an almost constant 230-232 degrees Celsius. Itoi et al. (2010) proposed another model which incorporates two recharge zone, not only beneath the Ginyu fault but also beneath the Shiramizugoe fault.

To tell the truth relocated hypocenters seem deeper than expected values. Another potential method uses empirical Green's function (Lay and Wallace, 1995). Sugihara et al. (1998) applied the method to the M0.6 event of the swarm which occurred in the Kakkonda field. Larger events can be deconvolved with the smaller event whose waveform is similar to the larger. Unfortunately, the surface seismometer often shows strange seismogram (Figure 6 right). It is possible to process the P waves and the former part of the S wave, however, difficult for the later part of S waves. However, we might apply the empirical Green's function method to the seismograms of the other seismic stations shown in Figure 1 right for the larger events.



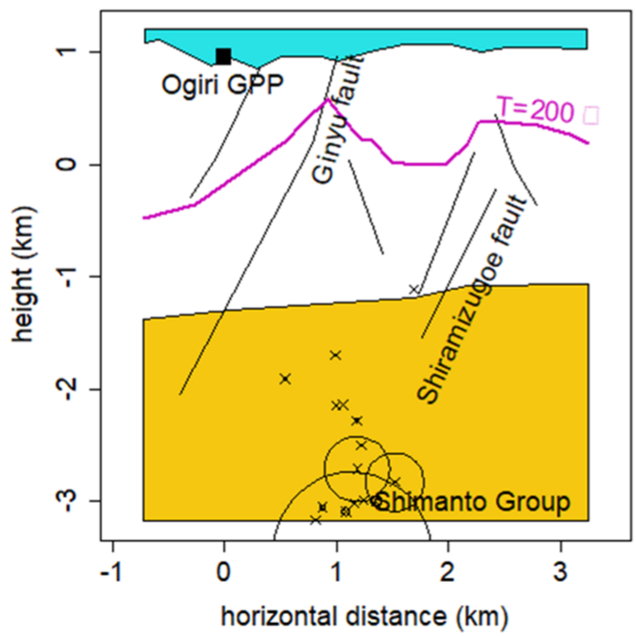


Figure 5: (left) Epicenter map of the relocated events. (right) Cross section of the relocated hypocenters.

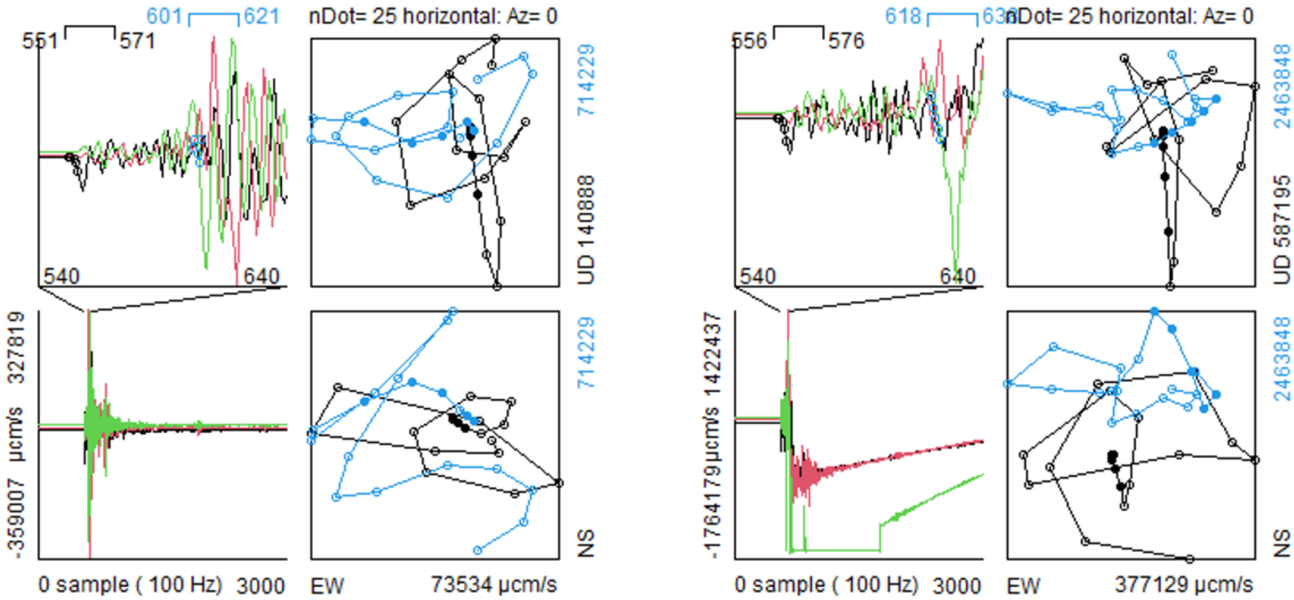


Figure 6: (left) Waveforms and particle motion plots of the M2.3 event at the 200m depth seismometer. (right) Waveforms and particle motion plots of the M2.3 event at the surface seismometer.

4. CONCLUSIONS

The new velocity model, which showed vertical and lateral changes in the region, resulted in lower uncertainty for locations of the microearthquakes. The relocated hypocenters, which distribute in the extension of the Shiramizugoe fault imply that geothermal fluid source charging the area lie to the east of the Ogiri field..

ACKNOWLEDGMENT

We used the JMA Unified Earthquake Catalog available at http://www.hinet.bosai.go.jp/?LANG=en (last access on 31 January 2025), and seismograms from Hi-net by NIED available at http://www.hinet.bosai.go.jp/?LANG=en (last access on 31 January 2025). Part of this work was done using R (https://www.rproject.org/, last access on 31 March 2022).

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