THE CORRELATION BETWEEN SEISMIC AND LOGGING DATA AND ITS GEOLOGICAL INTERPRETATION IN THE AKINOMIYA/WASABIZAWA GEOTHERMAL AREA

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ABSTRACT

Seismic surveys have not generally been applied for geothermal explorations due to mainly their complex subsurface geology. In the Akinomiya geothermal area in the Akita prefecture in northern Japan, the high resolution seismic survey using vibroseis as seimic source was acquired and processed in 2000, and more than 20 geothermal exploration and appraisal wells were drilled in the past 30 years in which the resistivity and pressure-temperature logs were acquired. The seismic interpretation and analysis of logging data was made in 2010. The geological interpretation with seismic-log correlation leads us to understand satisfactorily the regional subsurface geology, especially the assessment of characteristic and type of fractures; ones associated with high-angle dip fault and others of low-angle.

The series of left-lateral strike-slip faults with their dip of about 80 degrees, which originate from deep situated consolidated magma as deep as -3,000 masl to or near the surface, are interpreted as formed in the area under the active compressions of the Pacific Plate. Each strike-slip fault is inducing to build up corresponding flower structures in either transpression domain or transtention domain in its shallow part, which formulate a zone of fractures. Six fracture zones are recognized in the seismic section with approximately 500 m apart. Each fracture, generally thin with its width of 25 m at most, can be picked in the seismic section by its anomalous weaker seismic reflections than those of adjacent rocks, and is correlated with the zones of porosity build-up by well log analysis. These weak seismic reflectivities are interpreted as associated with either thermally altered rocks by steam and/or hot water, or intrusive rocks, or both. Upper parts of these fractures seem often to be of closed nature, possibly due to swelling of clay minerals formed through thermal alteration.

The continuous strong seismic reflections can be picked between 0 masl and -500 masl. Its dip is estimated as about 20 degrees and its strike of NW-SE orientation, which coincides with the results of FMI (Formation MicroImager). The similar feature of the seismic reflections can be also recognized in deeper part, of which dip is similar but strike is of different orientation. These low-angle dip faults are interpreted as surface planes of land slide possibly associated with the caldera formation process, which occurred several times in the Tertiary period.

Keywords: reflection seismic survey, strike-slip fault, fracture, flower structure

1. INTRODUCTION

In the Akinomiya and Wasabizawa geothermal area in the southern part of Akita prefecture, northern Japan, New Energy Development Organization (NEDO) has been conducting the geothermal development promotion surveys in order to promote for geothermal energy development. Series of geological studies were carried out, including drilling of more than 20 geothermal exploration and appraisal wells. In 2000, NEDO conducted the seismic survey. Prior to the NEDO survey, Central Research Institute of Electricity and Power Industry (CRIEPI) conducted the seismic survey in 1998 in order to study the realization of technologies relating to the extraction of energy from hot rocks. The acquisition and processing of both surveys were carried out by JGI, Inc. (JGI).

Electric Power Development Co., Ltd. (Jpower) is studying the commercialization of geothermal energy potentials in the Akinomiya/Wasabizawa geothermal area jointly with Mitsubishi Materials Corporation (MMC) and Mitsubishi Gas Chemical Company, Inc. (MGC). This study was carried out for assessment of principal seismic markers, seismic reflection pattern and characteristics of fractures etc., creating geological model, seismic correlation with log analysis of adjacent wells and then better understanding of subsurface geology of the area.

2. ACQUISITION AND PROCESSING OF SEISMIC DATA

The location of the study area is shown in Fig. 1. The study area is divided into the Akinomiya area (11.25 km^2) in the south-west and the Wasabizawa area (7.5 km^2) in the north-east. The line of the seismic survey of 4 km was laid along the prefecture road No. 310 and approximate direction is east-west. The line is inclining to the west with the average slope of 8.1 degree and the difference of height of 406m. The geophone arrays (9 per receiver point) were laid out along the road in every 10m (400 receiver points) for 4km. 179 vibration points were also laid out along the road, at each of which 7 sweeps of 25 seconds were made. The interval of vibration point was 20m. The CDP interval was therefore 5m.

Both NEDO data and CRIEPI data were combined and processed through the conventional processing flow by JGI. The stacked section as well as both time and depth migrated sections were obtained. The interpretation was made on the depth migrated section.

