A possible geothermal source at around 4 km depth estimated by the seismic observation in Ibusuki geothermal area

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Introduction: The Medipolis is located in Ibusuki geothermal area, Japan. There are three geothermal boreholes in the field. The geothermal characteristics of the boreholes were studied by NEDO (2008-2010). The IK-1 borehole is commercially used for the electric power generation. The IK-4 is used for observation. The depths of three boreholes are around 1,500 m. The temperature of the boreholes was approximately 250˚C around the 900 m-depth and the production depth for the steam is around 1,200 m. The temperature model by NEDO (2008-2010) proposes a hot reservoir around the NE direction of IK-1 and IK-4 boreholes although it is not confirmed by real drillings.

To know the precise geothermal characteristics of this field, we conducted a seismic observation by a fiber-optic distributed acoustic sensor (DAS) and ground surface seismometers in November 2018.

Field observation: We installed 20 sets of 3C seismometers along the 2 km-long EW line and deployed a fiber-optic cable for the DAS and distributed temperature (DTS) measurements down to 977 m depth. We measured the temperature and seismic signals using the same fiber-optic cable for DAS and DTS. The total DAS observation period is 4.5 days. The interval of ground surface seismometers is approximately 100 m. We observed seven natural earthquakes by DAS and surface seismometers. The largest observed earthquake is M5.2 which occurred west of Tanegashima with 123 km focal depth. The temperature of the IK-4 was measured as 264˚C by DTS at the 914 m depth.

Observed waveforms: The first arrivals of the M5.2 earthquake measured by DAS are traveling from the 977 m depth to the wellhead with the velocity of 4 km/s~3 km/s. There are no evident reflections from the deeper zone than 1,000 m. In addition, any evident attenuation of seismic waves is not identified in the high temperature zone around the 914 m-depth.

Surface seismometers show unusual waveform characteristics. Although the amplitudes of the P-wave first arrivals of M5.2 earthquake on vertical seismometers are small, the EW and the NS seismometers show small P first arrivals and succeeding large amplitude phase with a second delay. Because this phase is recognized only on EW and NS components, this phase is possibly P-to-S converted phase. The aftershocks of the M5.2 Tanegashima also showed similar waveforms as those of the M5.2 event. Other earthquakes also showed similar characteristics on the horizontal components.

Interpretation of P-to-S converted phase: We examined the cause of estimated P-to-S conversion. The delay time from the P first arrival to the P-to-S converted phase is estimated as ~0.8 s. We assumed a low Vp/Vs zone at the 4 km-depth with 500 m thick and calculated synthetic waveforms generated by deep seismic sources corresponding to natural earthquakes. The seismic velocity profile estimated by the DAS observation is used in the calculation. The models can explain the observed characteristics such as small P amplitude and large P-to-S converted phase on horizontal components, when incident seismic wave is slightly oblique to the low Vp/Vs zone. We also estimated borehole waveforms and ground surface waveforms.

Discussion and conclusions: According to the simulation, there is a chance to prove the presence of the low Vs zone at the 4 km-depth. Because the temperature around ~900 m is 264˚C, the low Vs zone might be useful for a future geothermal energy source. For either case, more detailed study of the proposed low Vs zone is required.

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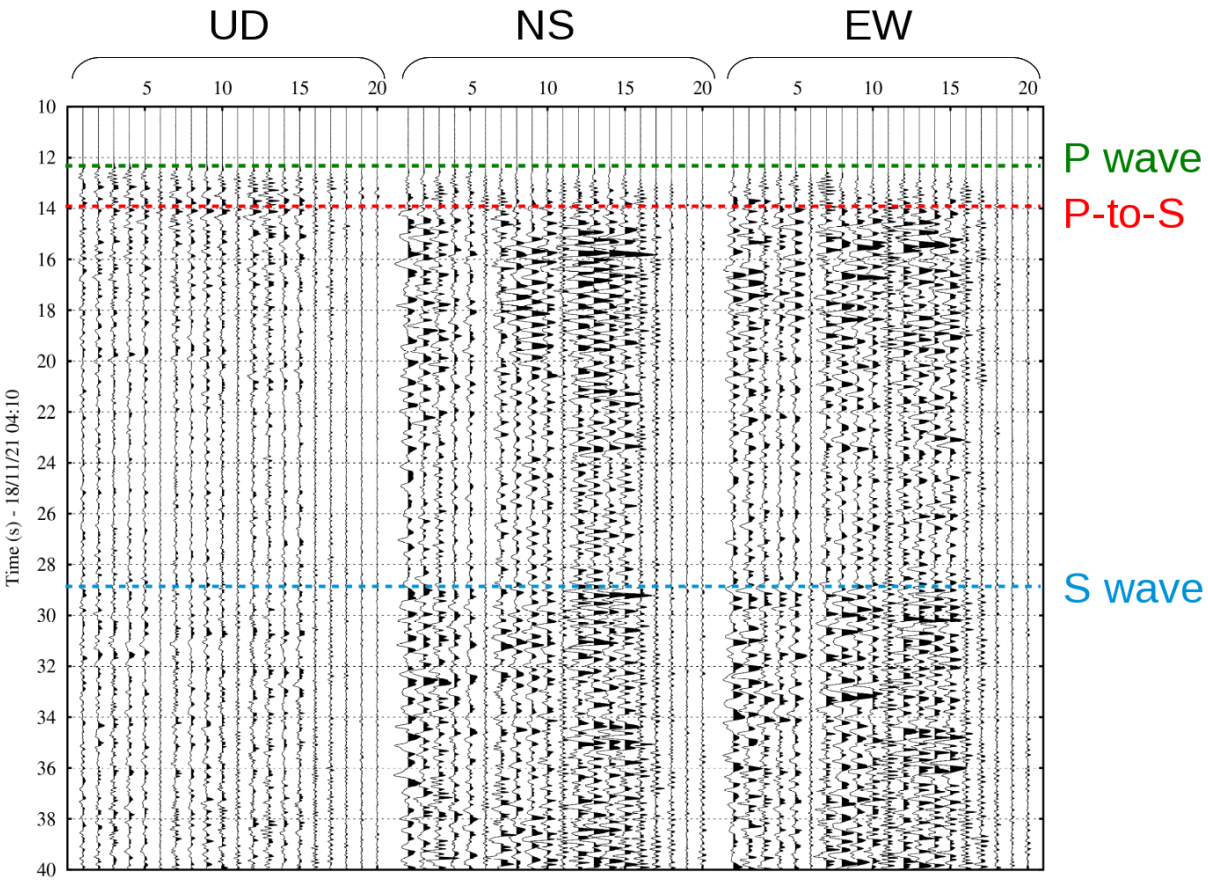
Keywords: Geothermal field, Seismic wave, Vp/Vs, P-to-S conversion, Geothermal reservoir, Passive seismic source



The seismic records of M5.2 Tanegashima earthquake obtained by the surface seismometers. The labels on the horizonal axis are the station numbers and the station interval is approximately 100 m. The vertical axis is time in seconds. The horizontal dotted lines denote arrival times for P, P-to-S, S waves, respectively.

