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APPLICATION OF FLUID INCLUSION STUDIES IN UNDERSTANDING THE THERMAL SYSTEMS IN SHIRAMIZUGOE AND APPI GEOTHERMAL FIELDS, JAPAN

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ABSTRACT

New Energy and Industrial Technology Development Organization (NEDO) has studied fluid inclusion measurement technologies through the R&D theme of Modeling Support Techniques on the Development of Technology for Reservoir Mass and Heat Flow Characterization Project since 1997. As case studies, fluid inclusion measurement technologies were applied in Shiramizugoe in Kyushu and Appi in Tohoku, Japan. NEDO is currently implementing an exploration program under the Geothermal Development Promotion Survey Project in these two geothermal areas.

In the Shiramizugoe area in southern Japan, drilling of five exploratory wells was completed. The lowest temperatures obtained from fluid inclusion analysis show good agreement with temperature profile from logging indicating that the combination of these two temperature data represent present subsurface thermal conditions.

In the Appi area in northern Japan, four exploratory wells have been drilled while fifth well was spudded in August, 2002. Salinity was calculated on the basis of final melting point of ice and melting point of hydrohalite. These calculated values provide clues on the origin of geothermal fluids. In contrast to the Shiramizugoe area, the fluid inclusion data in Appi do not show good correlation with temperature profile based on the final equilibrium static temperature. Thus, formation temperature should be delineated mostly from temperature logging data. However, combination of fluid inclusion data and final static temperatures may be used in reconstructing the thermal history of the wells.

1.0 INTRODUCTION

The Development of Technology for Reservoir Mass and Heat Flow Characterization Project has started since 1997 as one of R&D national projects under NEDO aiming at developing useful technologies for geothermal resource development in Japan. Fluid inclusion measurement technologies consisting of measurement of homogenization temperatures and final ice melting temperatures were studied in the project in detail, proving that those temperatures are useful in understanding the subsurface thermal conditions of geothermal areas.

NEDO has started national geothermal field exploration projects since 1980, and it is called the “Geothermal Development Promotion Survey (GDPS)”. In this project, NEDO takes the initiative in surveying promising geothermal fields where any development activities have not been undertaken due to risks with resource uncertainties expected at the initial exploration stage. The main objective of the GDPS then was to encourage the geothermal development activities among the private sector through the financial and technical support of NEDO and to promote geothermal power generation.

The GDPS is composed of three exploration stages, called “Survey A”, “Survey B” and “Survey C”. These stages are generally conducted based on the following conditions:

1) “Survey A” is conducted in the area of 100 to 300 km^2 to verify the presence of high temperature zone through various geoscientific studies and exploratory wells.

2) “Survey B” is conducted in the selected area of 50 to 70 km^2 based on the results of “Survey A”. The presence of geothermal reservoirs is verified through detailed