3. GEOLOGY

The study area is located in the high backbone mountain in Tohoku (Northeast) district, and fractures of NW-SE orientation are developed under active compression of the Pacific Plate.

The lithology is, from bottom to top, Pre-tertiary basement rocks, pyroclastic rocks of Miocene and Pleiocene, and Quaternary's volcanic rocks. There exist intrusive rocks of Tertiary.

The basement rocks consist of granite and granodiorite, while schist covers on top of them in Wasabizawa area. The pyroclastic rocks in Miocene consist of shale, argillaceous sandstone, tuff, tuff breccia and dasitic-andesitic lava under marine environment, while in Pleiocene they consist of tuff, tuff-breccia with intercalation of siltstone, conglomerate, mudstone and argillaceous sandstone under terrestrial environment. Quaternary's volcanic rocks consist of dacitic welded tuff and andesitic to dacitic lava. The former is not found in Akinomiya area. Intrusive rocks are rhyolite, andesite and dacite.

The basement high is extended from the north to the center of the study area. Two depressions developed, one to the east in Miocene and another to the west in Pleiocene.

4. INTERPRETATION OF SEISMIC DATA

As shown in Fig. 2, several continuous seismic horizons can be picked from surface to -1000 masl. Below -1000 masl, the reflections become weak and homogeneous except those found -2500 ~ -3500 masl in the eastern part. Six horizons are extracted; from top to bottom, 1) Quaternary-Tertiary boundary, 2) Top of Pre-Tertiary basement rocks, 3) Base of chaotic event, 4) Base of deeper chaotic event, 5) Top and 6) Base of deep reflections (possibly consolidated magma).

The fracture can be recognized by its weaker reflections than those of adjacent rocks in the study area. This may be due to the fact that steam and/or hot water passes through upon the formation of fracture and then hydro-thermal alteration occurs, making rocks uniform. The width of fracture seems to be thin, such as 5 CDP (25m) and generally closed in the upper part possibly due to swelling of clay minerals formed through hydro-thermal alteration. The principal fault cutting from deep reflections (interpreted as consolidated magma) to/near the surface is recognized. This principal fault is associated with conjugate faults, forming a zone of fractures as flower structures. Six zones of fractures are interpreted. Each principal fault is named as, from west to east, fault-a to fault-f. The orientation of principal fault is assumed to be NW-SE and its dip of 80 degree (Fig. 2 and Fig. 3).

The formation of flower structures is explained well by the model shown in Fig. 4. In the study area, left-lateral strike-slip fault is dominant under the compression of the Pacific Plate from the east.

5. LOG ANALYSIS

In the study area, well logs are restricted to those of resistivity, SP, PT etc. Therefore, log analysis of resistivity logs is applied for estimation of porosity and correlation with interpreted seismic section. Four wells, namely YO-4, AY-8, WZ-7 and WZ-9 are selected for analysis because of their proximity to the seismic line. The porosity and ratio of mud filtrate invasion in the transitional zones are calculated every 10 cm of drilling depth. The temperature in the borehole is estimated based on PT log. The correction is applied for such as resistivity of mud, bore-hole diameter and spacing of electrode, thermal joint formation on wellbore wall etc. As an example, the result of WZ-7 is shown in Fig. 5.

6. CORRELATION (SEISMIC & WELL LOG)

6.1 High angle dip fault/fracture

In Fig. 5, the numbers ②-⑦ are illustrated for correlation with interpreted fractures in the seismic section (Fig. 6).

The major faults-e and-f with conjugated fractures interpreted in the seismic section are examined to correlate with the wells WZ-7 and 9. In Fig. 6, the lithology and the ratio of mud filtrate invasion around the transition zone are drawn along the well traces in order to facilitate correlations with the seismic section. The points of the higher ratio of mud filtrate invasion tend generally to coincide with the faults/fractures interpreted in the seismic section. The fracture ① is correlated with the fracture-f (intrusive rocks), which extends possibly to the reservoir at WZ-9. The fractures ②, ④, ⑥ and ⑦ can be correlated with the fractures-e-4,-e-3,-e-1(conjugated fractures) and -e (principal fault) respectively. The fracture⑤ cannot be correlated, however there is the fracture-e-2 near-by. The correlation is fairly satisfactory except ③, considering the discrepancy of subsurface coordinates between seismic section and wells, low S/N ratio due to low CDP coverage etc.

