Proc. 6th NZ Geothermal Workshop 1984

FLUID INCLUSION STUDY IN THE TAKINOUE GEOTHERMAL FIELD, IWATE PREFECTURE, JAPAN : AN APPLICATION TO THE ESTIMATE OF THE PRESENT UNDERGROUND TEMPERATURE

YOICHI MURAMATSU

Geothermal Development Division, Japan Metals and Chemicals Co.,Ltd.
24 Ukai, Takizawa-mura, Iwate-gun, Iwate-ken, 020-01, Japan

ABSTRACT

Study has been made to measure filling temperatures and salinities of fluid inclusions in the cuttings of wells in the Takinoue geothermal field, Iwate Prefecture, Japan, by means of the heating and freezing stage microscope. Fluid inclusions are composed mainly of two-phase high density liquid inclusions. In almost wells, the minimum filling temperature has a tendency to increase abruptly from near the surface to about 400 m deep, and to be about constant from 212 to 236°C at the deeper parts. The minimum filling temperatures are in good agreement with the measured borehole temperatures. The salinities of fluid in primary and secondary inclusions are ranging from 0.1 to 1.5 wt.% and 0.05 to 0.7 wt.% NaCl equivalent, respectively.

The major results obtained are as follows:(1) The cap rock is existing at the northwestern part of the field,(2) At least about 900 m of overburden was possibly eroded after mineralization had taken place,(3) The last trapping fluid is probably the present deep geothermal fluid.

INTRODUCTION

Fluid inclusions in the minerals are undoubtedly the most important geologic material to the study of the genesis of ore deposits, because they are the only remaining samples of the original solution that formed the ore deposits. From this point of view, many fluid inclusion reports for various types of ore deposits are given (Roedder, 1978).

During the past one decades, the use of fluid inclusion for the geothermal field in the world has become widespread (Shimazu and Yajima, 1973; Browne et al., 1974; Taguchi and Hayashi, 1983; Sternfield et al., 1983; Belkin et al., 1983; Takenouchi and Shoji, 1984). The Takinoue (Kakkonda) field, Iwate Prefecture is famous for one of the geothermal field in Japan. Since 1972, the exploration of the Takinoue geothermal area has been carried out by Japan Metals and Chemicals Co.,Ltd. with cooperation of Tohoku Electric Power Co.,Ltd. to construct a power plant of 50 MW. This paper presents the results of detailed studies of fluid inclusion's use as a underground temperature logging in the Takinoue geothermal field.

GEOLOGY,MEASURED TEMPERATURE AND FLUID COMPOSITION

The Takinoue geothermal field lies in the northwestern part of the Morioka city, Iwate Prefecture, Japan (Fig.1). The geology of the field has been described by Nakamura and Sumi (1981), and Sato (1982). The subsurface geology consists of Neogene rocks, Tamagawa welded tuff and Quaternary volcanic rocks. Neogene rocks are divided into three formations in ascending order as follows; Kunimitoge, Takinoue-onsen and Yamatsuda formations. The Kunimitoge formation is made up largely of dacitic tuff but includes altered andesite and much black shale. The Takinoue-onsen formation consists mainly of black

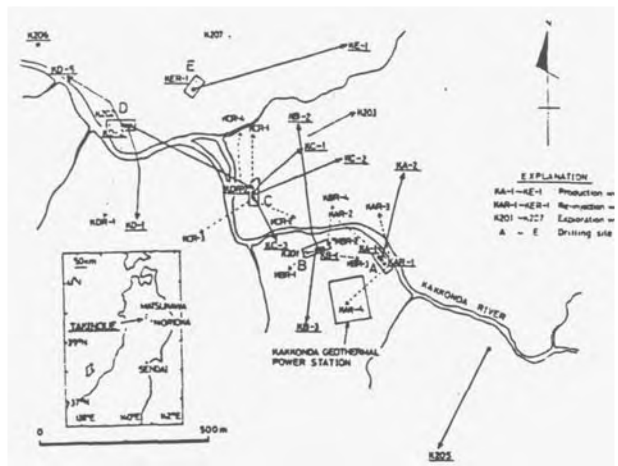

Fig.1. Distribution map of the wells at the operatio of the Takinoue geothermal power plant, except for KD-5 vell. The wells marked with underlines indicat the objective wells of this study.