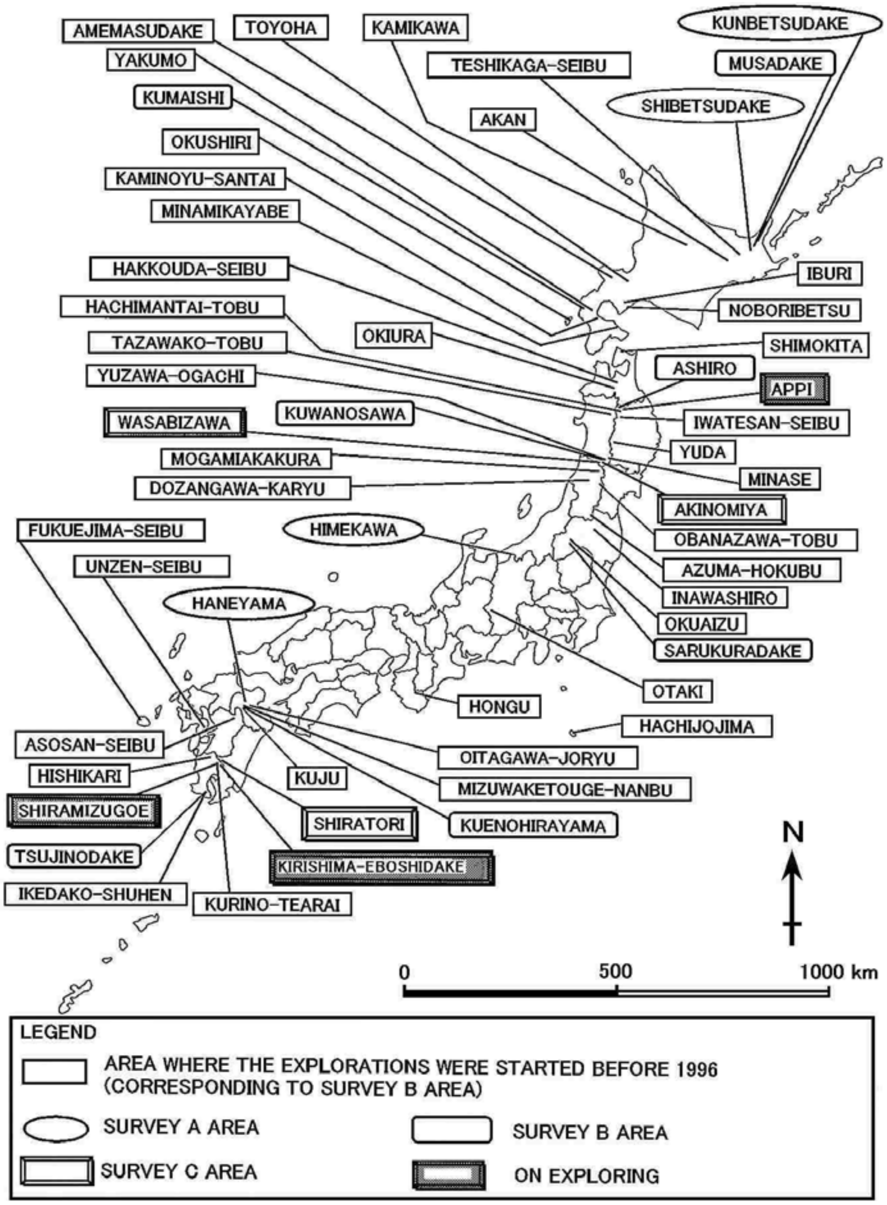

Figure 1. Geothermal development promotion survey areas.

geoscientific studies and production-size exploratory wells.

3) "Survey C" is the pre-feasibility study in the area of 5 to 10km^2. Some delineation exploratory wells are drilled, and the reservoir size and scale is studied based on production tests and numerical reservoir simulation study.

Up to the present, 52 projects were carried out (Fig. 1), and five (5) power stations such as Uenotai, Yamagawa, Yanaizu-Nishiyama, Ohgiri, and Hachijojima were constructed after GDPS. NEDO is currently implementing three GDPS projects in three geothermal areas such as Shiramizugoe, Appi, and Kirishima-Eboshidake. In "Survey C", reservoir potential should be evaluated taking all available geoscientific data into account. After an experimental study on fluid inclusion technologies in the Wasabizawa project area, the technology showed its effectiveness in the evaluation of subsurface thermal profile. The results of fluid inclusion measurements applied to the Shiramizugoe area and the Appi area will be discussed in this paper.

2.0 SHIRAMIZUGOE AREA

The Shiramizugoe project area is situated in the Kirishima geothermal field in the southern part of Japan. This area is bounded on the western side by the Ogiri geothermal area where a power plant of 30 MW has been operated. GDPS "Survey C" was started in 1999. Five exploratory wells (N12-SZ-1, N12-SZ-2, N12-SZ-3, N13-SZ-4 and N13-SZ-5) were drilled, and a long-term discharge test was carried out in August, 2002. Steam and hot water were successfully discharged from four (N12-SZ-1, N12-SZ-2, N13-SZ-4 and N13-SZ-5) out of five wells.