6.2 Low angle dip fault

The base of the chaotic event seems to be continuous in the seismic section (Fig. 3). The zones of porosity build-up of about 50 m are observed at the corresponding depth marked in circles in wells of YO-4 and AY-8 in Fig. 7, at which, however, intercalation of Tertiary's tuff and granite of Pre-tertiary is observed around -300 masl in YO-4, while only granite (granodiorite) of Pre-tertiary around -240 masl in AY-8. These observations can be interpreted as the base of chaotic event to be plain of either thrust or land slide rather than boundary of depositional sequences.

The intercalation of tuff and basement rocks is observed in the other wells in the study area such as WZ-4 to the north and AY-6 to the south of the seismic line. The projected N-S geological cross section passing WZ-4, AY-8, YO-4 and AY-6 is illustrated in Fig. 8. Fullbore Formation MicroImager (FMI) was acquired at AY-6. The chaotic event interpreted in the seismic section can be correlated with 60 ~ -470 masl (800~1300 MD) at AY-6, in which interval FMI readings show the dip of 20 degree and the strike of NW-SE.

The top of Pre-tertiary is defined as highest basement rock observed. However, the tuffs aged Tertiary are observed below this top of Pre-tertiary in AY-6, and formally interpreted as drilled along basement/depression boundary fault, getting in and out of the basement rocks (NEDO, 2000). Now, the base of chaotic event can be interpreted as surface plane of land slide inclining to south-west with dip of 20 degree, which may be associated with caldera formation (Fig. 9).

Another strong dip indication is observed at the depth deeper than -470 masl with the different orientation of E-W strike at AY-6 (Fig. 8). These facts implies at least 2 land slides occurred in Tertiary, the older one sliding possibly to the south while the younger to the southwest where depressions associated with possible caldera formation can be surmised.

7. SUMMARY AND CONCLUSION

The seismic survey is effective in the Akinomiya geothermal area, especially for assessment of fractures. In geothermal area, the rocks surrounding fractures is generally affected thermally by steam and/or hot water, and become more uniform than adjacent rocks which are not thermally altered. These features can be interpreted in the seismic section by its weaker reflections. The width of fracture is generally thin. The spatial high resolution seismic survey is recommended.

The alignment of fractures implies the series of high dip left-lateral strike slip faults under the active compressions of the Pacific Plate. Each strike slip fault induces to build up flower structures in its shallow part. The upper part of each fracture tends to be of closed nature due to swelling of clay minerals formed through thermal alteration.

Other fault systems can be recognized by interpretation of seismic section with correlation of well logs, FMI etc. These are low angle dip faults and interpreted as surface planes of land slide possibly associated with the caldera formation in Tertiary.

8. ACKNOWLEDGEMENT

The author would like to thank Jpower, MMC and MGC for their generous permission to publish their information.

