THERMAL EVOLUTION AND FLUID-ROCK INTERACTIONS IN THE ORAKEIKORAKO-TE KOPIA GEOTHERMAL SYSTEM, TAUPO VOLCANIC ZONE, NEW ZEALAND.

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ABSTRACT

The active Orakeikorako-Te Kopia geothermal system was drilled in the mid-1960's, down to 1405m, as part of a programme to investigate its electrical generation capability. Four wells were completed at Orakeikorako (23km NNE of Taupo) and two at Te Kopia, 9.5km further northeast. The exploration drilling provided information on the present day hydrological and thermal regime which is as hot as 265°C (1137m drilled depth (-801m RL) in OK-2). Major flows into the wells occurred at depths down to 850m, although poor permeability and decline in mass output discouraged development. The waters discharged were of near neutral pH and had low salinities (highest Cl content from OK-2 ≈546mg/kg), low discharge enthalpies and indicated water temperatures (T_{SiO_2} and T_{NaKCa}) of 210°C to 240°C.

A hydrologic model proposed here envisages a hot water reservoir in the OK-2 area (northeastern part of the Orakeikorako thermal area) with a lateral flow supplying water to the Red Hill (OK-4 area) in the southern part of the system and a concealed northeast flow which reaches the surface at Te Kopia.

The Orakeikorako thermal area occupies a surface area of about 1.8km^2, mainly on the east bank of the Waikato River, where dilute chloride-bicarbonate water discharges along faults and fractures in association with an extensive silica sinter sheet, boiling springs and geysers. The occurrence of a mordenite-smectite assemblage at shallow depths, plus the oxygen and hydrogen isotopic composition of surface discharge waters, indicate that the ascending chloride fluids are diluted by near surface (heated?) groundwaters. The δD shift from local groundwater composition may be evidence for a magmatic component to the convecting hydrothermal system. Incursion of fluids from the relatively cool (<120°C) steam-heated carapace into deep levels of the system and its mixing with the alkali-chloride fluids, produces argillic alteration, sealing and will eventually result in the demise of the system. Old silica sinter on the west bank, at the foot of the Tutukau Rhyolite Dome, is covered by Oruanui Ash (22,700 years B.P.) and demonstrates that the hydrologic character of this part of the system has changed due to a combination of fault movement, changes in the height of the watertable and sealing.

The Te Kopia thermal area is located along 2.5km of the Paeroa Fault scarp, a major structural feature inferred to be controlling migration of deep hydrothermal fluids in the Orakeikorako-Te Kopia area. Surface activity at Te Kopia is characterised by acid alteration (including fumaroles, warm acid pools and steaming ground), although neutral pH alkali-chloride fluids discharged here within the last 3000 years and deposited silica sinter (C^{14} age on wood enveloped by sinter is 3026 +/- 43years B.P.). New thermal areas in the past year have begun to develop in the northwestern part of Te Kopia, whilst cold hydrothermally altered ground (hosting a mordenite + clay assemblage) records a decline in activity in the southern part of the Te Kopia thermal area.

The system is hosted by a generally SE dipping sequence of Pliocene to Quaternary ignimbrite, tuff and rhyolite lavas of the Taupo Volcanic Zone. Point counting, electron microprobe analyses of surviving primary phases (Fe, Mg, Al and Ti contents of hornblende and biotite), together with X-ray fluorescence and neutron activation analysis were used to distinguish three extensive ignimbrites encountered in the Orakeikorako-Te Kopia drillholes: (0.33Ma, sanidine-bearing) Paeroa, (0.35Ma) Te Kopia and (undated) Akatarewa Ignimbrites, despite their having been hydrothermally altered. Ignimbrite recognition is made on the basis of a combination of immobile trace and rare earth element abundances and ratios: Ta and Yb (ppm), P_2O_5(%) and the ratios Zr/Yb, Zr/Y, Yb/Hf, La/Lu, Nb/Hf, Zr/Nb, Zr/Lu, Yb/Ta, Ta/Lu, La/Tb and Nb/Ta.

e.g.	Paeroa Ignimbrite	Te Kopia Ignimbrite	Akatarewa Ignimbrite
Zr/Y	4.89 - 6.35 (mean 5.56)	9.67 - 11.92 (mean 10.78)	7.55 - 9.22 (mean 8.21)
Yb/Ta	2.84 - 3.38 (mean 3.11)	3.22 - 3.67 (mean 3.39)	3.84 - 5.11 (mean 4.32)
P_2O_5	0.013 - 0.040 (mean 0.026)	0.060 - 0.075 (mean 0.068)	0.070 - 0.105 (mean 0.087)

