EVOLUTION OF THE OHAKURI GEOTHERMAL SYSTEM

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ABSTRACT

Mapping and petrographic study of hydrothermal alteration at the now-extinct Ohakuri geothermal field has revealed a long history of activity which varied in nature and lacation. Early flow of neutral to alkaline chloride-type water through rocks now exposed was followed by extensive near-surface flow of acid-sulphate water, with minor hot-spring discharges, which fdrmed scattered sinters, comprising the last activity. High permeability of the porous host rocks facilitated fluid movement, and regional hydrology may have significantly controlled flow patterns, whereas control by tectonic fractures appears to have been minor. Permeability in rock sealed by silicification was sustained by hydrofracturing which resulted in veining and local brecciation. Fluid temperatures probably did not exceed 200°C and were largely less than 100°C at the levels observed. The distribution of hydrothermal features suggests that upflow zones migrated northward and westward with time, and that the now-active Atiamuri geothermal system is probably descended from the fossil Ohakuri field.

INTRODUCTION

Hydrothermally altered rocks and hot spring deposits are exposed over an area of at least 15 km^2 near Lake Ohakuri, 25 km north of Wairakei in the Taupo Volcanic Zone (Fig. 1). These hydrothermal features are the remnants of a now-extinct geothermal system which was similar to presently-active thermal areas in the region. Variable erosion of the altered rocks affords an opportunity to study the upper 100 to 150 m of such a system in much more spatial detail than is possible in an active system.

Mapping of surface geology and alteration types, along with petrographic investigation of samples, allows reconstruction of a number of characteristics of the system, particularly its fluid composition and temperature and their variations through time, controls on fluid movement, and the duration of activity. This study shows that Ohakuri evolved over a long period, with significant changes in the nature and location of activity before the near-surface movement of geothermal waters ceased.

GEOLOGIC SETTING

The Ohakuri field, cut by the Waikato River, occurs in the western part of the Taupo Volcanic Zone, within the Maroa Volcanic Centre (Fig, 1). Hydrothermal activity took place within an area in which the dominant rocks are a sequence of rhyolitic pyroclastics, informally termed the Ohakuri Ignimbrite. The sequence consists of at least 150 m of nearly flat-lying, porous, pumice-rich, massive, nonwelded ignimbrite flows, with minor cross-stratified ignimbrites and thin airfall units. The age of the sequence is unknown, but its

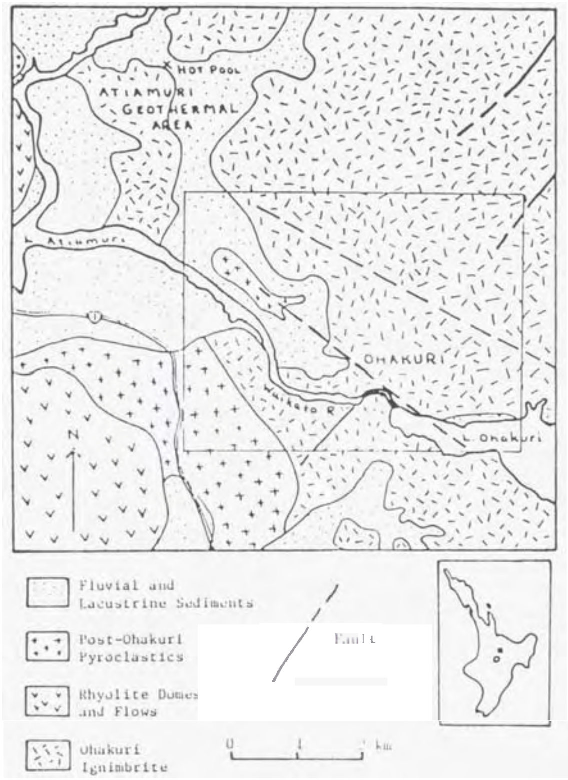

Figure 1: Geology of Ohakuri and vicinity, modified after Grindley (1959). Young tephras (542,000 yrs) not shown. Rectangle indicates area of this study (Fig. 2).

relationship to other volcanic units in the area indicates an age in the range of several hundred thousand to one million years (e.g. Grindley, 1959; Cole, 1979). Up to 10 m of fine-grained ash beds rest on the eroded surface of the Ohakuri Ignimbrite in a small area on the north shore of the Waikato River.

