0.14 to 0.56 wt-% equivalent MoS_2. Fluid-inclusion data from quartz and fluorite suggest that this assemblage was deposited from dilute fluids (0.2 to 0.5 equivalent wt-% NaCl) at temperatures of 195 to 215°C. Geochemical modeling using the SUPCRT data base indicates that under restricted pH and fO_2 conditions at 200°C, the molybdenite and associated phases would be in equilibrium with hydrothermal fluids now circulating in the caldera. Because the molybdenum mineralization was deposited from liquid water but now occurs in a zone where low-pressure vapor fills fractures, the surface of the liquid-dominated reservoir has descended since the deposit was formed. On the other hand, the salinity and bulk composition of the liquid-dominated reservoir have not changed drastically since the deposit was formed ≤0.98 m.y. ago.

CONCLUSIONS

The hydrothermal system at Sulphur Springs is merely one of several present subsystems within the Valles caldera. Hydrothermal activity has been continuously occurring within the caldera for the last one million years and deep reservoir fluids have not changed significantly in composition during this period (see also Goff and Shevenell, 1987). However, the presence of the molybdenum deposit at shallow depths within VC-2A indicates that major hydrologic changes have occurred in the hydrothermal system as it has evolved. It is hoped that further research on VC-2A and other bores will shed more light on the detailed evolution of the Valles hydrothermal system.

ACKNOWLEDGMENTS

This work was funded by the U.S. Department of Energy, Office of Basic Energy Sciences.

REFERENCES

Charles, R., Vidale, R., and Goff, F., 1986. An Interpretation of the Alteration Assemblages at Sulphur Springs, Valles Caldera, New Mexico. J. Geophys. Res. 91, 1887.

Ghazi, A. and Wampler, J., 1987. Potassium-Argon Dates of Clays from Brecciated and Hydrothermally Altered Rocks from VC-1, Valles Caldera, New Mexico. EOS 68(44), 1515.

Goff, F. and Nielson, D. L., 1986. Caldera Processes and Magma-hydrothermal Systems: Continental Scientific Drilling Program-Thermal Regimes, Valles Caldera Research, Scientific, and Management Plan. Los Alamos National Laboratory Report LA-10737-OBES, 163 pp.

Goff, F. and Shevenell, L., 1987. Travertine Deposits of Soda Dam, New Mexico and their Implications for the Age and Evolution of the Valles Caldera Hydrothermal System. Geol. Soc. Amer. Bull. 99, 292.

Goff, F., Nielson, D., Gardner, J., Hulen, J., Lysne, P., Shevenell, L., and Rowley, J., 1987. Scientific Drilling at Sulphur springs, Valles Caldera, New Mexico: Core Hole VC-2A. EOS, 68(30), 649.

Goff, F., Shevenell, L., Gardner, J., Vuataz, F., and Grigsby, C., 1988. The Hydrothermal Outflow Plume of Valles Caldera, New Mexico, and a Comparison with other Outflow Plumes. J. Geophys. Res. 93, 6041.

Hulen, J., Nielson, D., Goff, F., Gardner, J., and Charles, R., 1987. Molybdenum Mineralization in an Active Geothermal System, Valles Caldera, New Mexico. Geology 15, 748.

Hulen J., Gardner, J., Nielson, D., and Goff, F., 1988. Stratigraphy, Structure, Hydrothermal Alteration and Ore Mineralization in CSDP Core Hole VC-2A, Sulphur Springs Area, Valles Caldera, New Mexico. University of Utah Research Institute Report ESL-88001-TR, 44 pp.

Nielson, D. and Hulen, J., 1984. Internal Geology and Evolution of the Redondo Dome, Valles Caldera, New Mexico. J. Geophys. Res. 89, 8695.

Smith, R. and Bailey, R., 1966. The Bandelier Tuff: A Study of Ash-Flow Eruption Cycles from Zoned Magma Chambers. Bull. Volcan. 29, 83.

Smith, S. and Kennedy, B., 1985. Nobel Gas Evidence for Two Fluids in the Baca (Valles Caldera) Geothermal Reservoir. Geochim. Cosmochim. Acta 49, 893.

Starquist, V., 1988. Core Log, Valles Caldera #2A, New Mexico. Los Alamos National Laboratory Report LA-11176-OBES, 87 pp.

Truesdell, A. and Janik, C., 1986. Reservoir Processes and Fluid Origins in the Baca Geothermal System, Valles Caldera, New Mexico. J. Geophys. Res. 91, 1817.

Vuataz, F., Goff, F., Fouillac, C., and Calvez, J., 1988. A Strontium Isotope Study of the VC-1 Core Hole and Associated Hydrothermal Fluids and Rocks from Valles Caldera, Jemez Mountains, New Mexico. J. Geophys. Res. 93, 6059.

White, A., 1986. Chemical and Isotopic Characteristics of Fluids within the Baca Geothermal Reservoir, Valles Caldera, New Mexico. J. Geophys. Res. 91, 1855.

Woldegabriel, G., Goff, F., and Heiken, G., in press. Hydrothermal Alteration Events in the Jemez Mountains, New Mexico. Abst. Geol. Soc. Amer. Annual Mtg., Denver, CO Oct., 1988.

DETAILED STUDY ON THERMAL CONDUCTIVITY DISTRIBUTION IN JAPANESE GEOTHERMAL FIELDS

MATSUBAYASHI, O. and SUTO, S., Geol.Surv. of Japan, Tsukuba 305, Japan

1. Introduction

Thermal conductivity is an important physical property not only for the study of heat flow but also for many practical problems, which include extracting heat from a hot and dry rock body. However, as far as the actual values of subsurface thermal conductivity distribution for the Japanese Islands are concerned, very few systematic study has been made yet. The authors have measured thermal conductivity of a large number of drill-core samples, as well as some surface rocks in Japanese geothermal fields. In this paper, discussions are made on the relationship between thermal conductivity and other physical properties, in an attempt to obtain a better view of the nationwide distribution of thermal conductivity, which is necessary to convert existing temperature gradient values to heat flow values.