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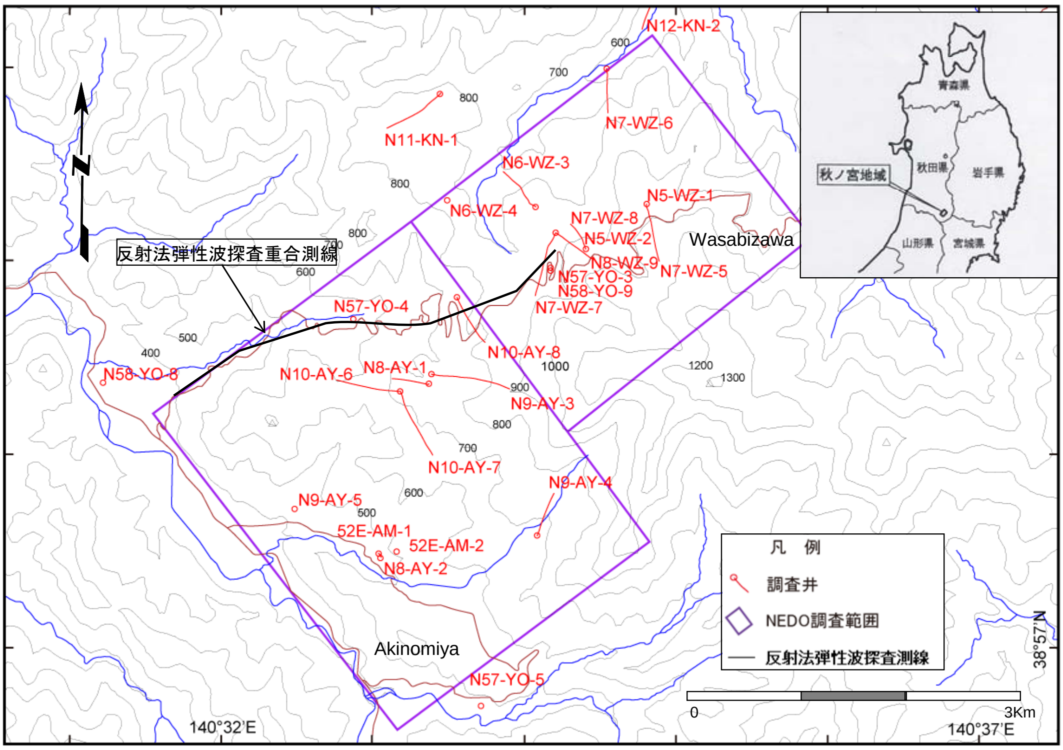

Fig.1 Location map modified from NEDO (2001), shows the location of the Akinomiya/Wasabizawa geothermal area in Akita prefecture, northern Japan. The solid line indicates the seismic line. The thin lines with small circle indicate the traces of drilled wells.

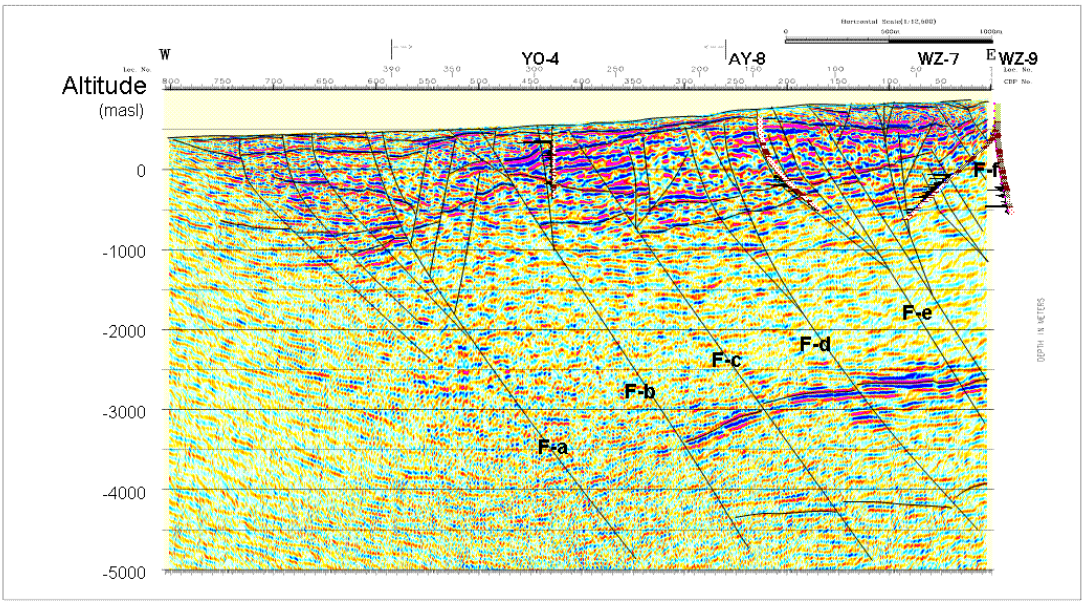

Fig. 2 Interpreted depth-migrated seismic section. The horizontal/vertical ratio is 5 to 2. Four wells of YO-4, AY-8, WZ-7 and WZ-9 are attached in the seismic section.