A number of terrace-forming fluvial and lacustrine deposits flank the river, reflecting fluctuating river levels and periodic inundation by lakes since the inception of hydrothermal activity. At least five terraces are present, and two or more of the older deposits have been altered by geothermal water in the same manner as the ignimbrites. The whole area is mantled by tephras which postdate the hydrothermal features now exposed. The oldest of these, the Rotoehu Ash, imposes a minimum age of 42,000 years on the bulk of the hydrothermal activity (Vucetich and Pullar, 1969).

Ohakuri lies on the southwest extension of the northeast-trending Ngakuru Graben, and also within the northwest-trending Maroa Graben proposed by Modriniak and Studt (1959). Tectonic deformation in the area is weak, but minor NE-trending faults have been identified, and several WNW-trending lineaments seen on aerial photographs appear to correspond to zones of more concentrated alteration. The setting of Ohakuri is similar to those of the Orakeikorako and Atiamuri thermal areas, both of which also flank the Waikato River within the Maroa Volcanic Centre and the inferred Maroa Graben.

HYDROTHERMAL ALTERATION

Hydrothermal fluids produced several types of alteration in the tuffaceous rocks now exposed. The different types can be distinguished in the field and correlate closely with petrographic distinctions determined by optical and X-ray Diffraction methods. Most of the alteration is pervasive, with alteration intensity and mineralogy remaining constant over distances of up to 10 m or more. However, variations over smaller distances (to as little as several cm) are frequently observed where the original rock was inhomogeneous, e.g. in thinly bedded pyroclastics with varying grain size distribution or pumice content. Veining, which is common only in intensely altered rock, has produced similar small-scale variations which are visible as alteration haloes. Transitions between types are usually gradual, occurring over distances of at least 10 m, but are locally sharp, particularly where later alteration overprints an earlier event.

Table 1 summarizes the characteristics of the various alteration types. The most intense alteration converted the tuffs to a quartz ± adularia ± sericite (illite and similar sheet silicates) ± pyrite assemblage, with minor amounts of chlorite, clinoptilolite and leucoxene. Quartz, the most abundant hydrothermal mineral, replaces virtually all vitric components and often fills cavities left by the leaching of primary grains. Plagioclase is replaced by adularia, with minor amounts of sericite and rare apatite, and frequently is partially leached.

TABLE 1: Summary of hydrothermal alteration types at Ohakuri

Alteration Type	Quartz - Adularia	Zeolite	Kaolinite	Hot Spring Deposits
Alteration Minerals Quartz Cristobalite Adularia Illite Chlorite Clinoptilolite Mordenite Montmorillonite Kaolinite Alunite Pyrite Hematite Leucoxene Apatite				
Veining	Common; locally intense	Rare	Sparse but locally intense	Rare
Probable Water Type	Neutral - alkaline chloride	Neutral - alkaline chloride (+ meteoric?)	Acid - sulphate	? Mixed chloride and sulphate?
Deduced Water Temperature (°C)	100 - 200	50 - 100	50 - 100	-100

