EXPLORATION OF THE ROTOKAWA GEOTHERMAL FIELD, TAUPO VOLCANIC ZONE, NEW ZEALAND.

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INTRODUCTION

The Rotokawa geothermal field, located 7 km east of Wairakei (figure 1), has been investigated episodically for its sulphur resources and power potential over the past 50 years. Exploration of the field has been slow and mostly unsystematic so that an account of this as a sequential case study would be too long; nevertheless the field does offer several useful lessons. In this paper I therefore first describe our present knowledge of the superficial geothermal activity and geology of the field and then consider how our understanding of its subsurface geology and hydrology has been developed by drilling at three different periods.

SURFACE ACTIVITY

The surface geothermal activity and associated alteration were well known to the Ngati Tahu Maoris who lived nearby prior to the first European visits in the mid 1860's (Stokes, 1988). Then, as now, the main feature of the field is a lake, Rotokawa ("bitter lake"), which covers an area of about 0.6 km^2; its water has a pH of 2.2 being fed by ascending gases, steam and surrounding acid sulphate-chloride springs. The lake drains into the Waikato River via the Parariki Stream (figure 1). On the northeast side of the lake there are areas of steaming ground, gas vents, fumaroles, occasional mud pots and acid sulphate-chloride springs (natural heat flow is in excess of 236 MW (Lynne, 1983). Approximately 35 dissolution and collapse craters are also known and further warm ground is indicated by stunted vegetation. A few, feeble steam vents occur outside the main thermal area both north and south of the Waikato River (figure 1).Numerous alkaline chloride-bicarbonate springs discharge into the Waikato River but are visible only at low water level (Khabar et al, 1986).

The surface alteration coincides with prevailing thermal activity but also records its migration. In the main thermal area, kaolin, alunite, natroalunite and silica residue predominate and a 2.5 million ton sulphur deposit underlies and partly surrounds the lake (Jury, 1984); this is now being exploited in a small way but may soon be mined on a larger scale. In one area about 250,000 oz of gold may have deposited and still continues to do so (Krupp and Seward, 1987). Small patches of steam-related produced alteration also occur north of the Waikato River and rocks exposed along both banks of the river are weakly silicified (figure 1). The distribution of the surface alteration, in fact, almost coincides with the boundaries of the field as revealed by resistivity measurements (G. Risk data in Henley and Middendorf, 1985); other geophysical techniques (seismic, gravity and high level aeromagnetics) have been largely unsuccessful as exploration tools.

The present surface discharge waters comprise mainly acid sulphate-chloride and near neutral pH chloride-bicarbonate types (Table 1; figure 2); alkali chloride water does not reach the surface undiluted as it did at Wairakei, but becomes acidified by, and obtains sulphate from, the shallow sulphur beds (Ellis and Wilson, 1961). Elsewhere acid sulphate pools form directly from the oxidation of H_2S.

SURFACE GEOLOGY

Structural Setting

The Rotokawa geothermal field is located at the eastern margin of a postulated caldera (Wilson et al, 1986) that bounds several other geothermal fields in the region (but not Wairakei). However, within the Rotokawa field itself the major structural features are northeast striking, normal faults (Grindley, et al, 1986) which are common throughout the Taupo Volcanic Zone.

Surface Stratigraphy

The surface stratigraphy (Table 2) comprises deposits younger than 20 thousand years except for older rhyolite flows deriving from Mount Oruahinawae on which drillhole RK8 was drilled (figure1).

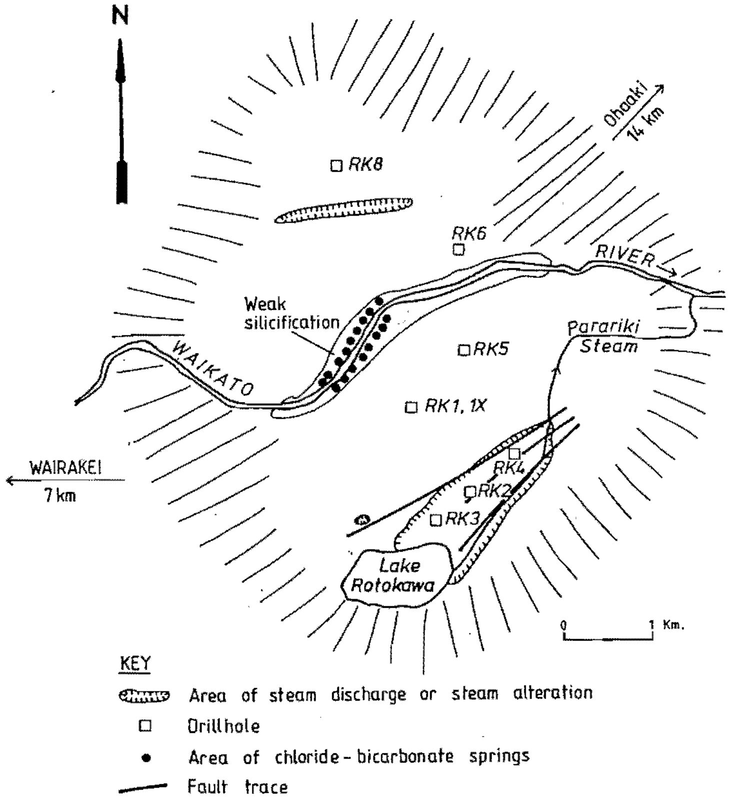

FIGURE 1. Sketch map showing boundary of Rotokawa field from resistivity survey (G. Risk data in Henley and Middendorf, 1985), main thermal features and distribution of hydrothermal alteration.

