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THE APPLICATION OF FLUID INCLUSION GEOTHERMOMETRY BASED ON SECONDARY INCLUSIONS IN PRIMARY IGNEOUS QUARTZ CRYSTALS

K.J. YOUNGMAN

Geothermal Institute
University of Auckland

ABSTRACT

Primary igneous quartz crystals in the cores and cuttings of volcanic rocks from the Wairakei–Tauhara geothermal field usually have been fractured. Secondary fluid inclusions have formed along many of the fracture planes as the fractures have healed. These inclusions exhibit little variation in homogenization temperature within single fracture planes, suggesting that annealing was rapid.

Due to the large size (up to 5mm diameter) and common occurrence of primary igneous quartz crystals at Wairakei–Tauhara, more detailed and complete fluid inclusion geothermometry of the field is now possible compared to the previous use of hydrothermal minerals only. This, in turn, allows a better evaluation of past variations in the thermal regime of the field.

Results for samples from well TH1, for example, show that temperatures of over 280°C have occurred at 975m depth in the past, but that it has since cooled to the present 250°C.

Introduction

Fluid inclusion geothermometry is a technique that has important applications in geothermal investigations (Roedder 1984, Browne and Ellis 1970, Leach 1982, Hedenquist and Henley 1985).

As hydrothermal minerals form within geothermal systems, microscopic quantities of fluid are trapped within the crystal, forming fluid inclusions. In the situation where the geothermal fluid is liquid, then the fluid inclusion formed also contains a liquid. However, on cooling of the crystal, such as when a core is recovered, the liquid in the inclusion contracts. The result is a two phase inclusion containing both liquid and vapour. Subsequent reheating, on a microscope stage will re-homogenise the two phases to a single liquid phase. The homogenisation temperature can be directly related to the trapping temperature if the salinity of the inclusion fluid, and pressure at trapping are known. For inclusions which are trapped at saturated vapour pressure, the homogenisation ternperture is the trapping temperature. For inclusions that form at any pressure above that of saturation, a correction must be made. In geothermal environments where salinity (1-2000 mg/kg Cl^-) and pressure (5–15 MPa) are low, the correction is small and the homogenisation temperature is used rather than the temperature of trapping.

Inclusions in Hydrothermal (Secondary) Material

Inclusions that form during the growth of a hydrothermal crystal are termed "primary" inclusions and record the temperature of formation of the crystal. Inclusions may also form subsequent to the completion of crystal growth; these occur in planes along annealed fractures, and are termed "secondary" inclusions. Often primary and secondary inclusions in the same crystal record different trapping temperatures, and are thus evidence of thermal change within a system. Furthermore, trapping temperatures may also differ between planes of secondary inclusions as a result of differing fracture ages and changing thermal regime.

Inclusions in Primary Material

To date, fluid inclusion geothermometry in the Taupo Volcanic Zone has been undertaken in a number of fields using both primary and secondary inclusions in hydrothermal quartz, calcite, sphalerite and zeolite (Browne 1970, Hedenquist 1983, Kakimoto 1983).

The limitation that the use of hydrothermal minerals places upon fluid inclusion geothermometry is one of sample availability. Data can only be determined where hydrothermal veins or large single crystals occur in cores or cuttings. Often hydrothemal minerals form alteration products that are too small to manipulate.

Recent work indicates, however, that primary igneous quartz phenocrysts in the silicic rocks of the Taupo Volcanic Zone are also suitable for fluid inclusion geothermometry. Primary quartz crystals in the Wairakei–Tauhara area (notably in the Wairakei Ignimbrite) usually have been fractured, most probably as a result of deformation. Furthermore, these fractures have annealed, as is the case with fractured hydrothermal crystals, to contain planes of secondary fluid inclusions. Homogenisation temperatures measured within a single fracture plane commonly exhibit only 2 or 3 degrees variation, suggesting that annealing is rapid. Shelton and Orville (1980) demonstrated that planes of fluid inclusions could be produced in fractured quartz in three days at 500°C and 2 kbar. It seems probable that fractures in primary igneous quartz that occur in geothermal fluid saturated with respect to quartz would anneal within a period that was of a similar order of magnitude.