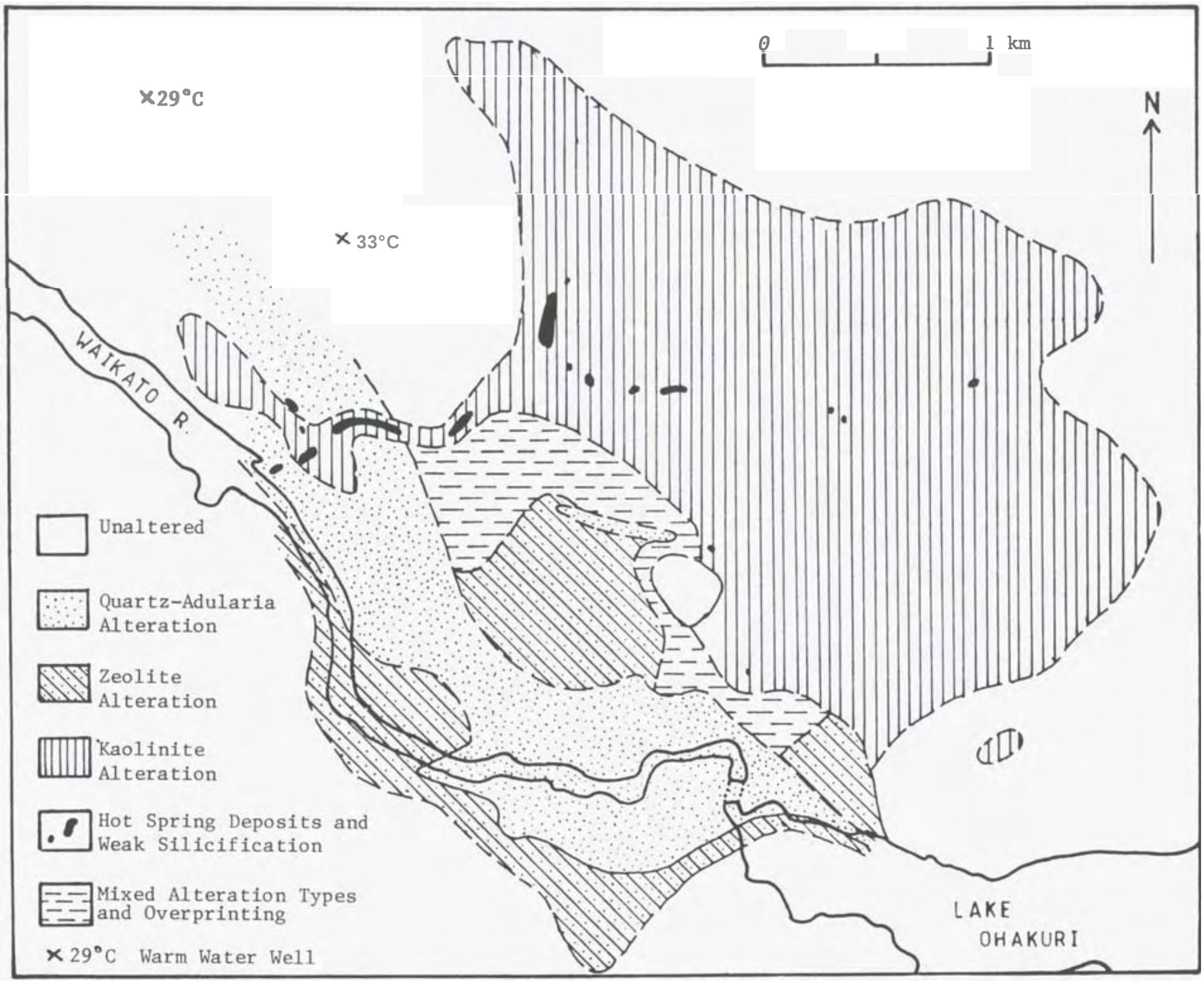

Figure 2: Distribution of alteration types, Ohakuri area. Kaolinite alteration is locally discontinuous. Temperatures of wells (depths 40 - 60 m) were measured February 1982.

Veins of quartz and quartz + pyrite which vary in thickness fom microscopic to several cm are common in zones of quartz-adularia alteration. Zoning within veins, and crosscutting relationships between veins, indicate that a number of distinct episodes of quartz and quartz + pyrite precipitation took place. As many as four such episodes can be recognized in single outcrops. Successive generations of veins follow a progression from extremely thin (<2 mm) fillings with broad haloes to thick (>1 cm) veins without haloes. Many of the thickest veins contain angular clasts of wallrock, and appear to be gradational with hydrothermal breccias present at several locations. These breccias consist of angular and rounded clasts in a quartz ± pyrite matrix, and range from about 1 m to several tens of meters in thickness. The breccias and most veins are thought to be the product of violent hydrofracturing with subsequent infilling by mineral precipitation (e.g. Grindley and Browne, 1976).

Quartz-adularia alteration forms a central zone in the southern portion of the area (Fig. 2) which grades both upward and outward into a zone of less intense zeolite-type alteration (Table 1). This latter type is characterized by weaker silicification, little to no veining, and less dense rocks. Mordenite, montmorillonite and cristobalite are the most abundant hydrothermal minerals, and plagioclase is fresh or only partially replaced by sericite + adularia. The zeolite zone grades into fresh rock, in places through a narrow (10 - 50 m wide) zone in which the only alteration is leaching of pyroxene and amphibole crystals.

Zeolite and quartz-adularia alteration types extend from Ohakuri dam at least 2.5 km to the WNW towards Atiamuri. Though lack of exposure prohibits tracing the zones further, the trend of the mapped alteration indicates that the active Atiamuri system is contiguous with, and very likely descended from, the Ohakuri system. Such a relationship is also suggested by resistivity anomaly-patterns (Dawson et al, 1981) and by the presence of warm water wells at the western margin of the Ohakuri area (Fig. 2).

