FLUID INCLUSION EVIDENCE FOR RECENT TEMPERATURE RISING AT FENTON HILL HOT DRY ROCK TEST SITE WEST OF THE VALLES CALDERA, NEW MEXICO, U.S.A.

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Introduction

The fluid inclusions in calcite veins and those in quartz of the host Precambrian rocks from GT-2 drill hole have been studied microthermometrically to determine the recent thermal history of the Fenton Hill Hot Dry Rock test site west of the Valles caldera, New Mexico.

The volcanic activity in the Jemez mountains began in Miocene time with basaltic and rhyolitic eruptions, culminating in the ignimbrite eruptions forming the Valles caldera 1.45 Ma and 1.12 Ma ago (Smith and Bailey, 1966; Doell et al., 1968; Gardner et al., 1986; Self et al., 1986). The resurgent doming and ring fracture volcanism followed the caldera collapse (Smith and Bailey, 1968). The youngest volcanism is the Banco Bonito obsidian at 0.13 Ma on the southern margin of the caldera (Marvin and Dobson, 1979).

Deep holes were drilled at Fenton Hill to test a method for extracting geothermal energy from hot and impermeable rocks (Smith, 1975). The active heat source for them is believed to be present beneath the Valles caldera (Laughlin, 1981). An early thermal modeling for the HDR test site was constructed based on the assumption of simple cooling of the magma reservoir related to the caldera-forming ignimbrite eruptions (Kolstad and MacGetchin, 1978). The reexamination of the geotherm of the deep holes and an $^{40}Ar/^{39}Ar$ isotopic study, however, indicate recent temperature increasing at the HDR test site (Harrison et al., 1986).

Fluid inclusions from the GT-2 drill hole

The well GT-2, one of the deep drill holes for the HDR project, penetrates the Cenosoic and Paleozoic volcanic and sedimentary rocks above 722 m depth, and the Precambrian basement to the total depth of 2929 m. The temperature gradient changes remarkably at the boundary between the Paleozoic and Precambrian rocks, because of the lateral flow of hot water above the boundary (Kolstad and McGetchin, 1978; Laughlin, 1981). The bottom hole temperature is 197°C (Albright, 1975).

An early fluid inclusion study on the reequilibration of secondary inclusions in Precambrian crystalline rocks from EE-1 and GT-2 revealed that a thermal maximum of the paleo-geotherm was 10-20°C/km higher than the present gradient (Burruss and Hollister, 1979). Since this study focuses on the thermal history after this thermal maximum, the hydrothermal calcite veins in addition to quartz in the host rocks have been investigated. Although several core samples with hydrothermal mineral veins were recovered from the deep drill holes, most of them are too thin for a microthermometric study of fluid inclusions. Only two calcite veins from 1876 m and from 2624 m are adequate in size.

The calcite veins from both depths contain primary and secondary inclusions. The primary liquid-rich inclusions are present in a three dimensional array, and the secondary inclusions occure on healed fracture planes. The secondary inclusions from 2624 m are mainly liquid-rich and subordinately monophase liquid, and those from 1876 m are all monophase liquid. The secondary inclusions in quartz of the Precambrian crystalline rocks are distributed along healed fracture planes. They are liquid-rich two phase and monophase liquid inclusions.

Microthermometry

The homogenization temperature (Th) and final melting point of ice (Tm) of the primary and secondary two-phase liquid-rich inclusions in calcite and the secondary liquid-rich inclusions in quartz of the host Precambrian rocks were measured using a USGS type gas flow heating/freezing stage (Fig. 1). Tm was not measured on several inclusions in calcite whose Th was measured, because ice was invisible on freezing runs. Secondary inclusions with high density, whose bubble disappeared on freezing, showed positive values of Tm, probably because of metastability from negative pressure (Roedder, 1967).

