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GEOLOGICAL STRUCTURE AROUND THE OGACHI HOT DRY ROCK TEST SITE USING SEISMIC REFLECTION AND CSAMT SURVEYS

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ABSTRACT

We have conducted a basic experiment to utilize Hot Dry Rock energy as an electric power at the Ogachi test site in northeast part of Japan. It was confirmed by 1,100 m drilling data that the depth to the top of pre-Tertiary granitic rocks at the site was about 300 m and the temperature was measured 230℃ at 1,000 m depth. A seismic reflection and Controlled Source Audio-frequency Magneto-telluric (CSAMT) methods were carried out in order to locate a fault exactly and to estimate vertical displacement of the fault in granitic rocks. The fault was inferred to position at the west of the site by the previous gravity surveys. A CSAMT method was performed with 60 measurement points scattered in an area of 2 km x 2 km and the seismic reflection method was carried out along the E-W line with a length of 3.5 km using two vibro-seis sources. The resistivity profiles by a 2-D inversion of the CSAMT method indicates that the low resistivity zone (10-50Ωm) corresponds to Neogene volcanic rocks and a high resistivity zone (100-1,000Ωm) to pre-Tertiary granitic rocks. The low resistivity zone is found about 500 m southwest of the Ogachi site and the boundary between the low and high resistivity zone is likely to oriented in NW-SE. The geological boundary between the volcanic rocks and the granitic rocks was recognized as reflectors clearly in the seismic reflection profiles. The elevation of a reflector was about GL 300 m near the Ogachi site, however, at the west of the site it was about GL -300 m. Therefore, we estimated the fault position at about 500 m west of the site and the vertical displacement of the fault of 600 m in granitic rocks.

1. INTRODUCTION

The Central Research Institute of Electric Power Industry (CRIEPI) has been conducting a hot dry rock (HDR) test at the Ogachi site in northeast part of Japan since 1989. An injection well (OGC-1) and a production well (OGC-2) were drilled to depth of 1,020 m and 1,100 m, respectively and a temperature was 230℃ at 1,000 m depth. Two artificial reservoirs were created at about 720 m and 1,000 m in depth, respectively and circulation tests have been conducted. Furthermore, another new production well will be drilled in 1999 to improve the water recovery. A fault is inferred to be located west of the site due to previous surveys (Takeno, 1988). If this fault was positioned near the site, the injected water flow into the fault and a water loss occurs significantly. Therefore, it is very important to estimate the fault position more accurately. This paper deals with the recent results of geophysical exploration in order to evaluate the depth distribution of the top of pre-Tertiary granitic rocks around the test site.

2. STUDY AREA

The Ogachi HDR test site is situated inside a Neogene caldera (Fig. 1). The size of caldera is about 30 km long and 20 km wide, and formed during 6-2 Ma due to an intensive felsic volcanic activity (Ito, 1996). The bedrock of the site consists of pre-Tertiary granitic rocks and mylonite, which underlies Neogene and Quaternary felsic volcanic rocks (Fig. 2). Almost vertical block movement occurred before and during the caldera formation. The Ogachi site is located in an area where the top of the bedrock is higher than its surroundings. It was confirmed by the drilling data (OGC-1, 2) that the Neogene and Quaternary felsic volcanic rocks were about 300 m thick and the elevation of the top levels of the bedrock is nearly constant around the Ogachi site. However, the vertical displacement of the block movement between the Ogachi site and the Akinomiya site at 4 km southwest is estimated more than 1000 m. From core survey of OGC-2, the number of fractures per 1 m ranges from 10 to 20 and overall natural fractures are intensely developed in the bedrock. The parts of the core exist as aggregates of rubble and clayey, however obvious crush zone is not found (Kondo, 1994).

3. METHODS

The seismic reflection method was conducted along the E-W survey line with a length of 3.5 km using two vibro-seis sources (Fig. 3). A part of the line was coincided with a B-line of the CSAMT method. The CDP grouping process was performed to arrange CDP points along a straight line because the shot and receiver points were positioned along the mountainous curved road. The final migrated depth profile was analyzed by the seismic data processing.