tuff, mudstone, tuffaceous sandstone, tuffaceous sil stone and laminated siltstone. Neogene rocks are covered with Tamagawa welded tuff and Quaternary volcanic rocks. The Inlier exposed along the Kakkonda river was formed by NW-SE fold,and by NW-SE and E-W faults.

The alteration can be classified into the regional one characterized by chlorite, sericite, mixed-layer mineral of sericite and montmorillonite, and the local one characterized by kaolin, alunite and/or pyrophyllite (Kimbara, 1983). Quartz is the most abundant hydrothermal mineral. Other hydrothermal minerals include K-feldspar, calcite, epidote, amphibole, gypsum,anhydrite, prehnite, biotite, tourmalin wairakite, yugawaralite, laumontite, stilbite, mordenite, pyrite, sphalerite, galena, monoclinic pyrrhotite and molybdenite. The geothermal fluid is encountered in fractures developed in the Takinoue-onsen and Kunimitoge formations.

In general, borehole temperatures were measured at intervals of fifty meters with the Kuster type thermometer. The measured fluid supply temperatures, usually 220-265°C, which are broadly confirmed by geothermometer estimated from the silica concentrations of the discharged borehole waters (Akeno, 1978) The discharged hot water can be characterized as weakly alkaline dilute chloride solution; the water contains 0.07-0.12 wt.% NaCl and 420-792 ppm SiO_2 as major constituents. The non-condensible gas occupied 0.04-0.10 vol.% of the steam components, is composed mainly of 37.8-73.6 vol.% (Akeno, 1978).

SAMPLE AND EXPERIMENT

Samples of quartz and calcite used in this study were collected from the cuttings of 11 production for the cores because of no core-drilling. Fig.1 shows the distribution of these geothermal wells mostly constructed through directional drilling from five drilling base areas named A,B,C,D and E. Using a pincette, small thin chips (<0.5 mm thick) of quartz and calcite were prepared for microscopic observation. Most of quartz and calcite are produced for veinlet, and a little for fragment. Most of quartz are rock crystals which are generally 1–5 mm size. It is inclined that the inclusion in rock crystal is gathering at the part of root. Size of fluid inclusions are usually less than 10 μm; rarely from 30 to 50 μm. They are two-phase high density fluid inclusions (liquid inclusions), and two-phase low density fluid inclusions (gaseous inclusions). Almostly all the inclusions are liquid inclusions. The gas bubbles disappear on heating. Polyphase inclusion, CO_2-rich inclusion, and an intimate coexistence of gaseous and liquid inclusions in a cluster are not observed. It is indicated that boiling did not occur through the cooling process after mineralization.

Filling and freezing temperatures of fluid inclusions were measured in a silicon oil-filled cell by a combined heating-freezing stage of my own production, using a Olympus 40 long working distance objective lens. A chromel-alumel thermocouple was used to measure temperature. The heating stage was calibrated by measuring the melting point of indium, tin, bismuth and lead metal standards, and filling temperatures should be correct to ± 1°C. The salinities were obtained from freezing point depression of inclusion fluid calibrated by freezing solution of known salinities. The freezing stage was cooled by circulating nitrogen gas.

RESULT

All filling temperatures were determined two or three-times to avoid including data from leaking inclusions. Fig. 2–3 illustrate the distributions of filling temperatures along with summary lithology, mineral and occurrence of measured sample, and measured static borehole temperature for two production wells (KE-3 and KD-2) in the Takinoue geothermal field. These temperatures have not corrected for pressure (depth) or salinity. Location of the wells are shown in Fig.1.