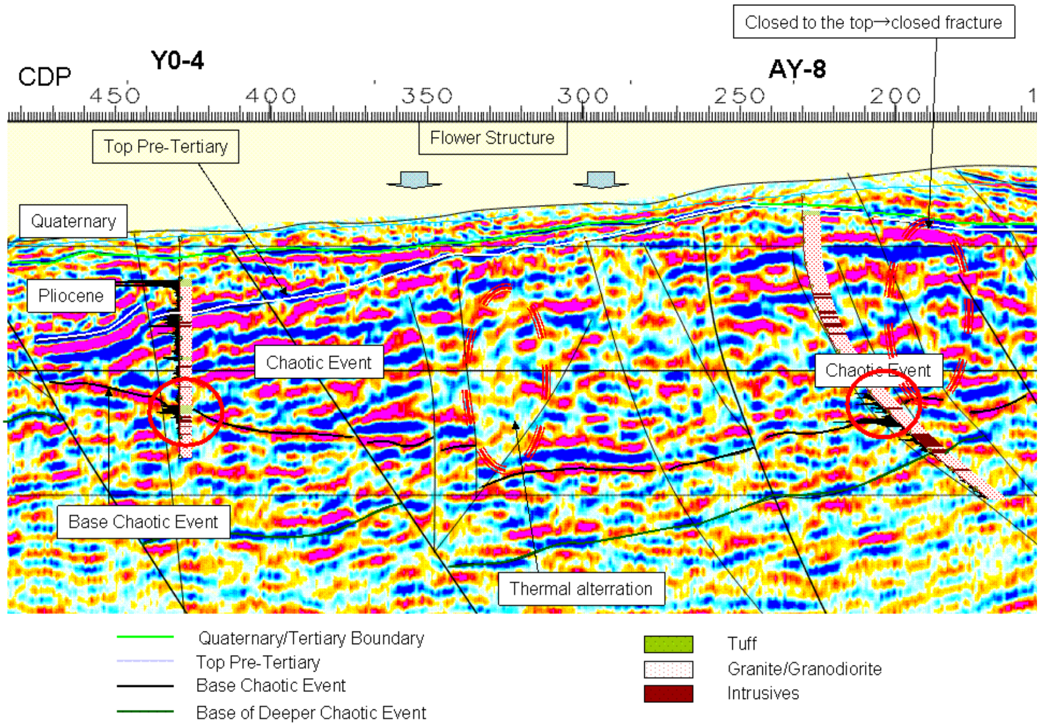

Fig. 3 Enlarged interpreted depth-migrated seismic section shows how fractures, which are altered thermally by steam, hot water or intrusive rocks, can be recognized by their weaker and more uniformed seismic reflections than the adjacent rocks (see red oval shape at CDP 330), how the flower structures are formed (see fault patterns at CDP between 300 and 420), how fractures become of close nature in their upper parts (see red oval-shape at CDP 190). The chaotic event of mixture of strong and weak seismic reflections is defined as eye shape between Top of Pre-Tertiary horizon (marked as white line) and Base of chaotic event (marked as black line). The red circles are so drawn at the wells of YO-4 and AY-8 as to make seismic correlation with the corresponding wells described in Fig. 7 regarding the identification of the base chaotic event.