A third type of alteration, dominated by kaolinite plus variable amounts of cristobalite, hematite and local alunite (Table 1), affected both fresh rocks and rocks previously altnred to zeolite and quartz-adularia types. Rocks of kaolinite type are bleached white and mainly converted to kaolinite or kaolinite + cristobalite. Feldspars have been leached away, and the rock usually has a low density. Local silicification, however, is intense and infilling of leach cavities by cristobalite has occurred. Cristobalite veins, in places containing alunite and pyrite, are present in some zones of stronger silicification. The mineralogy and bleached appearance of the rock are characteristic effects of alteration by acid-sulphate waters, usually produced by condensation of steam (plus oxidation of H_2S) boiled from deeper chloride waters (Ellis and Mahon, 1977).

Alteration to kaolinite type is only found north of the Waikato River (Fig. 2), and lenses of unaltered rock are present within its zone of occurrence. The most intense kaolinization occurs in the north-central part of the zone, diminishing sharply northward and more gradually to the south. This alteration locally overprints quartz-adularia and zeolite types, and has affected younger pyroclastics which lie on the eroded surface of rocks previously altered to quartz-adularia type. These relationships suggest that most, if not all, of the observed acid-sulphate alteration postdates the activity that produced the other types, possibly following an erosional interval.

Several types of local hot spring deposits are present north of the river, being most abundant in the northwestern part of the area (Fig. 2). These include laminated and massive siliceous sinters, weakly silicified fluvial deposits, and silicified breccias containing fragments of sinter and other surficial material. Relative ages of the hot spring deposits are not always known, and their formation may have been partially concurrent with kaolinite alteration. However, stratigraphic relationships suggest that the waning stages of surface activity took the form of small hot springs depositing sinters and causing weak silicification at shallow levels.

PHASES OF ACTIVITY

Field relationships indicate that the area of exposed hydrothermal features at Ohakuri is a now-inactive part of a geothermal system which includes the present Atiamuri geothermal area. Movement of hydrothermal fluids through the Ohakuri Ignimbrite may have begun several thousand years ago, and probably continued intermittently until surface activity ceased over *40,000* years ago. The earliest phase of activity presumably consisted of upward and lateral flow of neutral to alkaline chloride waters, which produced the zones of quartz-adularia and zeolite alteration now exposed over much of the southern portion of the area mapped and possibly extending farther north and west (Fig. 3A). A subsequent period of erosion was followed by near-surface flow of acid-sulphate waters, cohdensed from steam and oxidized H_2S produced by boiling of chloride water at depth, which altered fresh and previously altered rocks to kaolinite type. The main uplow zone for the deep chloride water was north of that for the earlier phase, with shallow fluids flowing southward toward the Waikato River, then following approximately its present course (Pig. 3B).

The presence of widespread acid water at levels previously dominated by chloride water 'suggests that a drop in the water table took place between the two alteration episodes. Such a change could be due to local tectonic uplift, or to a change in regional hydrology. While tectonic movement is a possibility, the abundant lacustrine deposits near Ohakuri, and throughout the Taupo Volcanic Zone, are evidence of the repeated formation and draining of large lakes in the region, which could cause significant water table fluctuations.

The last activity at Ohakuri consisted of minor hot spring discharges which produced small sinters and weakly silicified various surface deposits. This activity took place in the northwestern part of the area, reflecting the progressive migration of the system towards Atiamuri. Although surface activity at Ohakuri is now absent, the continued flow of hot water at depth is not precluded. Additionally, the indications of episodic activity in the past suggest that the resumption of near-surface and hot-spring activity is not impassible.

FLUID PROPERTIES

The approximate temperature and composition of the waters that produced the different alteration types can be inferred from the mineral assemblages present in each type. Minerals useful as temperature indicators include the silica polymorphs, epidote, sheet silicates (montmorillonite, illite and others), and zeolites; common temperature ranges are summarized by Browne (1978). The absence of minerals such as epidote and wairakite suggests that temperatures or fluids causing quartz-adularia alteration probably did not exceed 200°C at the depths exposed, while waters precipitating cristobalite in the zeolite zone were probably cooler than 100°C (Table 1). The abundance of cristobalite and rarity of quartz in kholinite-altered rocks and surficial deposits similarly indicates that the associated fluids were seldom hotter than 100°C.