The distribution of filling temperature versus depth of KB-3 well, from which the steam of 70 t/hr is produced, is shown in Fig.2. The filling temperatures were measured on vein calcite from depth of 50 m, and on vein quartz and rock crystal from another nine different depths. These in quartz and rock crystal vary in wide ranges from 46 to 108°C, but one in calcite vary in narrow ranges in 26°C. The cluster around the minimum filling temperatures is observed at depth of 50, 100, 250, 390, 410, 510 and 920 m. The minimum filling temperature has a tendency to increase abruptly from near the surface to 390 m deep, and to be about constant from 220 to 222°C at the deeper parts. The minimum filling temperature at eight levels except for 390 and 410 m agrees well with the static borehole temperature measured in 1976. These characteristics are shown at almost of another wells except for the wells of D,E areas and E206 well.

Fig.3 shows the filling temperatures of liquid inclusions from nine different depths in KD-2 well yielded the steam of 38 t/hr. The cutting at the shallower parts of 90 m could not obtained. The samples are vein quartz and rock crystal except for a fragment quartz of dacitic tuff from 350 m. The filling temperatures of each depth except for 350 m have wide ranges from 51 to 118°C. The minimum filling temperature curve against depth differ from one of the previous well. It gradually increases from near the surface to 540 m deep, and abruptly increases from 540 to 600 m which is distributed by altered andesite. At the deeper parts of 600 m, it is about constant from 243 to 251°C which is the

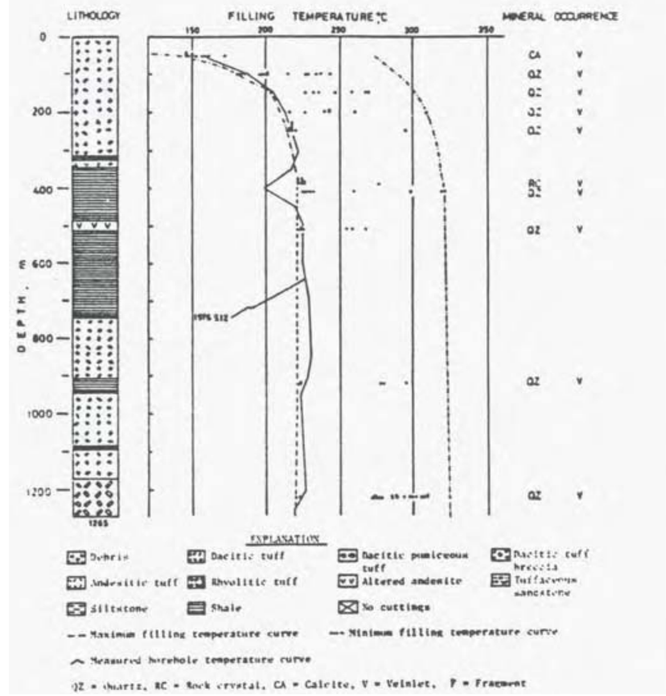

Fig.2. Distributiou of filling temperatures with lithology, mineral and occurrence of measured sample, and measured static borehole temperature for KB-3 well.