The lowest temperatures from homogenization temperature analysis correspond well with the present formation temperature in the Kirishima geothermal area. This indicates that most of the fluid inclusions in the secondary minerals have resulted from the present hydrothermal activity. It is expected that the present formation temperature can be estimated from the homogenization temperature in the project area.

N12-SZ-1 was drilled to a total depth of 1500 m. The final static temperatures calculated from temperature logs were compared with the lowest homogenization temperatures obtained from fluid inclusion of the well sample. Both temperatures from depths between 400 m and 900 m show good correlation.

On the contrary, the final static temperatures between 950 m and 1200 m are lower than the lowest homogenization temperatures. These differences may be attributed to the influence of cool waters injected during drilling. It is regarded that the lowest homogenization temperatures represent the present formation temperature rather than the final static temperatures. At 1300 m, the fluid inclusion temperatures also show good agreement with the final static temperatures. The present formation temperature below 800 m is expected to be in the range of 250 to 300°C.

Similar comparative graphs for well N12-SZ-3 (Fig. 2) show that the lowest homogenization temperatures have mostly good correlation with calculated final static temperatures, especially for depth intervals between 650 m to 1250 m. A similar comparison was done for other exploratory wells. As for N13-SZ-4, homogenization temperature distribution range

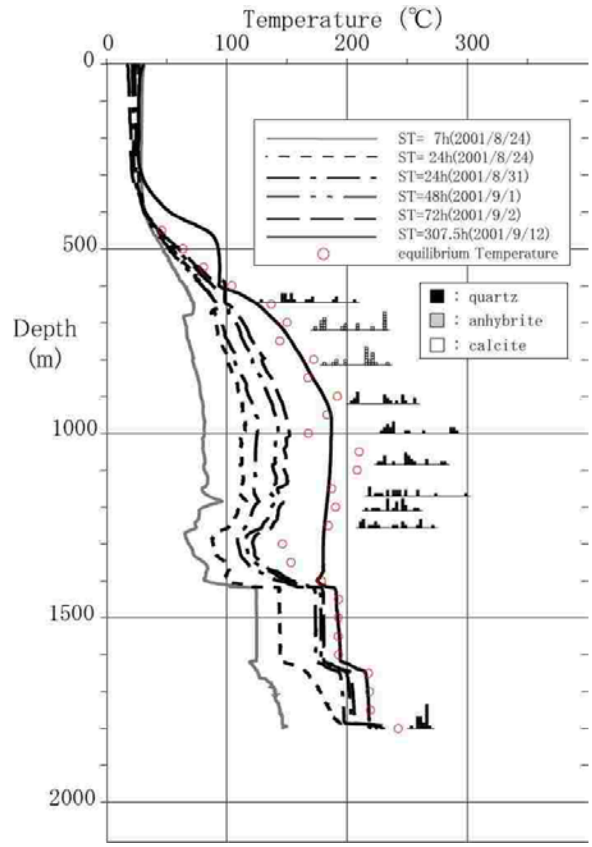

Figure 2. Temperature profile of N12-SZ-3.

at each depth is comparatively narrower than those of other wells. At some depths, the final static temperatures are higher than the lowest homogenizations temperatures. In N13-SZ-5, the final static temperatures show good correlation with the most frequent values of homogenization temperatures, but not with the lowest ones. The formation temperatures of these four wells are estimated to be 250 to 270°C in N12-SZ-2 at 1300 m, 200 to 230°C in N12-SZ-3 at 920 m, 255 to 266°C in N13-SZ-4 at 1635 m, and 250 to 260°C in N13-SZ-5 at 1500 m.

From the comparison studies between the final static temperatures and fluid inclusion homogenization temperatures mentioned above for exploratory wells drilled in the Shiramizugoe geothermal area, fluid inclusion homogenization temperatures can be useful in delineating the subsurface thermal conditions in addition to temperature logging data.