The neutral to alkaline chloride waters of the early phase of activity were rich in SiO_2 and K^+, and the absence of hydrothermal calcite, common in most geothermal systems, indicates a low dissolved CO_2 content. Temporal changes in fluid chemistry are reflected in the episodic precipitation of iron sulphide in quartz veins. Progressive mineral changes observed in the transition from quartz-adularia to zeolite rock and on to fresh rock probably reflect changes in fluid temperature and composition due to mixing of thermal with meteoric water, and perhaps different degrees of rock-water interaction as well.

The complexity of near-surface alteration and hot-spring deposits associated with the later phases of activity appears to reflect local variations in fluid chemistry. Such variations may have been produced by mixing of different hot-spring waters, possibly of both acid-sulphate and chloride types.

CONTROLS ON FLUID MOVEMENT

Flow of hot water through the Ohakuri Ignimbrite was initially facilitated by high primary permeability. Such permeability is indicated by the pervasive nature of rock alteration, and by the abundance of adularia as a hydrothermal feldspar (Browne, 1978). There is little evidence for significant local control of flow by tectonically-induced fractures such as faults, though the general location of upflow zones may have been controlled by such features.

Fluid movement was apparently not constrained by any lithologic barriers such as an impermeable cap rock, so near-surface flow may have been strongly influenced by the regional hydrologic regime. The sharp transition to unaltered rock at the eastern margin of the quartz-adularia and zeolite zones, compared with a much more gradual change to the east and northeast, may be the result of a dominant northwesterly groundwater flow. Such flow would cause rapid dilution and cooling of ascending thermal water over a narrow zone in the east, whereas dilution would occur over a broader zone at the other margins.

Precipitation of quartz and other minerals caused a progressive reduction of permeability in the quartz-adularia zone during the first phase of activity. Permeability was maintained as local fluid overpressure due to sealing caused hydrofracturing and the formation of breccias. The fractures produced served as fluid channels until precipitation of vein minerals again led to sealing, causing the hydrofracturing cycle to repeat. The geothermal system was thus self-sustaining through multiple episodes of self-sealing.

CONCLUSIONS

Hydrothermal alteration at Ohakuri has recorded the evolution of a geothermal system that underwent significant changes during its lifetime. Similar changes have been documented in a number of active systems, including Matsukawa, Japan (Sumi, 1968), Roosevelt Hot Springs, U.S.A. (Parry et al, 1980), and Orakeikorako (Lloyd, 1972). These temporal changes reflect the complex, dynamic nature of the interactions between geothermal waters, heat sources, host rocks, tectonic activity and regional hydrology that constitute a geothermal system.

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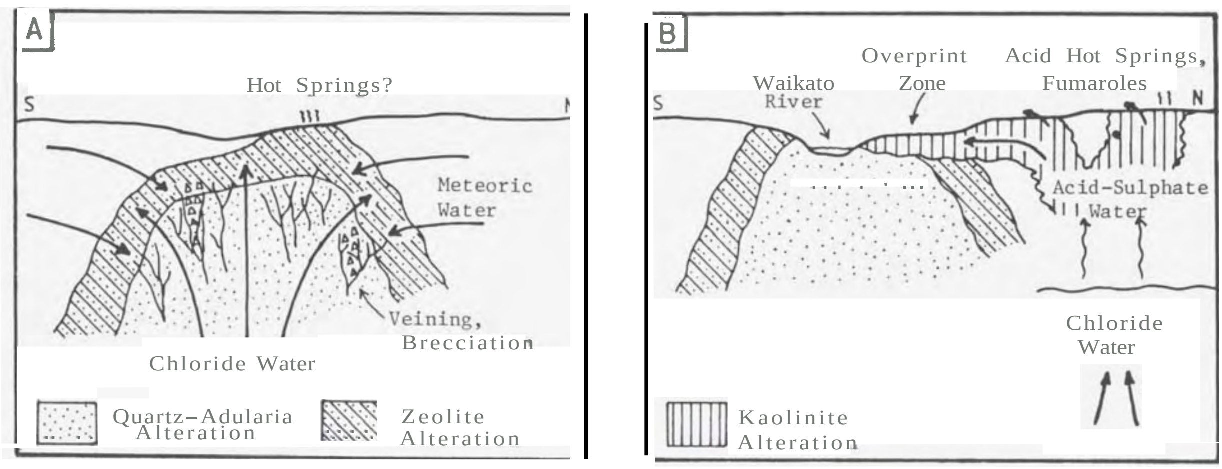

Figure 3: Schematic cross section of the Ohakuri geothermal system during early (A) and later (B) phases of activity.

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