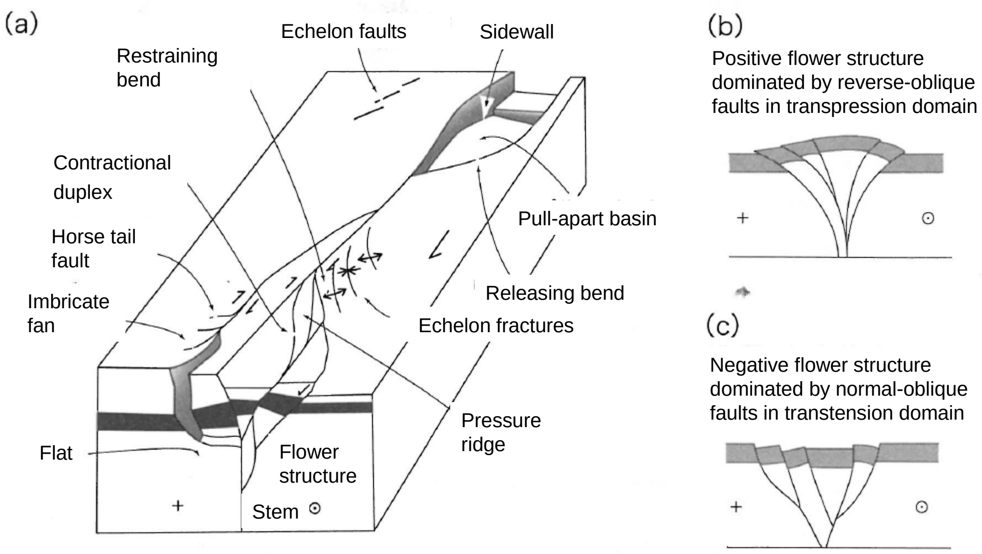

Fig. 4 Geological structures associated with right-lateral strike-slip faults (Hancock, 1994 & Taira, 2001,p.229).
(a) Schematic view: As the faults bend, there exist the restraining bend where compressive forces dominate and the releasing bend where extensive forces dominate. In the restraining bend, there appears echelon flexure, contractional

duplex, horse-tail fault etc. Near the restraining bend, the strike-slip compressive forces make the pressure ridges (mountainous highland) develop. In the releasing bend, the strike-slip extensive forces make the pull-apart basin develop. This causes the sediments supply from highlands to lowlands along the strike-slip faults.

(b) Flower structures in transpression (strike-slip compressive) domain

(c) Flower structures in transtension (strike-slip extensive) domain

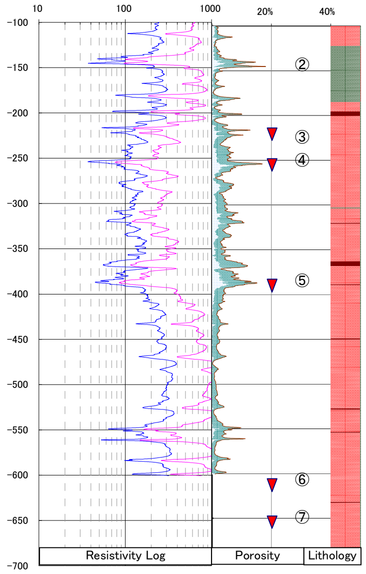

Fig. 5 Log Analysis and Interpretation of WZ-7. From left to right, 1) the raw resistivity readings of short (pink) and long (blue) normal, 2) analyzed porosity and type of fluid in the pore space at the transition zone (mud filtrate (gray) and connate hot water (marine blue)) with indication of reservoir zone (▼) and 3) lithology (granite (pink), schist (gray), intrusive rocks (brown)).