Two geophysical explorations, the CSAMT and the seismic reflection methods, were performed to estimate the depth of bedrock around the site and the inferred fault position. The CSAMT method was conducted with 60 points distributed in an area of 2 km x 2 km (Fig. 4). Electromagnetic signals generated by a current dipole source was grounded along the road trending E-W at about 7 km south from the site and the frequency of the signals were ranged from 2.1 Hz to 5120 Hz. An E-W electric field and a N-S magnetic field were measured at each point using the complex phase detector system (Mogi et al., 1990).

Resistivity profiles were analyzed along three E-W lines (A, B, C) and two N-S lines (D, E) using a 2-D inversion technique based on statistical criterion ABIC (Uchida, 1993).

4. RESULTS

We note a 2D inversion resistivity profile along the B-line including the Ogachi site (Fig. 5). It indicates that a low resistivity zone (10-50 Ω m) covers a high resistivity zone (100 - 1000 Ω m) at a depth of 400 m near the site, while the top of this high resistivity zone becomes deeper toward west of the site. Near the surface another high resistivity zone with about 100 m thick covers the low resistivity zone. Resistivity level slices based on five 2-D inversion profiles were represented at different ground levels in Fig. 6. From both GL 200 m and 0 m slices, a low resistivity zone (10 - 50 Ω m) is found about 500 m southwest of the Ogachi site. Furthermore, the boundary between the low and high resistivity zone is likely to be oriented in NW-SE.

The migrated depth section by the seismic reflection methods does not represent the reflectors obviously, however, two main reflectors (A, B) can be found. The reflector "A" exists at about 1000 m west of the Ogachi site at about GL -300 m, while the reflector "B" exists near the Ogachi site at about GL 300 m (Fig. 7). The vertical displacement between reflector "A" and "B" can be estimated about 600 m. These reflectors are inferred to correspond to the resistivity boundary in the B-line of the CSAMT method.

5. DISCUSSION

The results of electric logging in OGC-1 show that resistivity of the bedrock is ranged from 100 to 1,000 Ω m and that of volcanic rocks is from 10 to 50 Ω m. The geological interpretation due to the CSAMT and the seismic reflection methods is summarized in Fig. 8. In the CSAMT resistivity profiles (Fig. 5), the low resistivity zone (10 - 100 Ω m) corresponds to the Neogene felsic volcanic rocks and the high resistivity zone (100 - 1,000 Ω m) corresponds to pre-Tertiary granitic rocks. Another high resistivity zone up to about 100 m deep corresponds to the Quaternary volcanic rocks. While, the seismic reflectors "A, B" (Fig. 7) are inferred to coincident with a geological boundary between the granitic rocks and the volcanic rocks. The elevation of the top levels of the bedrock is nearly constant (about GL 300 m) between the Ogachi site and 500 m west of the site (B4 in Fig. 5 or CDP No. 350 in Fig. 7). It becomes deeper gradually toward the west of the point "B4" and GL -300 m at the point of CDP No. 150 in Fig. 7. The vertical displacement of the bedrock can be estimated about 600 m between these two points.

To estimate the elevation of bedrock (pre-Tertiary granitic rocks) based on the CSAMT resistivity profiles, we consider the resistivity of 100 Ω m was a boundary between the granitic rocks and the volcanic rocks (Fig. 8). The resulting elevation map represents both the top levels of the granitic rocks and the topography shown by wire mesh around the Ogachi site (Fig. 9). We can assume that a fault is located about 500 m west of the Ogachi site and oriented in NW-SE with steep dip. While, the elevation of about 500 m southwest of the Ogachi site is about 250 m higher than that of the site.

6. CONCLUSIONS

1) The elevation map of the top of pre-Tertiary granitic rocks (hot dry rock) around the Ogachi site is estimated using resistivity profiles of the CSAMT and electric logging, and seismic reflection profiles.
2) A fault can be located about 500 m west of the Ogachi site with about 600 m vertical displacement and oriented in NW-SE with steep dip.