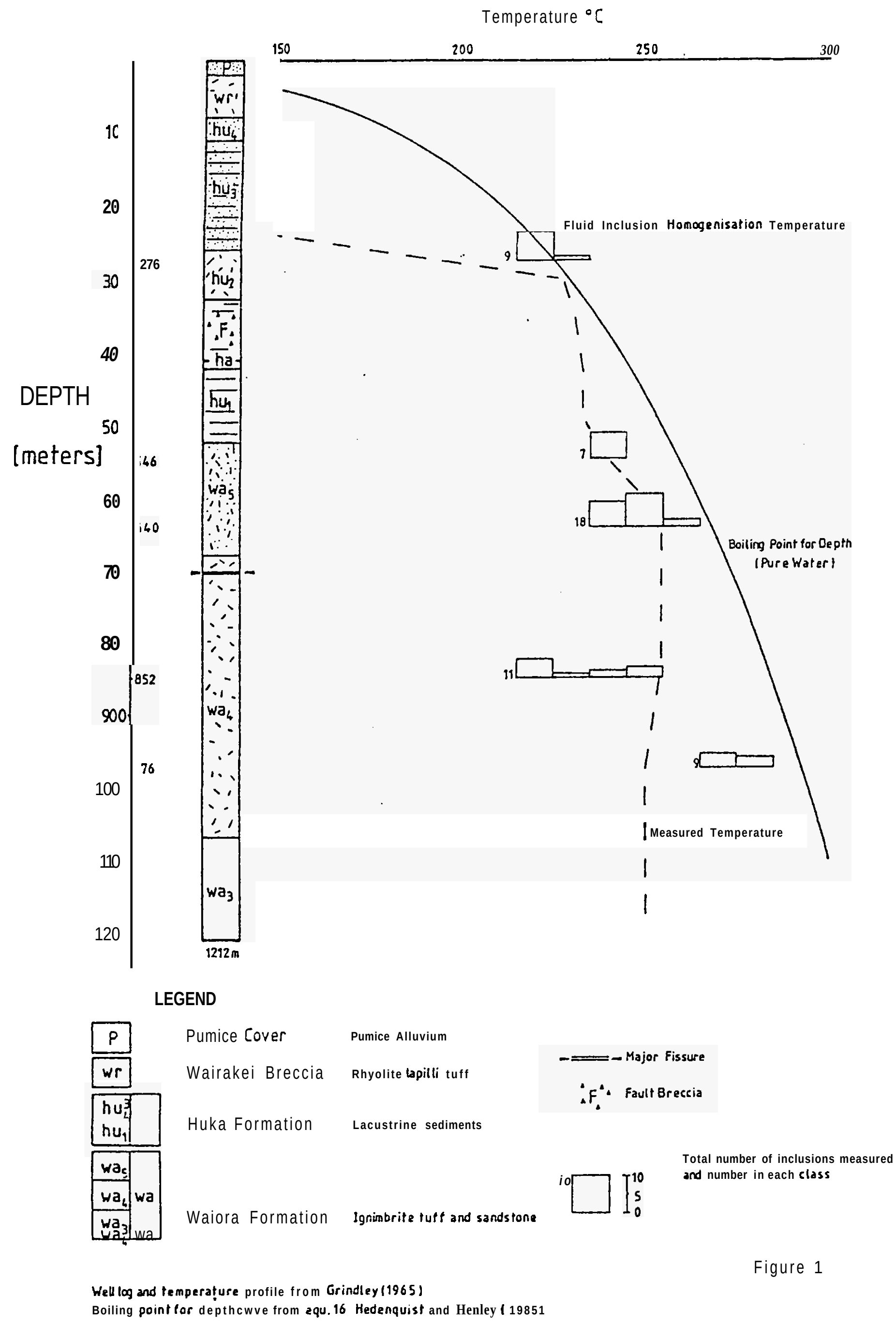

Figure 1: Geologic log of well TH1, showing secondary fluid inclusion homogenization temperatures obtained from primary quartz phenocrysts, compared with the measured temperature and the boiling point for depth.

The presence of secondary fluid inclusions in primary igneous quartz at Wairakei-Tauhara greatly extends the application of fluid inclusion geothermometry in this region. By examining secondary fluid inclusions in primary quartz, it is now possible to obtain a more detailed appraisal of the thermal evolution of a geothermal system than is possible using only hydrothermal minerals. This is due to three factors: firstly, the presence of quartz is almost ubiquitous in the rhyolitic rocks of the Taupo Volcanic Zone systems. Secondly, the large size (0.5-5mm dia) of the primary crystals makes extraction and preparation relatively easy. These two factors combine to allow much closer and more uniform sampling to be undertaken. Thirdly, the primary quartz crystals were present before the onset of the geothermal system and present the opportunity of recording the evolution of the thermal regime, albeit episodically, since its inception. In contrast, it is seldom possible to establish whether or not a hydrothermal mineral is relatively recent or ancient.

Belkin et al. (1985), in an evaluation of the geothermal fields of Tuscany, Italy, used secondary inclusions that had formed along fracture planes in detrital quartz. Here, the detrital quartz within the sediments fulfills the same function as that of igneous quartz at the Wairakei-Tauhara field; that is, both were present before the system was established, and both subsequently record parts of the thermal evolution.

Example of the application of Fluid Inclusion Geothermometry in Igneous Quartz at Wairakei-Tauhara

Presented here (Fig. 1) are the results of a reconnaissance survey of one well from the Wairakei-Tauhara area - TH1. (See Grindley 1965, Steiner 1977, Kakimoto 1983).

Quartz phenocrysts were extracted by hand picking from 10-15 g of crushed core. After preparation, the crystals were 1 to 1.5mm dia and 0.5 to 1mm thick. Homogenization temperatures were obtained using a commercial model of the U.S. Geological Survey gas-flow heating/freezing stage (Woods et al. 1981), calibrated against synthetic quartz standards (Steiner and Bodnar 1984); the accuracy is considered to be ±2-3°C. The homogenization temperature for each inclusion was obtained by repeated cycling, and has a precision of ±0.5°C.

Homogenization temperatures were measured on inclusions from a single crystal at each depth, with the exception of 276m where 3 crystals were used. Ideally, a number of crystals should be sampled at each depth.

At 852m depth, the inclusions record a range of temperatures from the present 250°C to as low as 220°C. This could be interpreted either as evidence of an inversion, due to lateral flow of cooler fluid, or that the lower values represent the system at an early part of its development.

At 976m depth, inclusions record a significantly higher temperature (280°C) than occurs today (250°C). This suggests the absence of an inversion at depth in this area and implies that the well is located in a zone that is at present, or at least has been in the past, one of upflow, rather than a lateral outflow from under Mt. Tauhara to the east.

Temperatures obtained from 640, 546, and 276m depth? are near to modern temperatures and suggest a boiling point for depth relationship for the fluid.

Conclusions

It is apparent that secondary inclusions in igneous quartz are an important adjunct to the thermal profiles of wells obtained by direct measurement; furthermore, they may more truly reflect the conditions in the predrilled field than do measurements made after a well is completed.

An immediate application of this technique could be at the drillsite, where it would be possible to have thermal information about a well as it is drilled, and within 2 or 3 hours of core or cutting recovery. Fluid inclusion geothermometry in this situation could help avoid costly drilling into inversions.

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