Th and Tm of the fluid inclusions in the host Precambrian rocks are remarkably different from those in the calcite. Burruss and Hollister (1979) revealed that Th and Tm of the fluid inclusions from the surface and shallow core samples range widely, but Th in the samples below 1500 m depth increases regularly with increasing of Tm. This evidence can be explained by reequilibration of the fluid inclusions in the deep core samples involving small scale hydrofracturing by reheating rocks containing fluid inclusions entrapped at lower temperatures (Burruss and Hollister, 1979). Because an isochore of low salinity inclusion is steeper than high salinity one, compositional variation of the fluid inclusions formed under the same temperature and pressure may give the variation of Th. Actually the intersections of the isochore of low salinity inclusions with high Th and that of high salinity inclusions with low Th at several depths are close to the slope of 70°C/km. This indicates that these inclusions may have reequilibrated under the temperature and pressure at these intersections close to this slope (Burruss and Hollister, 1979).

In the present study, Th and Tm of several secondary inclusions on each healed fracture

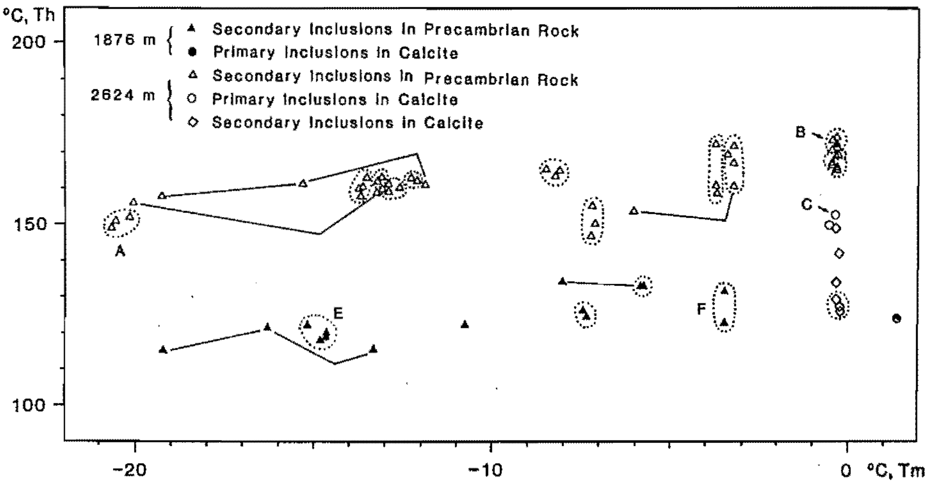

Fig. 1. Th-Tm diagram for fluid inclusions. Th : homogenization temperature, and Tm : final melting point of ice. Secondary inclusions on the same fracture plane are encircled by a dotted line, or they are connected with a solid line. Letters correspond to those in Fig. 2.