3.0 APPI AREA

The Appi area is situated in the Hachimantai geothermal field in the northern part of Japan. Four geothermal power plants consisting of Matsukawa (23.5 MW), Kakkonda (80 MW), Onuma (9.5 MW) and Sumikawa (50 MW) are located in the Hachimantai area. GDPS "Survey C" was started in 2000. Five exploratory wells (N12-AP-1, N13-AP-2, N13-AP-3, N14-AP-4 and N14-AP-5) were drilled, and steam and hot water were successfully discharged from one well (N13-AP-3). A long-term discharge test is planned for next year.

N12-AP-1 was drilled to a total depth of 2000 m. A down flow phenomenon was recognized in N12-AP-1 as shown in Figure 3. Thus, formation temperatures deeper than 140 m above the sea level cannot be estimated from temperature logging data because of this down flow. To estimate the formation temperatures, the homogenization temperature measurement technology was adopted, and temperatures are also shown in Figure 3. The final static temperatures calculated from temperature logs with the average homogenization temperatures obtained from fluid inclusion are mostly comparable between 1000 m and 1370 m. The average homogenization temperatures show higher values than the final static temperatures below 1500 m. The relationship between salinities and drilled depth of N12-AP-1 is given in Figure 4. Salinity was calculated on the basis of final melting point of ice (Bornar, 1993). In this well, salinities range between 0.4wt.%NaCl and 6.3wt.%NaCl and are concentrated between 1.0wt.%NaCl and 3.5wt.%NaCl.

N13-AP-2 was drilled to a total depth of 1887 m. The thermal history of the well can be reconstructed based on estimated formation temperature and the distribution pattern of the homogenization temperatures,. The present hydrothermal activity around the well is estimated at depths of 1600 m and 1695 m using homogenization temperatures. Salinities range between 0.4wt.%NaCl and 4.0wt.%NaCl and exhibit a trend of reverse correlation with depths.

N13-AP-3 was drilled to a total depth of 2515 m. Similar to well N13-AP-2, the thermal history of the well was reconstructed using estimated formation temperature and the distribution of the homogenization temperatures. From

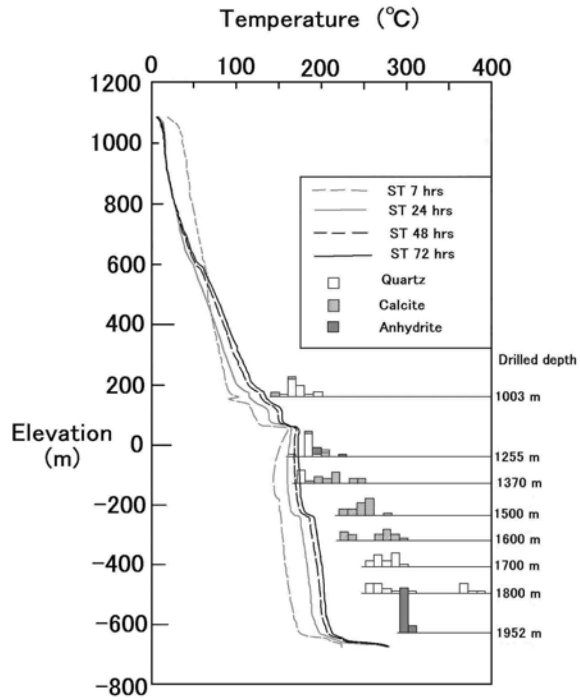

Figure 3. Temperature profile of N12-AP-1.

homogenization temperatures, the present hydrothermal activity around N13-AP-2 is judged to be active below 1495 m. Salinities are categorized into two groups. Salinities of group 1 range between 0.5wt.%NaCl and 7.5wt.%NaCl while those of group 2 have an average value of about 20 wt.%NaCl. Salinities of group 1 are confirmed at mostly every depth, and do not correlate with the homogenization temperatures. Salinities of group 2 are remarkably high, and were obtained from fluid inclusion with associated halite contained in a quartz phenocryst at 2410 m The homogenization temperatures of group 2 are extremely high (>570°C),. It is known that highly saline fluids are released at the crystallization process of felsic magma. It is herefore possible that those of group 2 originated from magmatic fluids. Salinity of multi-phase fluid inclusion was calculated on the basis of melting point of hydrohalite (Brown, 1998).