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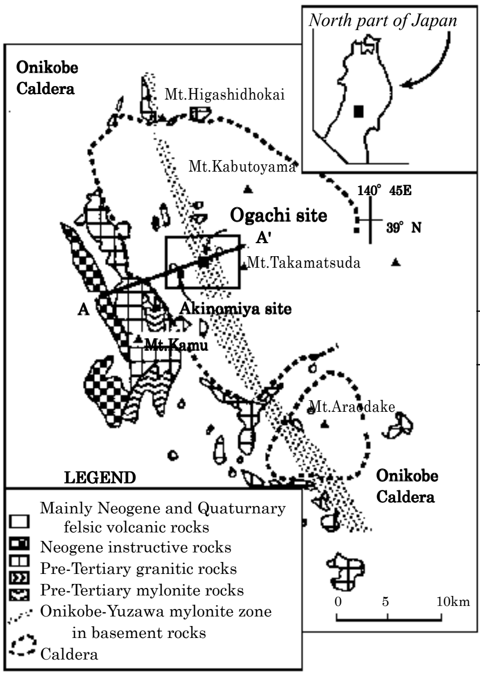

Fig.1 Geology around the Ogachi HDR site. Modified from Sasada (1984) with the caldera positions from Takeno (1988).

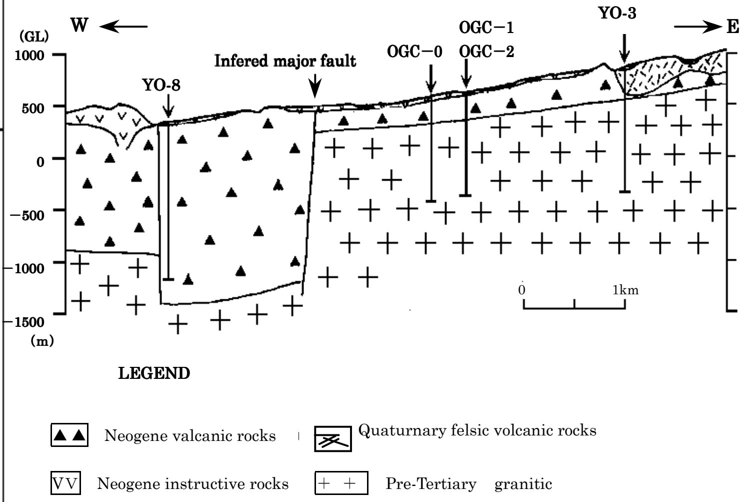

Fig.2 Cross section of A－A' in Fig.1

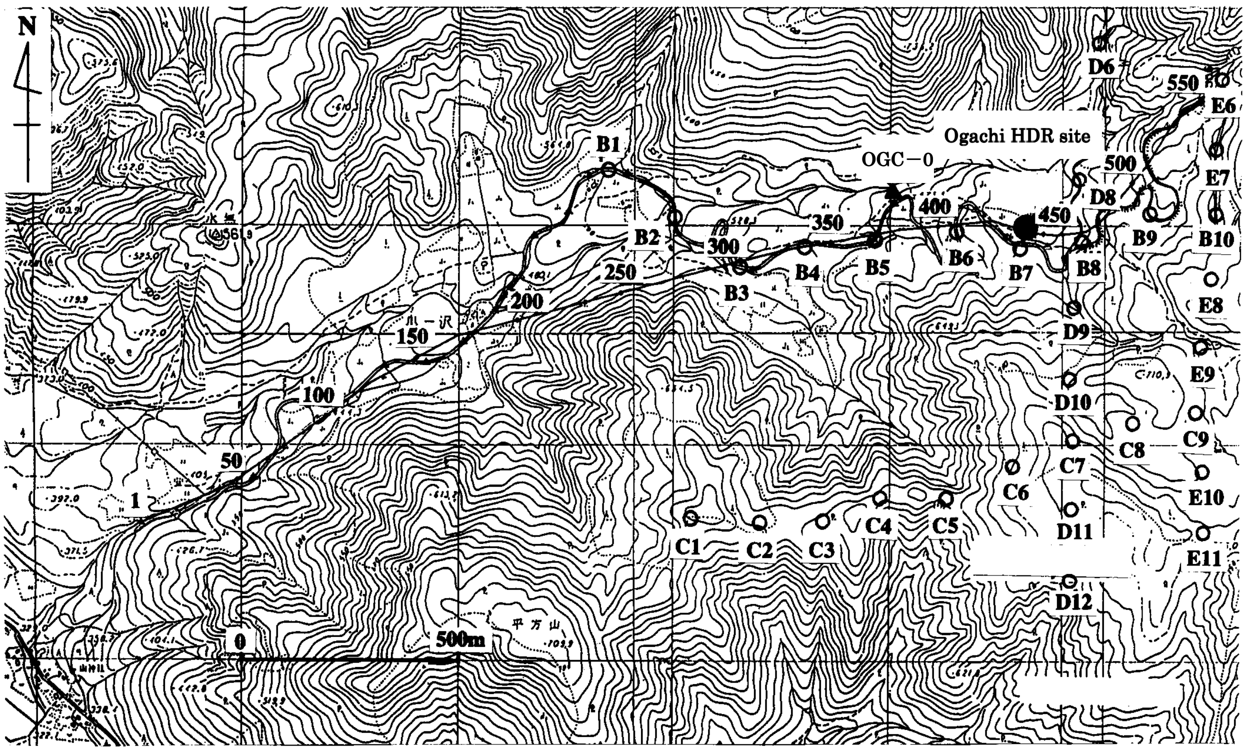