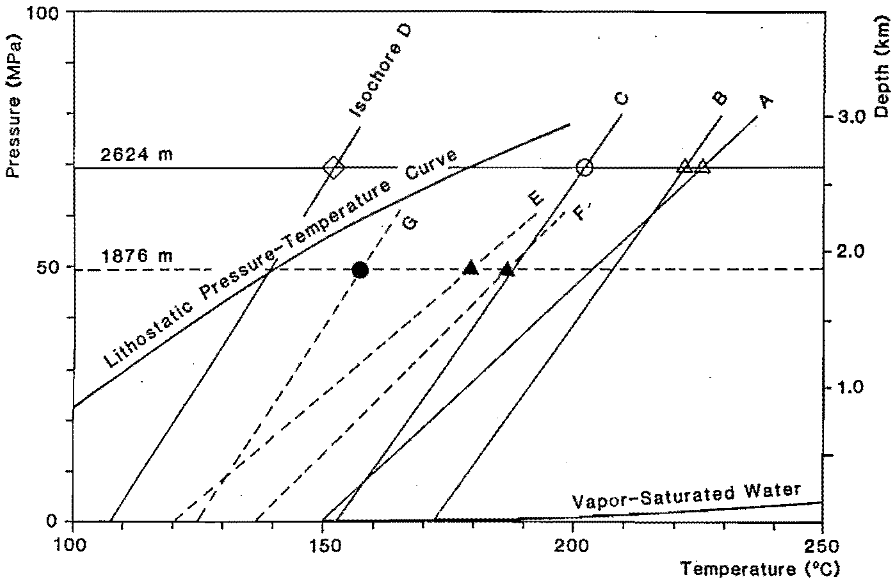

Fig. 2. Trapping temperatures of fluid inclusions determined from their isochores under the assumption of lithostatic pressure calculated, using a density of 2.7 g/cm^3 which is the mean value of the rocks from GT-2 (LASL HDR Project Staff, 1978). Isochores are represented approximately by straight lines based on the data of Potter and Brown (1977). Solid and dashed lines are for 2624 m and 1876 m respectively. Letters A-F correspond to those in Fig. 1. Trapping temperature for these inclusions are represented by the symbols common to Fig. 1. The isochores D and G are produced on the assumption that their salinity is 0.5 and 0.2 wt % NaCl eq. respectivery.

plane were measured in the samples from the both depths (Fig. 1). The present results on Th-Tm relation are generally consistent with those of Burruss and Hollister (1979). The range of Th

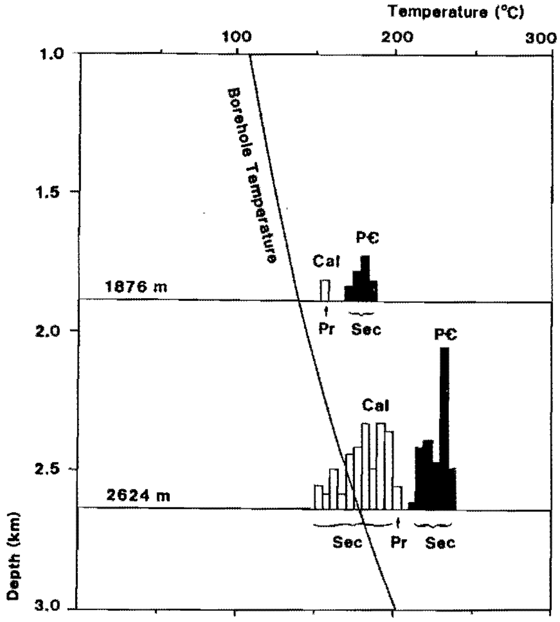

Fig. 3. Trapping temperature of fluid inclusions, assuming lithostatic pressures, on a temperature-depth diagram with the thermal profild of GT-2. Solid symbols are for fluid inclusions in the host Precambrian rocks, and open symbols are for fluid inclusions in calcite.

in all groups of secondary inclusions in small. The range of Tm in most groups is also small, but that in several groups is greater than five degrees. This indicates that most fluid inclusions within a given plane reequilibrated without fluid change, but several fluids occasionally were mixed across the planes.

Since tha fluid inclusions trapped the non-boiling fluids, the trapping temperature should be on the isochores starting from the Th. If a trapping pressure is known, a trapping temperature is determined from the isochore. Although the pore pressures at which the calcite precipitated in the fractures are unknown, the maximum trapping pressure probably does not exceed the lithostatic pressure. The amount of surface erosion after calcite precipitation is probably of little significance. Thus the maximum trapping temperature may be determined from the isochores as shown in Fig. 2. The reequilibration temperature of the secondary inclusions in the host rocks under the lithostatic pressure are also determined on Fig. 2, using the assumption of insignificant amount of erosion.

Thermal history

The highest temperature of the GT-2 are recorded in the secondary fluid inclusions in the Precambrian crystalline rocks. They show a thermal gradient of 70°C/km, which is 10-20°C/km higher than the present geothermal gradient (Burruss and Hollister, 1979). The thermal maximum represented by the reequilibration temperature of the secondary inclusions in the Precambrian rocks (Fig. 4) is presumably related to the heating from the magma reservoir which erupted the Bandelier tuff.

The trapping temperatures of the primary inclusions, which indicate the temperature of the precipitation of calcite in the fractures of the Precambrian crystalline rocks 10°C to 15°C lower than the minimum reequilibration temperature of the secondary inclusions in quartz of the host rocks (Fig. 3). Since calcite stretches above Th more easily than does quartz (Prezbindowski and Larese, 1987; Gratier and Jenatton, 1984), the primary inclusions in the calcite must have not formed before the reequilibration of the secondary inclusions in quartz. Hence the veinings of calcite are younger than the reequilibration of the secondary inclusions in the host rocks (Fig. 4).