4.0 CONCLUSION

Applying the fluid inclusion measurements to an experimental (Wasabizawa) area reveals that the measurements give information about subsurface formation temperature and salinity of hot fluids. In the cases of the Shiramizugoe and

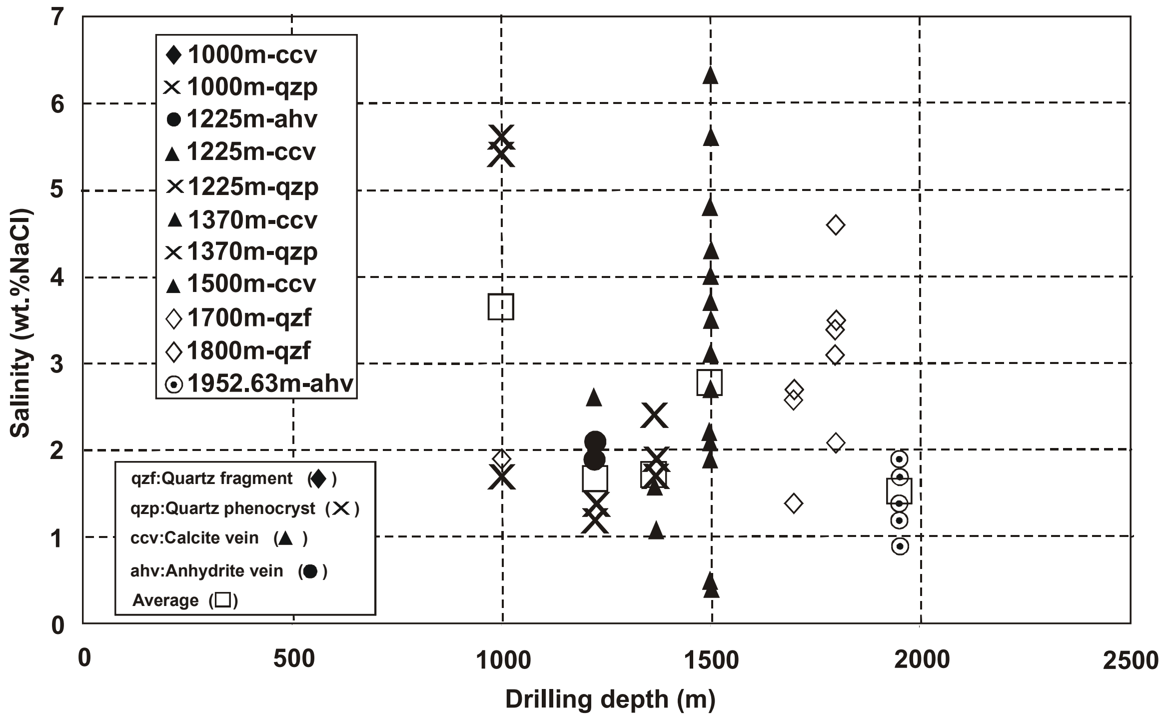

Figure 4. The relationship between salinities and drilling depth of N12-AP-1.

the Appi areas, it is shown that we can estimate formation temperature despite insufficient time to heat up the drilled well or if down flow phenomenon occurs in the well. Moreover, the application study in the Appi area shows that the measurements can give information about thermal history. From these results, it is concluded that the fluid inclusion measurements provide useful information to estimate thermal profiles and conditions.

Recently, the economical aspects of geothermal development has been required more intensively in Japan. On GDPS, NEDO will continuously study scientific technologies through R&D projects. It will be more involved in effective exploration for resource evaluation while emphasizing savings in the total cost.