Fig.3 Location of Seismic reflection survey line. "B1～B10","C1～C9","D6～D12",”E6～E11" show a part of CSAMT points.

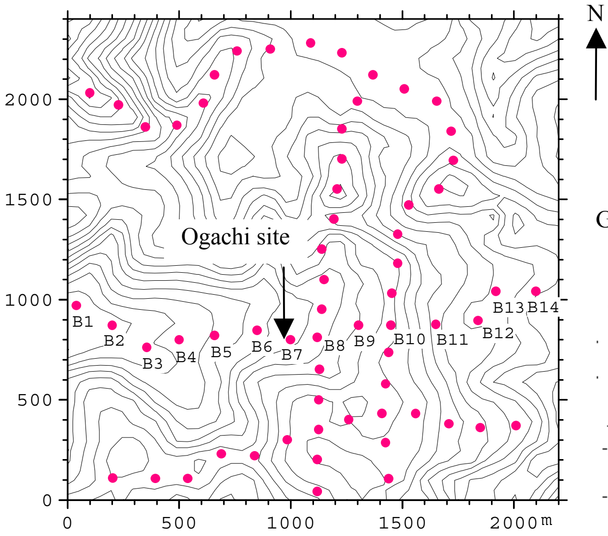

Fig.4 Location map of CSAMT survey points

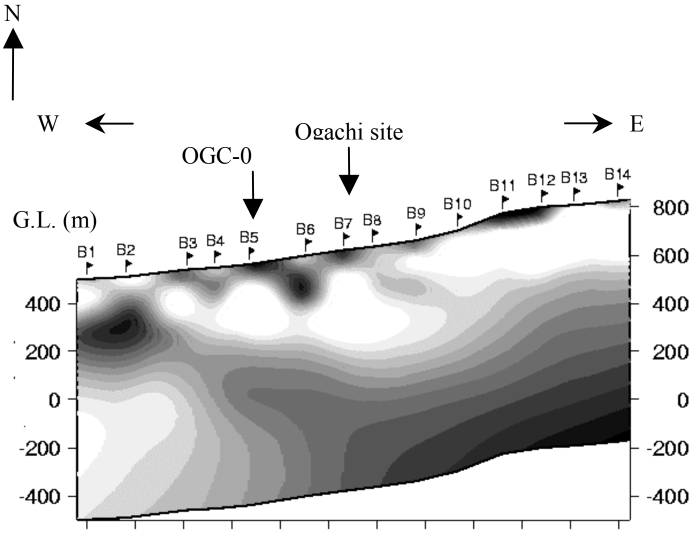

Fig.5 Resistivity profile along B-line in CSAMT method.