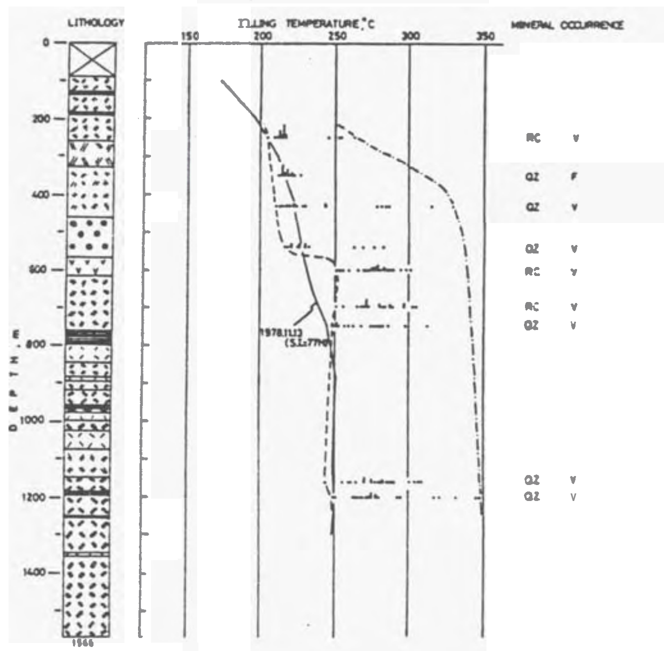

Fig.3. Distribution of filling temperatures with lithology, mineral and occurrence of measured sample, and measured static borehole temperature for KD-f well. The symboles are the same as those in Fig.2. The abbriviation of S.T. denotes the standing time.

temperature measured 77 hours after drilling, but at the deeper parts, those accord with borehole temperatures measured in 1978. It is considered that abrupt temperature up from 540 to 600 m result from the existence of altered andesite corresponding to the cap rock. This abrupt temperature up characteristics is recognized for the wells of D,E areas and K206 well.

In Fig.4, I plot the relationship between the minimum filling temperature and the measured static borehole temperature in KA-1,2, KB-1,2,3, KC-1,2,3, KD-1,2, KDR-2, KE-1, R205 and K206 wells. It is

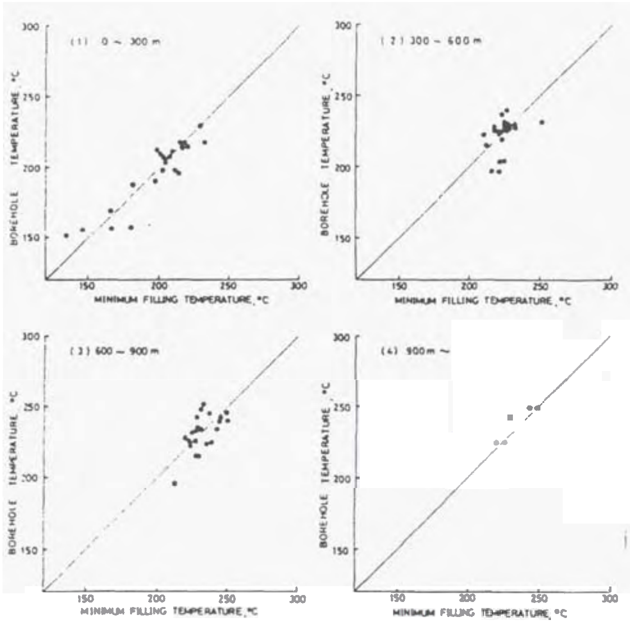

Fig.4. Minimum filling temperature - borehole temperature relations at depths of four group.

Calculated salinities against filling temperatures are shown in Fig.5. The salinities of fluid in primary inclusions in quartz are ranging from 0.1 to 1.5 wt.% NaCl equivalent concentration. These in secondary inclusions in quartz are ranging from 0.05 to 0.7 wt.% NaCl equivalent concentration, particularly gathering from 0.05 to 0.1 wt.% NaCl equivalent concentration,which are equal to those of the present deep geothermal fluid, mamely 0.05-0.09 wt.% NaCl equivalent calculated from the chemical analyses of discharged hot waters and enthalpy of deep geothermal fluid.

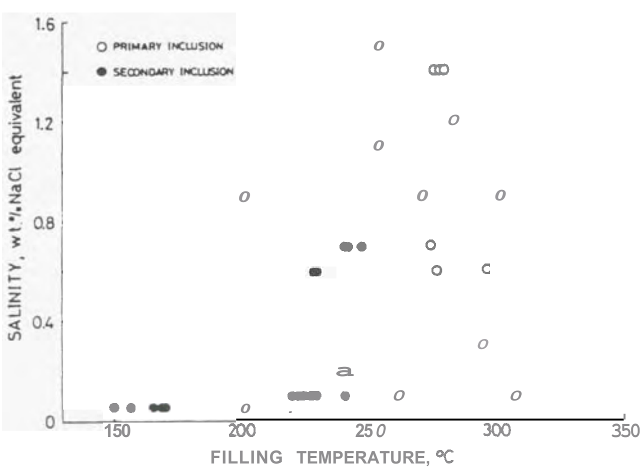

Fig.5. Diagram showing relation between filling temperatures and salinities of liquid inclusions in quartz from the Takinoue geothermal field.