2. Sample Preparation and Measurement

All the thermal conductivity measurements in this work were made by a transient type method using QTM ("quick thermal conductivity meter" produced by Showa Denko Co., see Sass et al(1984) for comparison experiment with the divided-bar method). One of the advantages of this method is that water saturation of rock samples can be easily maintained during the measuring time of one sample, which is only 40 seconds. Together with thermal conductivity, bulk density and effective porosity were measured on the same samples. The standard steps taken for both thermal conductivity and bulk density (and porosity) determination on saturated samples were the followings:

(1) evacuate the pore of a sample for about one day using a vacuum chamber and then, without introducing the air, admit distilled water into the sample in a bucket placed in the vacuum chamber.

(2) leave the samples in the water-filled bucket under atmospheric pressure for two days.

(3) measure the thermal conductivity by QTM with a thin wrapping film on its surface for keeping the saturated condition. Instrumental error of conductivity measurement is usually less than $\pm$ 3 %.

(4) measure the weights in air and in water to get the bulk volume of the samples. Experimental error of bulk density measurement is usually less than $\pm$ 0.2 %.

(5) lastly dry the samples in an oven at 95°C for 7 days or more to measure the "dry weight", which is used to calculate the porosity value.

Surface rock samples were studied for the Sengan field, one of the largest geothermal resource area in Northeast Japan, having a coverage of a wide range of lithologies, from Paleozoic sedimentary rocks to igneous rocks of varied compositions, namely granitic, rhyolitic, dacitic, and andesitic rocks, and the volcanics are composed of tuffs, welded tuffs and lavas. The core samples studied in this work have as large variability of rock types as the surface rocks.

3. Correlation between thermal conductivity and bulk density

In the first place, Fig.1 shows the correlation between thermal conductivity and bulk density measured on the core samples from deep drill-holes (solid squares), as well as the surface rock samples (open squares) in and around the Sengan field. Square symbols indicate the average of individual geological units, each of which containing 10 to 40 measured samples. The bold alphabets attached to them are the code name of the geological units. It is noticed in Fig.1 that there is a good positive correlation between these two properties:

formations with higher thermal conductivity generally have higher bulk density. This observation can better be understood, if we look at the corresponding effective porosity values at the same time (Table 1). Unit K (Kanto-no-sawa Formations) is the most porous of all in the table hence characterized by the lowest thermal conductivity. Unit P (Paleozoic) is the densest of all, so that it gives the highest conductivity. Thus, as a first order approximation, the variational trend of thermal conductivity vs. density may be attributed to the effect of porosity. If we examine the correlation plot for a particular unit, such a trend can be interpreted reasonably. For example, Fig.2 is the correlation plot for the unit D, indicating the effect of variable porosity.

However, as previously recognized, even after correction is made to get the zero-porosity conductivity, called the intrinsic thermal conductivity hereafter, there is a range of thermal conductivity value for different rock-forming minerals. According to Horai(1971), materials with the same M.A.W.(Mean Atomic Weight) have a conductivity (K) vs. density (D) relationship expressed as

$$K = \underline{a} + \underline{b}\, D$$

where $\underline{a}$ is a decreasing function of M.A.W. but $\underline{b}$ is a constant. Therefore, minerals rich in Fe and Mg with higher atomic weight have lower thermal conductivity for the same density. This means on the plot shown in Fig.1 that, assuming the same porosity, Fe and/or Mg-rich rocks make the points to the upper left direction, whereas SiO_2 enriched rocks move to the lower right direction. The relation between the unit L (mostly andesitic lavas) and the unit Tt (Tertiary tuffs of more felsic composition) with nearly equal porosity is a good example.

Next, a family of standard curves of hypothetical materials having different intrinsic thermal conductivity values is superimposed on the correlation plot given above (Fig.3). From this figure, the intrinsic conductivities common to the units are estimated to be 2.4, 2.7 and 2.9 W/mK for the units L, D and G, respectively. The value for unit R may have a range between 3.2 and 3.6.

In the same way, a correlation plot together with the same standard curves is produced for the core samples from deep drill-holes in the Hohi area, Kyushu (Fig.4). The stratigraphic sequence by Tamanyu(1985) is followed here. The intrinsic conductivities of the basement units are estimated to be 2.6 and 3.1 W/mK for the units B and I, respectively. The values for the Hohi Volcanics (HG, HN,HS,HC,HB and HK) are variable and lower than 2.6. It is noted that unit AI, one of the younger volcanic unit, is indistinguishable from the Hohi Volcanics. The reasons for the higher thermal conductivity of units KM and AY are now under investigation.

4. Thermal conductivity distribution

The above data are very useful for conversion of rock density data, which is relatively well known, to thermal conductivity. Fig.5 is one of the results of such an approach. In this case, vertical distribution of thermal conductivity for a drill-hole is generated from the density log data independently taken for the same hole. Further studies along this line on horizontal and vertical distribution of thermal conductivity are in progress.

References

Horai, K. (1971) Jour. Geophys. Res., 76, 1278-1308.

Sass, J. et al.(1984) Jour. Volcanol. Geotherm. Res., 20, 145-153.

Tamanyu, S. (1985) Report Geol. Surv. Japan No.264, 115-142.