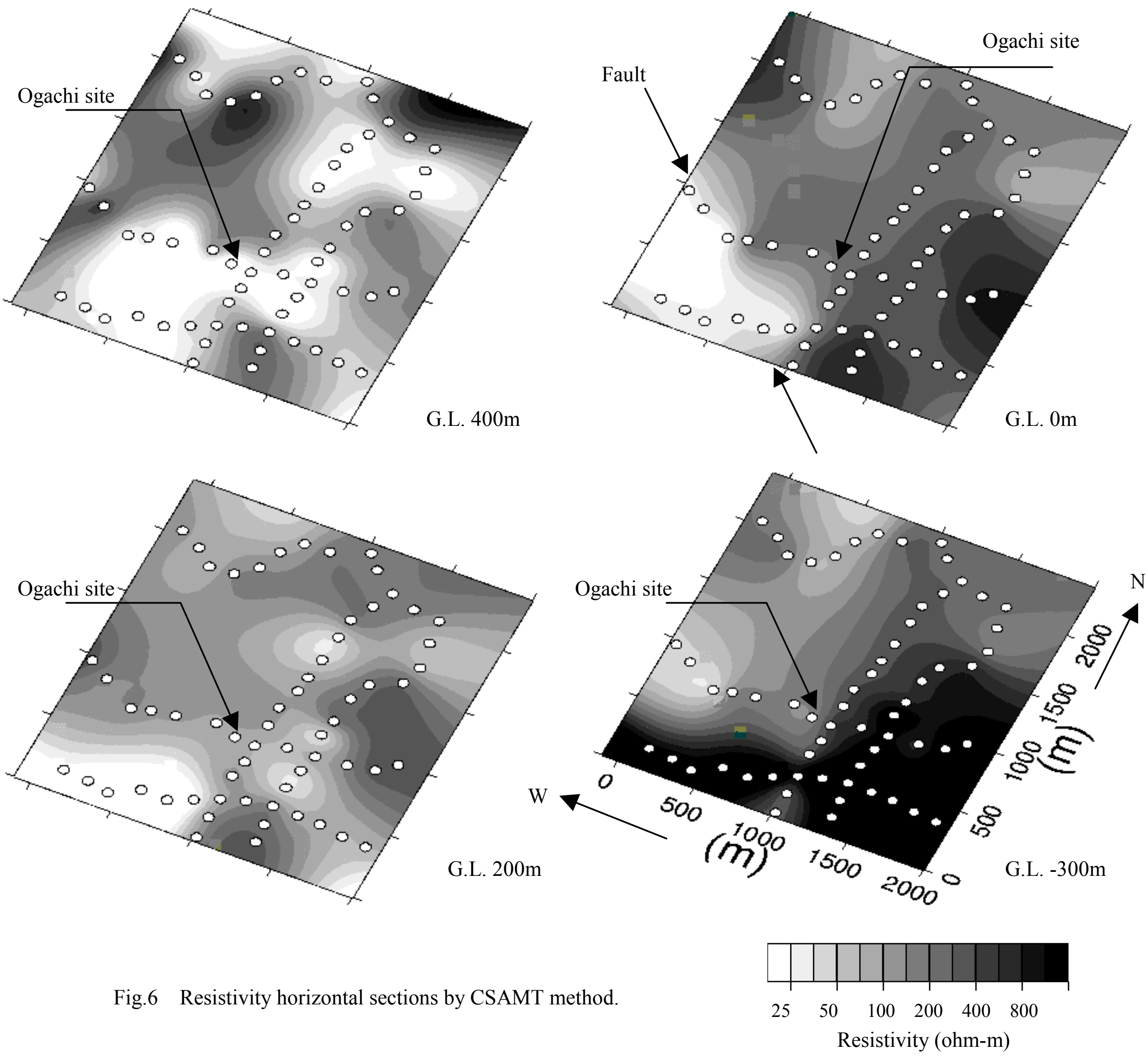

Fig.6 Resistivity horizontal sections by CSAMT method.