DISCUSSION

As shown in Fig.4, it is suggested that the minimum filling temperature is applicable to the present underground temperature without correcting for pressure or salinity in the Takinoue geothermal field. Therefore, the direct temperature estimate method is very useful to make predictions before temperature logging survey. I was successful in estimnting the underground temperature during drilling in new KD-5 well using the minimum filling temperature of liquid inclusions in vein quartz.

In Takinoue, the hot water separated near the production wells is directly transported to the heads of the re-injection wells without exposing hot water to the air and injected into the wells with the vapor pressure occurring in the separator. The static borehole temperature was not obtained in re-injection wells, nevertheless I can estimate the underground temperature by the inclusion method. Fig.6 shows filling temperatures of liquid inclusions from five depths in KAR-1 well into which the water of 160 t/hr is reinjected. The samples are rock crystals. The filling temperatures of each depth have narrow ranges from 4 to 28°C. The minimum filling temperature curve against depth is very similar to that of KB-3 well.

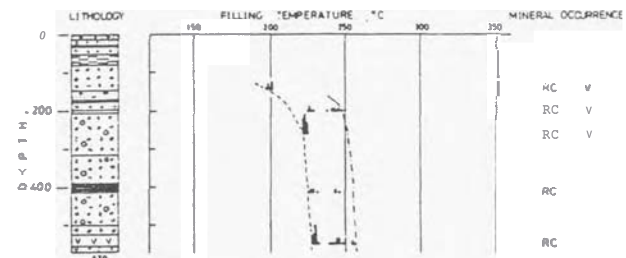

Fig.6. Distribution of filling temperatures with lithology, mineral and occurrence of measured sample for KAR-1 well. The symboles are the same as those in Fig.2.

When it is expected that the underground temperature is cooled because the hot water injects into the subsurface in the Takinoue geothermal field, the minimum filling temperature is useful to estimate a degree of cooling. But, the inclusion method has a weak point as follows; if the cutting obtained by mud-drilling after lost circulation is very tiny, and the cutting can not be obtained during air-drilling, it is difficult to measure the filling temperature of fluid inclusion.

Judging from the shape and distribution, in some cases it is decided that the maximum filling temperatures for liquid inclusions are primary inclusions. Filling temperatures and salinities of the primary inclusions provide information on the highest of the surface at the time of mineralization. If the fluid were open to the surface during mineralization and the pressure on the fluid were hydrostatic, the maximum filling temperatures would be an indication of the minimum pressure operated on the mineralizing fluid. Fig.7 shows a plot of those with the measured depths for 16 wells of the Takinoue field. If the maximum filling temperatures obtained for the samples from 140 m depth of K206 well, 660 m depth of KE-1 well, 820 m depth of KA-1 well and 1200 m depth of KD-2 well represent the temperatures near boiling-point curve of 2 wt.% NaCl solution with the maximum values of the levels, I can estimate that the surface at the time of mineralization was situated about 900 m above the present surface. On the basis of the above results, microscopic evidence shows that at least about 900 m of overburden was possibly eroded after mineralization had taken place.

