

Synthetic Fluid Inclusion Logging

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Abstract: A new logging tool of synthetic fluid inclusions has been developed for temperature measurements in high-temperature geothermal wells. Fluid trapped in fracture planes of a mineral results in fluid inclusions through healing. Fluid inclusions in quartz can be synthesized easily in the borehole environment. Cracked crystals of quartz soaked in silica-saturated alkaline solution in a gold capsule mounted on a container are placed in a geothermal borehole for temperature measurements. Trapping temperatures of fluid inclusions in quartz are determined by microthermometric measurements using a heating stage, and by pressure correction. Since α -quartz is stable to 573°C, this tool can be applied to high temperature geothermal boreholes whose temperature cannot be measured by conventional tools.

Key words: synthetic fluid inclusion, temperature logging, microthermometry, quartz, Kakkonda geothermal field

INTRODUCTION

Synthetic fluid inclusion logging is a new tool for temperature measurements and fluid sampling in boreholes, and the new logging method was proposed within the drilling project in Valles Caldera, New Mexico (Bethke *et al.*, 1990). It can be applied to very high temperature geothermal wells in which conventional logging tools do not work. This new tool is being developed for the logging of WD-1, which is a 4,000m-deep research hole at the Kakkonda geothermal field, drilled by New Energy and Industrial Technology Development Organization (NEDO) (Yagi *et al.*, 1994). The depth of the hole was 1,500m in May, 1994. It will be completed in 1996. The first downhole experiment was conducted in WD-1 in the fall of 1994.

LOGGING PROBLEMS FOR HIGH TEMPERATURE GEOTHERMAL WELLS

Temperatures higher than 350°C have been determined in a number of geothermal wells drilled in igneous-related geothermal systems in several countries. The highest temperature measured in a Japanese geothermal system is 373°C (Fushime, southern Kyushu) where the salinity of the geothermal fluid is close to that of sea water. The highest temperature geothermal wells occur in Italy (Bruni *et al.*, 1983) and exceed 419°C (melting point of zinc). The temperatures at deep levels of the Kakkonda geothermal system, where WD-1 is being drilled, are also estimated to be above 350°C from the previous drill hole data. The highest equilibrium temperature is calculated to be 412°C (Saito, 1994).

One of the current problems logging high temperature geothermal holes is temperature logging equipment itself. A conventional mechanical downhole instrument of bi-metal application has a temperature limit of 370°C. When platinum resistance is applied to a sensor, a very wide range of temperatures can be measured. However, the problem is the strength of a cable for data transfer. A high-temperature downhole cable is made up of Teflon, whose tensile strength has a length limit of 3,000m over 315°C. On the contrary, an electronic device installed in an insulated vessel can measure temperatures at deeper levels, if good insulation is fabricated. This type of tool can currently measure temperatures as high as 375°C in our country. The high temper-

atures in the Italian geothermal wells were measured using metals whose melting point is known. This tool only indicates that the maximum temperature is higher than the melting point of the metal that fused in the well. Thus, we have no logging tools applied to depths deeper than 3,000m, that can accurately measure temperatures over 375°C.

PRINCIPLES OF SYNTHETIC FLUID INCLUSION LOGGING

Synthetic fluid inclusion logging can be used to measure temperatures as long as the host crystal is stable. α -Quartz is one of the most suitable minerals for this tool, because it is stable up to 573°C. The fluids trapped in microcracks in quartz result in fluid inclusions through healing. This process occurs very commonly in hydrothermal minerals within natural geothermal systems. Thus, the use of synthetic fluid inclusions is an application of natural crack healing in minerals. We do not know how long it takes to heal natural cracks in minerals. If it takes several years, this method will not be appropriate for logging. The healing speed is dependent on temperature and chemistry of fluids, especially the pH. Thus, we can control the time of fracture healing by altering chemistry of the fluids in capsules isolated from the borehole fluid.