The Paeroa Ignimbrite is distinguished by its Eu anomaly ($(Eu/Eu^*)_{cn}$ is 0.48 to 0.54), whereas the Te Kopia and Akatarewa Ignimbrites are characterised by their flatter REE Spidergrams ($(Eu/Eu^*)_{cn}$ is ~1.0 and ~0.8 respectively). The correlation of the extensive ignimbrites was satisfactorily effected by a combination of their characteristic bulk rock and pumice chemistry, plus primary mineralogy, to enable the subsurface stratigraphy and structure of the Orakeikorako-Te Kopia geothermal system to be defined.

The alteration assemblage below 500m consists of quartz, albite+adularia, with variable abundance and distribution of chlorite, pyrite, calcite, wairakite, epidote, pyrrhotite, titanite, leucoxene, siderite and clinozoisite; illite is a late overprint. Rare almandine occurs in rhyolite in OK-1: 1312.5m; this is the first known occurrence of garnet in an active geothermal system of the TVZ. The surficial alteration assemblage of kaolin, cristobalite, alunite, hematite and jarosite reflects alteration by acid sulphate-steam heated waters.

The occurrence and textural relations exhibited by the hydrothermal mineral assemblage define the geochemical structure and thermal evolution of the Orakeikorako-Te Kopia system. The activities of components of minerals, determined from electron microprobe analyses and composition-activity relationships (OK-2 discharge: $\log\alpha_{K^+}/\alpha_{H^+}=3.6$, $\log\alpha_{Na^+}/\alpha_{H^+}=4.8$) support the petrologic observation that illite is now the stable potassium phase (overprinting adularia), although a state of equilibrium between the sheet silicate and the fluids is clearly not fully reached. The Na/K ratio of the altering fluid is controlled by the albite-adularia reaction (dissolution of albite and replacement by adularia, after andesine), whilst the H_2/H_2S ratio is buffered by the virtually complete replacement of pyrrhotite by pyrite. The fluids are now slightly undersaturated with respect to calcite, this is shown by etched surfaces on some calcite grains.

In the past the deep fluid boiled adiabatically from >300°C to ~250°C as it ascended, resulting in the deposition of adularia, quartz and bladed calcite. The system has cooled, resulting in lower subsurface temperatures (as recorded by fluid inclusion geothermometry) suppressing boiling, and migrated northwards as a consequence of self sealing. The thermal decline and retention of CO_2 in the deep alkali-chloride fluid shifted the alteration assemblage from one of albite-adularia stability to illite stability.

The homogenisation (T_h) temperatures of primary and secondary liquid-rich inclusions in 27 cores from different depths mostly match measured temperature profiles (e.g. OK-1 (shallow levels) and OK-2). Never-the-less, fluid inclusion data support mineral-inferred stability temperatures which indicate that parts of the Orakeikorako-Te Kopia system have cooled appreciably (e.g. OK-1, deep levels) and OK-4 (maximum T_{bore}=238°C, maximum T_h=312°C; epidote abundant). In contrast, the northwestern margin (OK-6 area) has heated (OK-6:1113.4m; T_{bore}=261°C, T_h=210-221°C). Some inclusions in the Te Kopia drillholes have T_h values that exceed T_{bore} by as much as 50°C, and are deduced to have been uplifted by movement on the Paeroa Fault. Freezing data indicate that the trapped fluid was dilute (~0.2 to 1.7 wt% NaCl equivalent) since most T_m values range from -0.1 to -0.5°C.

The outflow portion of the Orakeikorako-Te Kopia system has evolved recently, both chemically and physically. Movement on the Paeroa Fault, that uplifted pyroclastic rocks hosting a quartz-adularia-illite assemblage, combined with a lowering of the watertable has resulted in an overprinting of the neutral pH hydrothermal mineral assemblage by a kaolinite-alunite type assemblage which derives from an acid sulphate fluid. Quartz crystals found 150m above the base of the Paeroa Fault scarp host dilute (~1.5wt% NaCl equivalent) fluid inclusions with T_h values that range from 180-206°C (average 196°C). Bladed quartz (after calcite) did not contain usable inclusions. It is deduced that the inclusions formed about 120-160m below the ground, which indicates uplift in the order of ~300m. Assuming a constant rate of uplift of 4m/ka (based on the offset of 330ka Paeroa Ignimbrite), the minimum duration of activity at Te Kopia is 75,000 years.

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