Secondary inclusions were formed by healing the fluid-filled fractures during the cooling process after the formation of primary inclusions (Fig. 4). Judging from the comparable salinity of the secondary and primary inclusions, similar hydrothermal fluids circulated through thin cracks in the calcite veins, or the fluids in the secondary inclusions were derived from the primary inclusions. No low-Th secondary inclusions in quartz of the host rocks comparable to those in the calcite indicate that the hydrothermal activity is limited to the thin fractures.

The trapping temperatures of some of the secondary inclusions are definitely lower than the present borehole temperature, assuming formation under lithostatic pressure (Fig. 3). The lowest trapping temperature of the secondary inclusions determined is 152°C, that is, it is 26°C lower than the present borehole temperature of 178°C at 2624 m depth (Figs. 3 and 4).

Since the present temperature is higher than the trapping temperature for some of the secondary inclusions, stretching may have occurred (Bodnar and Bethke, 1984; Prezbindowski and Larese, 1987). Measured Th lower than 125°C are less frequent than the higher Th. This might be due to stretching of high density inclusions. The possible stretching and the presence of the high density monophase secondary inclusions suggest that the lowest temperatures reached after forming the calcite vein are presumably lower than the minimum trapping temperature determined (Fig. 4).

Conclusions

The fluid inclusions in the calcite veins and those in quartz of the Precambrian crystalline rocks from the GT-2 indicate heating up to the thermal maximum, cooling and calcite

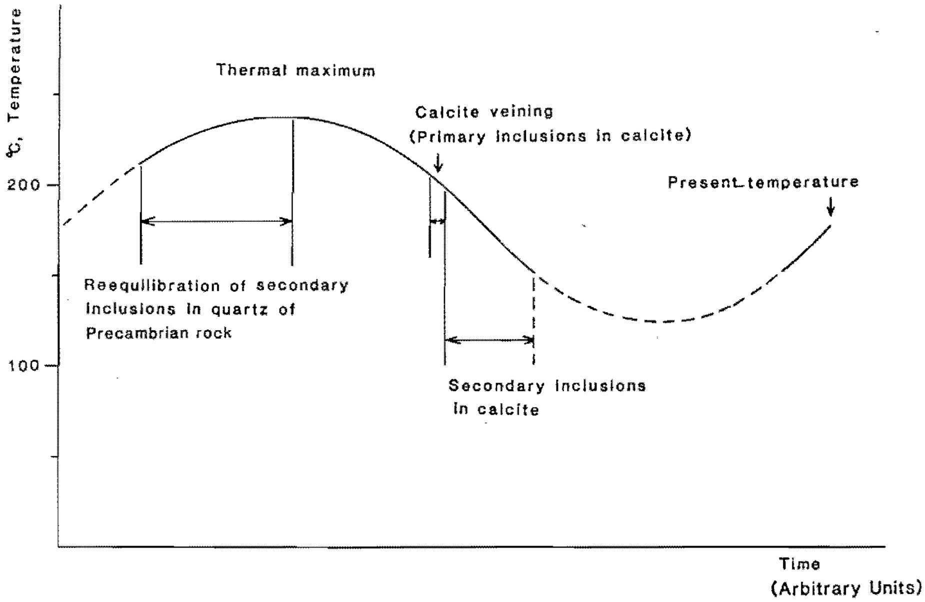

Fig. 4. Schematic diagram for temperature change with time at 2624 m of GT-2 drill hole.

veining, and heating again to the present temperature. The reequilibration of secondary inclusions in the Precambrian crystalline rocks occurred at the thermal gradient maximum of 70°C/km. The calcite veins formed at the temperatures of 10-15°C lower than the minimum reequilibration temperature. The lowest temperature reached after the thermal maximum is 152°C or lower at 2624 m. It is at least 26°C lower than the present borehole temperature of 178°C. The temperature has increased again to the present thermal gradient.

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