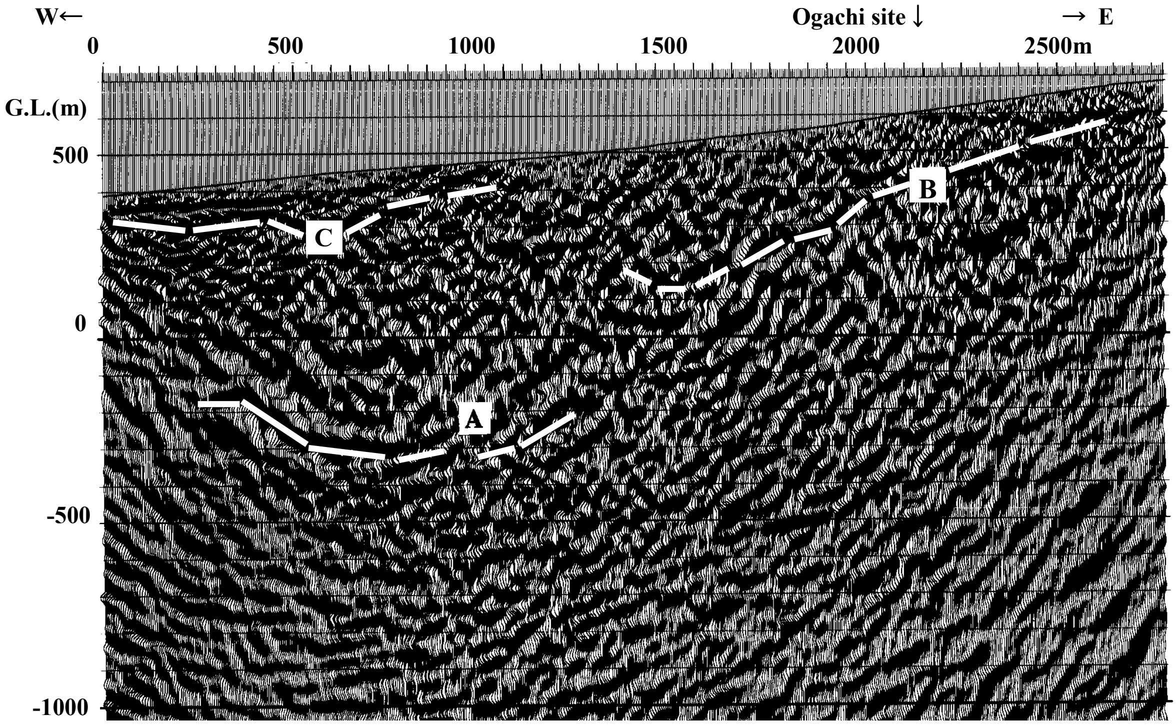

Fig.7 Seismic reflection profile after migration analysis.