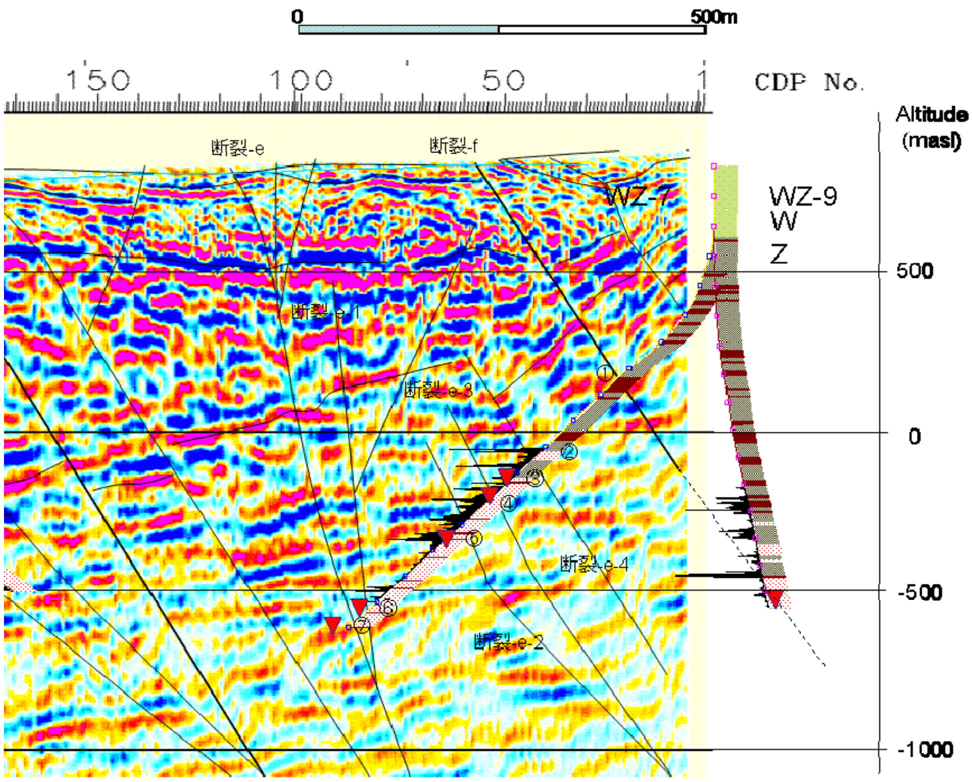

Fig. 6 Seismic correlation with wells.

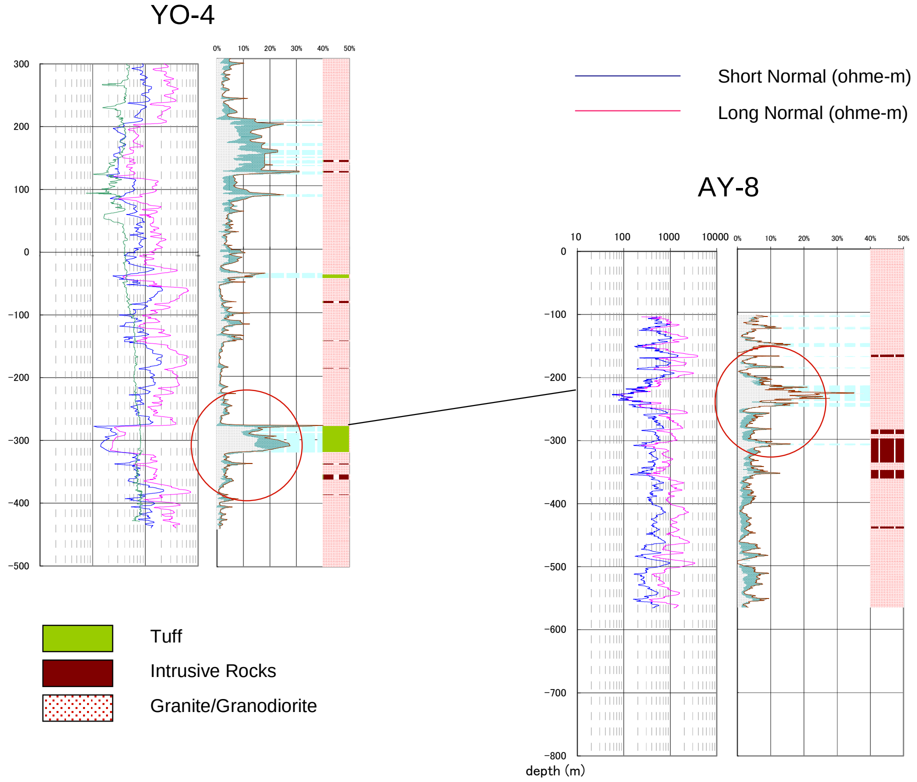

Fig. 7 Log Interpretation of YO-4 and AY-8. The each graph shows the raw resistivity readings, analyzed porosity and type of fluid in the pore space in the transition zone and lithology.