Fig.8 shows a plot of the minimum filling temperatures with the measured depths for 16 wells of the Takinoue field. It is generally suggested that the underground temperature of main drilling base areas named A,B and C is widely about constant values from 212 to 236°C at the deeper parts of about 400 m, but that the underground temperature at the deeper parts of 700 m of D and E areas is ranges from 228 to 251°C which is slightly higher than that of the previous areas. The feature described above results mainly from the existence of remarkable parallel quartz veins and cap rock of

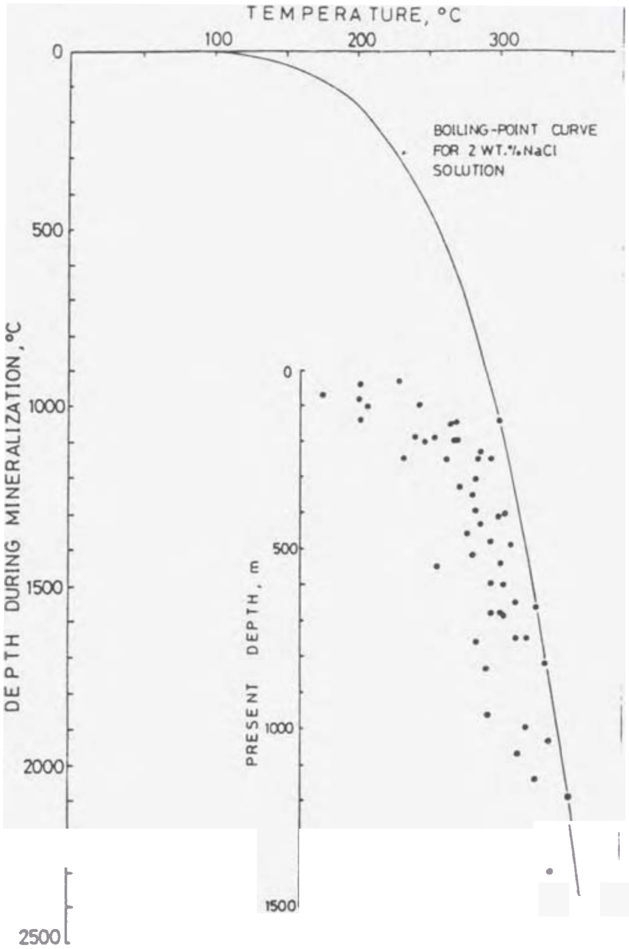

Fig.7. Maximum filling temperatures of fluid inclusions with the sampling depths for the Takinoue geothermal field. Boiling-point curve for 2 wt.% NaCl solution was drawn by Haas' data (1971).

field will be mentioned in another report in near future.

From the general facts that the filling temperatures of each depth in almost wells have wide ranges from 50 to 110°C, and that the salinities of fluid in secondary inclusions are lower than that in primary inclusions in almost samples (Fig.5), I can estimate that large changes in temperatures and salinities of the fluids have taken place between the time of mineralization and the trapping fluid after mineralization. The correspondence between the minimum filling temperature and the measured static borehole temperature suggests that there was no major change in the thermal regime as they evolved from the last fluid trapping stage to the present fluid stage. And, the result of salinities supports the idea that the last trapping fluid is probably the present deep geothermal fluid.

CONCLUSIONS

For the evaluation of the geothermal resource for a well, it is necessary to estimate the borehole temperature. The minimum filling temperature of the secondary liquid inclusion is very useful to make prediction of the underground temperature before temperature logging survey in the Takinoue geothermal field. Besides, the fluid inclusions give us the important informations about the past history of the geothermal fluid and field geology.

ACKNOWLEDGEMENTS

The writer would like to express his sincere for their help with this investigation.