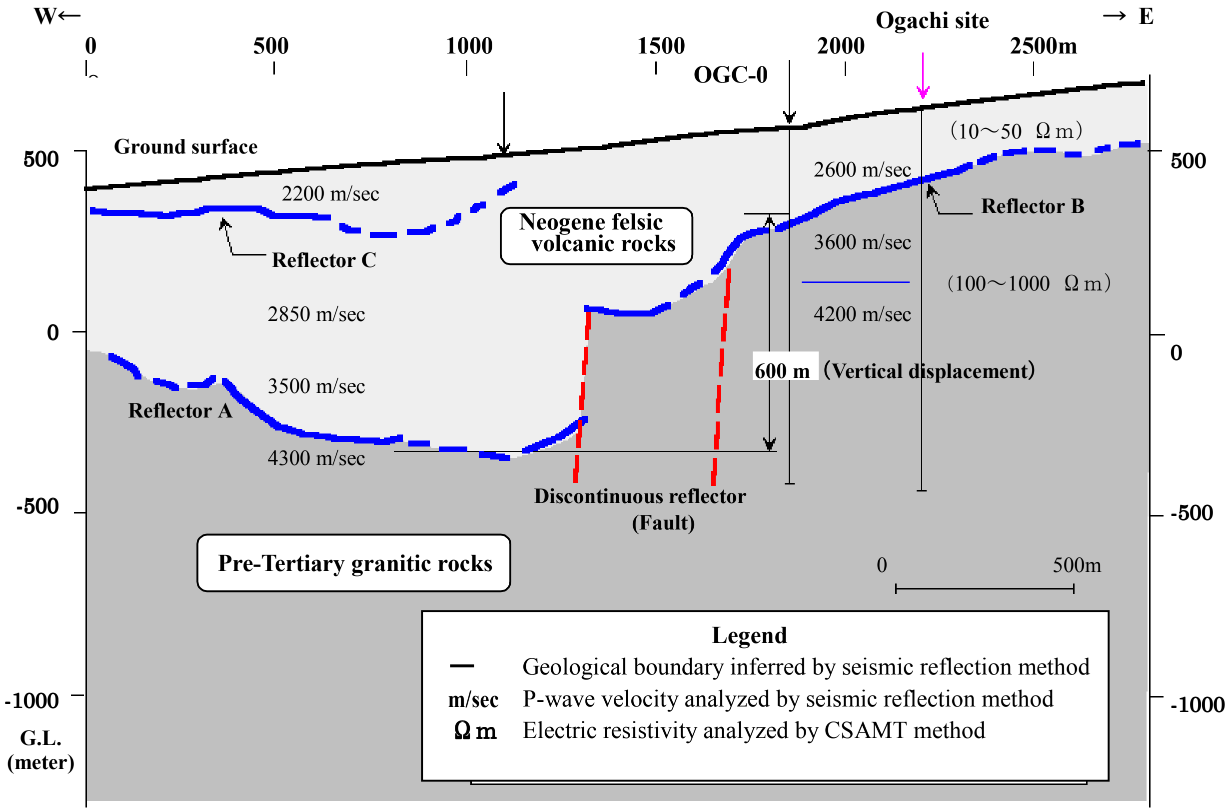

Fig. 8 Geological structure inferred by seismic reflection method.

Vertical displacement between the Ogachi site and a point "CDP No.150" is about 600 m. A discontinuous position between reflector "A" and "B" are inferred to the faults.

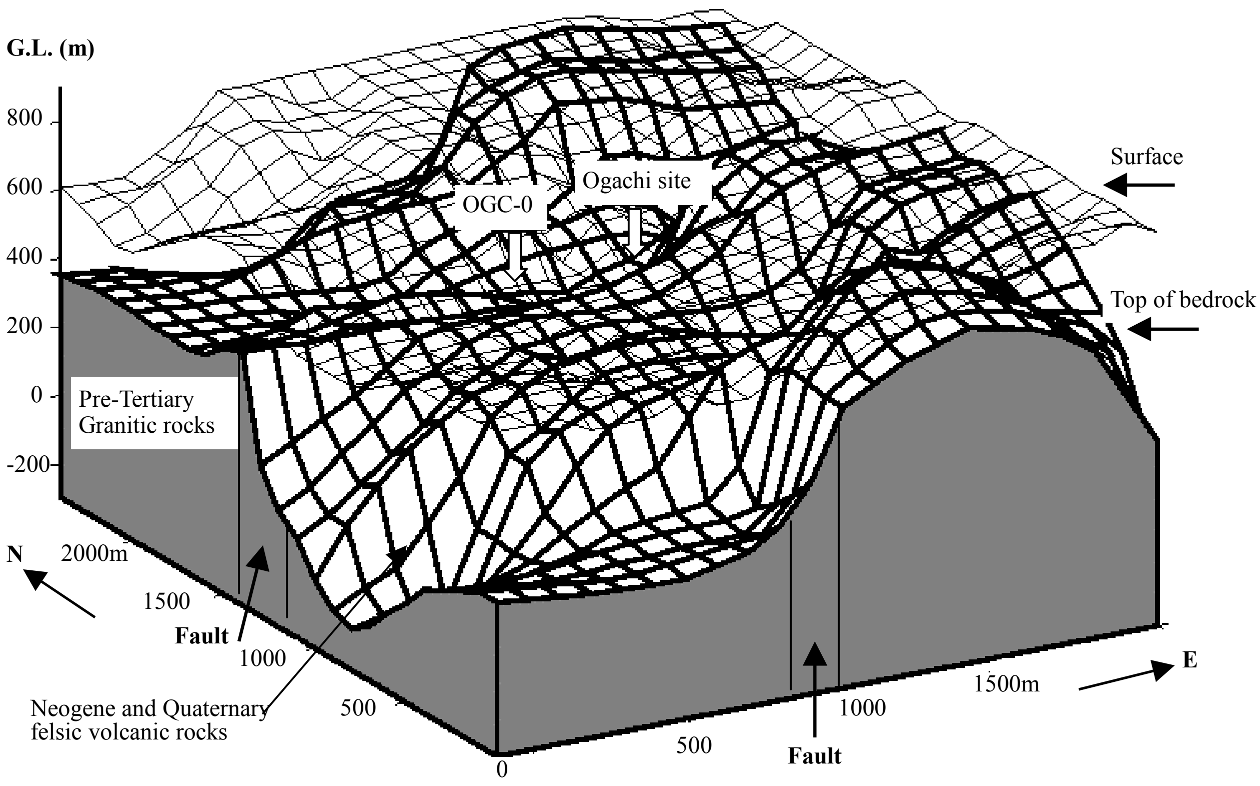

Fig.9 Geological structure interpreted by CSAMT and seismic reflection methods around Ogachi site.