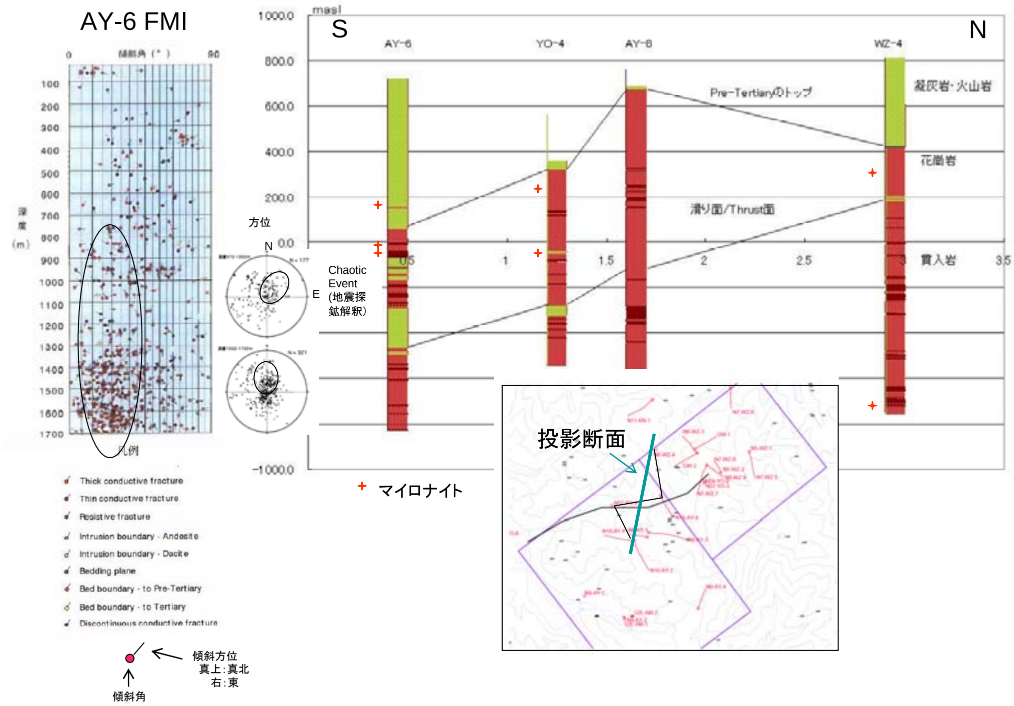

Fig. 8 Projected N-S geological cross section (WZ-4~ AY-8~YO-4~AY-6). The graph on the left is the results of FMI of AY-6.

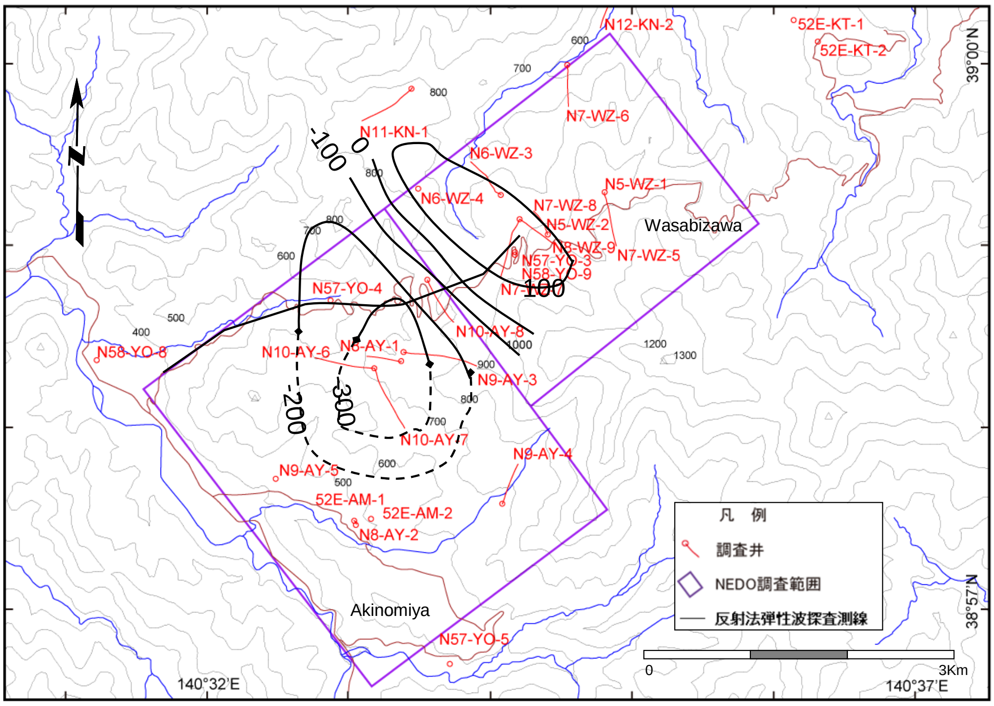

Fig. 9 Depth contour map (Base Chaotic Event) shows that the base of chaotic event inclines with dip of about 20 degree towards south-west where Pleiocene's depression exists. This coincides well with the FMI results at AY-6 of 20 degree's dip and of NW-SE strike at the corresponding depth (800-1300 MD) to the chaotic event defined in the seismic section.