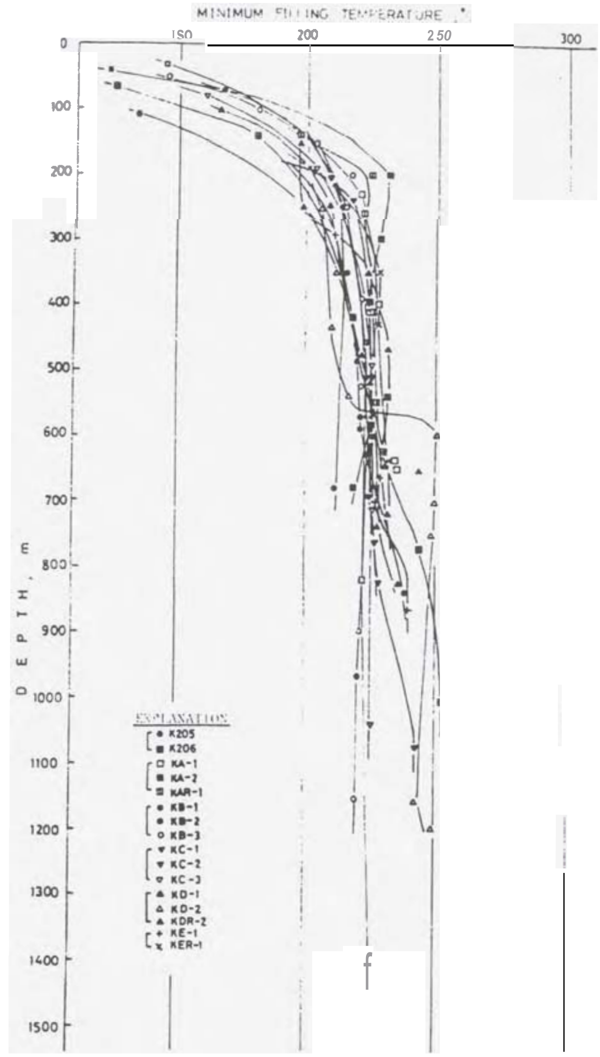

Fig.8. Minimum filling temperatures of fluid inclusions from the each wells of the Takinoue geothermal field.

REFERENCES

Akeno, T., 1978, Geochemical survey in Takinoue geothermal field, Iwate pref., Japan, using the ratios of methane to hydrogen in gases issued fumaroles and hotsprings: Chinetsu (Jour. Japan Geotherm. Ener. Assoc.), v.15, p.75-85 (in Japanese with English abstract).

Belkin,H., Vivo,B.D., Gianelli,G. and Lattanzi,P., 1983, Fluid inclusion reconnaissance study of hydrothermal minerals from geothermal fields of Tuscany (Italy): Proceedings of the Fourth International Symposium on Water-Rock Interaction, p.43-47.

Browne,P,R,L.,Roedder,E. and Wodzicki,A., 1974, Comparison of past and present geothermal waters from a study of fluid inclusions,Broadlands field,New Zealand: Proceedings International Symposium on the Water-Rock Interaction, p.140-149.

Haas,J.L.,Jr., 1971, The effect of salinity on the maximum thermal gradient of a hydrothermal system at hydrostatic pressure: Econ.Geol., v.66, p.940-946.

Kimbara,K., 1983, Hydrothermal rock alteration and geothermal systems in the eastern Hachimantai geothermal area,Iwate Prefecture,northern Japan: J.Japan.Assoc.Min.Petr.Econ.Geol., v.78, p.479-490.

Systems: Principles and Case Histories, ed.L. Rybach and L.J.P.Muffler. John Wiley & Sons Ltd. p.247–272.

Roedder, E. and Kozlowski, A., 1978, Fluid inclusion research: Proceedings of COFFI, v.11, p.291

Sato, K., 1982, Analysis of geological structure in the Takinoue geothermal area: J.Geotherm.Res. Soc.Japan, v.3, p.135–148.

Shimazu, M. and Yajima, J., 1973, Epidote and wairakite in drill cores at the Hachimantai geothermal area, northeastern Japan: J.Japan.Assoc.Min. Petr.Econ.Geol., v.68, p.363–371.

Sternfield, J., Keskinen, M. and Blethen, R., 1983, Hydrothermal mineralization of a Clear Lake Geothermal Well, Lake County, California: Ceothem. Resources Council, Transactions, v.7, p.193-197.

Taguchi, S. and Hayashi, M., 1983, Past and present subsurface thermal structures of the Kirishima geothermal area, Japan: Geotherm. Resources Council, Transactions, v.7, p.199–203.

Takenouchi, S. and Shoji, T., 1984, Some geological methods applied to the exploration and evaluation of geothermal resources: Research on Natural Energy, v.8, p.481–486.