Cracked quartz is one of the optimum host materials for synthetic fluid inclusions. It is soaked in a silica-saturated alkaline solution in a gold capsule, which is mounted in a container. The containers are placed in a geothermal hole for several days to

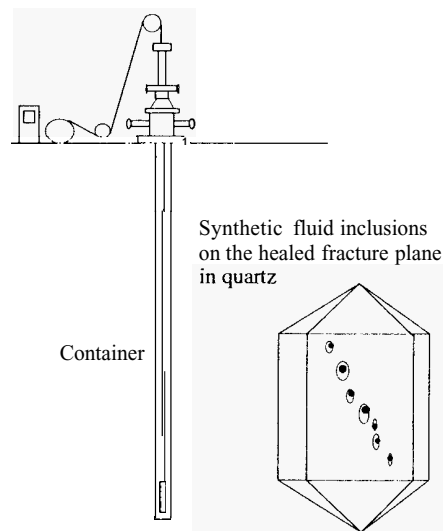


Figure 1. Synthetic fluid inclusion logging

several tens of days to heal fractures in the host quartz crystals (Fig. 1). The crystals that are recovered from the boreholes contain a number of fluid inclusions. Trapping temperatures of fluid inclusions are determined by conventional microthermometric measurements using a heating stage.

Since the host material of α -quartz is stable to temperatures as high as 573°C, as described above, synthetic fluid inclusion logging can be applied to high-temperature geothermal boreholes whose temperature cannot be measured by conventional tools.

HYDROTHERMAL EXPERIMENTS IN AN AUTOCLAVE

Fluid inclusions have been synthesized in many laboratories for geological and geochemical studies (e.g. Sterner and Bodnar, 1984). The most popular host crystal is quartz because it is stable in a wide range of temperatures, and because it is not chemically very reactive. Fluid inclusions can easily be produced in microcracks of quartz in hydrothermal experiments. All the previous hydrothermal experiments, however, have been carried out under pressures much higher than found in the geothermal environments.

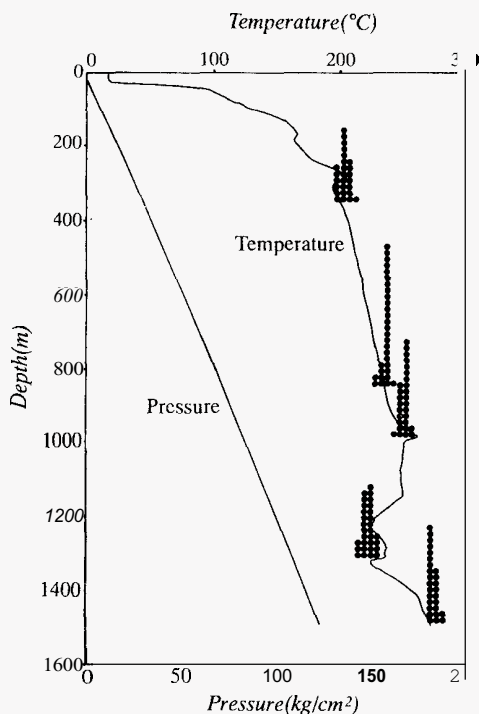


Figure 2. Results of synthetic fluid inclusion logging in WD-1. T_h of the fluid inclusions are plotted at class intervals of 5°C.

Preliminary experiments at the Geological Survey of Japan have been conducted, using an autoclave under vapor-saturated temperature-pressure conditions approximating geothermal environments. A fracture-healing speed under vapor-saturated pressures is slower than under high pressures. For the rapid formation of fluid inclusions in microcracks, pH must be controlled in the solution. A silica-saturated NaOH solution is suitable for rapid formation of fluid inclusions in cracked quartz, because quartz is more soluble in alkaline solutions. Thus, fluid inclusions can be synthesized under vapor-saturated pressures, when cracked quartz is soaked in a silica-saturated alkaline solution in a gold capsule. We succeeded in synthesizing fluid inclusions in this solution of pH 13 at a temperature of 200°C under vapor-saturated pressures.

DOWNHOLE EXPERIMENTS

The first borehole experiment was conducted in WD-1 at the Kakkonda geothermal field from September to October 1994 (24 days), when the depth of the borehole was 1,500m. Containers with quartz crystals were placed at five levels. The quartz crystals were soaked in silica-saturated NaOH solutions of pH 13 in gold capsules. After the experiment fluid inclusions were synthesized in all the recovered quartz. Homogenization temperatures (T_h) of the fluid inclusions measured by a heating stage are nearly consistent with borehole temperatures measured by a conventional logging tool (Fig. 2). But trapping temperatures, which are calibrated T_h by pressure correction based on isochores of water, are slightly higher (1–6°C) than the borehole temperatures. Difference of physical properties between NaOH solutions and water could be one of the reasons for this temperature discordance. If isochores of NaOH solutions are much steeper than those of water, pressure correction might be negligible. We must elucidate this problem for accurate temperature determination. Next borehole experiments will be carried out two more times when WD-1 reaches 3,000m and 4,000m, respectively.

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