The youngest material (< 1800 years) consists of pumice and rhyolite alluvium comprising the Waikato River flood plain but all other deposits exposed are the direct products of silicic volcanic eruptions elsewhere or of hydrothermal eruptions that originated within the thermal area itself (Collar and Browne, 1985). The former produced tephras of regional extent that have been used to date the latter and show that at least 8 hydrothermal eruptions have occurred at Rotokawa in the last 20 thousand years. The biggest occurred about 6000 years ago but there is no evidence for any in the past 3400 years. Despite their great focal depths (about 400 m) the ejected material covered areas extending less than 3 km from their deduced vent locations (Collar and Browne, 1985).

EXPLORATION DRILLING RESULTS

State of Knowledge in 1964

At the date of the first deep well the most closely studied part of the Rotokawa field was that surrounding the lake where shallow drillholes had revealed a large deposit of sulphur; shallow (<50m deep) wells had also been drilled along the banks of the Waikato River but neither series of drillholes gave clues about the geology or subsurface conditions below about 50m depth. The surface geology, however, was known from geological maps at a scale of 1.'63,360 (Grange, 1937; Grindley, 1961); Grindley, (1960) also recognised the hydrothermal eruption deposits. The chemistry of the surface discharges had been analysed and interpreted (Ellis & Wilson, 1961) and an estimate of 600MW for the heat flow made (Fisher, 1960). Geophysical data collected during a survey of the geothermal resources of the Taupo Volcanic Zone included a resistivity survey that outlined an area of low resistivity measuring about 3 by 2.75 km and nearly circular in shape but with a lobe extending north of the Waikato River (see Browne. 1974).

Results of Drilling 1965-66

Rotokawa was one of several geothermal fields explored by drilling in the mid-1960's and 3 wells were drilled here; RK1 x (308m deep), RK1 (1198m) and RK2 (885m). The measured temperatures were the highest then recorded in New Zealand: RK1 had 307° at well bottom and RK2 reached 280-290° but cooled about 20° after 6 months discharge. Despite the high temperatures, well outputs were low (RK1: 21,000kg/hr at a WHP of 13.8 bars and enthalpy of 1396 kj/kg; RK2 only 7,500kg/hr at 13.8 bars WHP but an enthalpy of 2093 kj/kg showing it was drawing on two phases. The water discharged from the wells was of the usual neutral pH alkali chloride type with Cl contents of 1100 (RK1) and 2500 ppm (RK2). Their Cl/B ratios, suggested to Ellis and Mahon (1977) that "considerable rock-water reaction has occurred in the past". The gas contents of the deep waters were deduced to be in the range 0.5 - 0.2 mole/kg CO_2 and 0.01 - 0.06 mole/kg for H_2S. The chemists concluded that deep alkali chloride water ascended and was locally hydrolysed by the shallow sulphur deposits to discharge as acid-sulphate chloride springs (Ellis and Mahon, 1977); i.e. the same model as prevailed prior to drilling. A notable feature of the discharge from RK2 was the bright red coating it deposited upon surrounding trees; this comprised 30% antimony, 0.5% thallium, 70 ppm gold and 30 ppm silver (Weissberg, 1969). The three wells encountered a stratigraphy described, for RK1, as "quite different from those common at Wairakei" (Steiner, 1977) but a sequence that Grindley regarded as having several units in common with Wairakei (Grindley, 1966; Browne, 1974). The Huka Falls and Waiora Formations occur at both fields but at Rotokawa a 400-500m thick rhyolite flow was encountered which does not correlate with any rhyolite known at Wairakei. Steiner (1977) also recognised faults from core slickensides (e.g. RK1, 1140m) but, in contrast to Wairakei, considered them impermeable. The poor permeability and fluid types matched the observed hydrothermal alteration, with acid leached rocks occurring to 122m in RK2 and alkaline-chloride produced assemblages below (e.g. albite, epidote, chlorite, quartz, calcite, local wairakite).

Despite the high temperatures the poor permeability discouraged further drilling at Rotokawa as the Ohaaki field (Broadlands) was then a much better prospect.

Drilling in 1977

A further well was drilled in the main thermal area (figure 1) to 911m; this had a mass output of 143,000 kg/hr at 8 bg WHP and an enthalpy of 1260 kj/kg. The maximum temperature was 287° and both the stratigraphy encountered and the composition of the discharge fluid were very similar to that discharged from RK1 and RK2. Drilling this well did not add significantly to our knowledge of the field as far as I can judge.

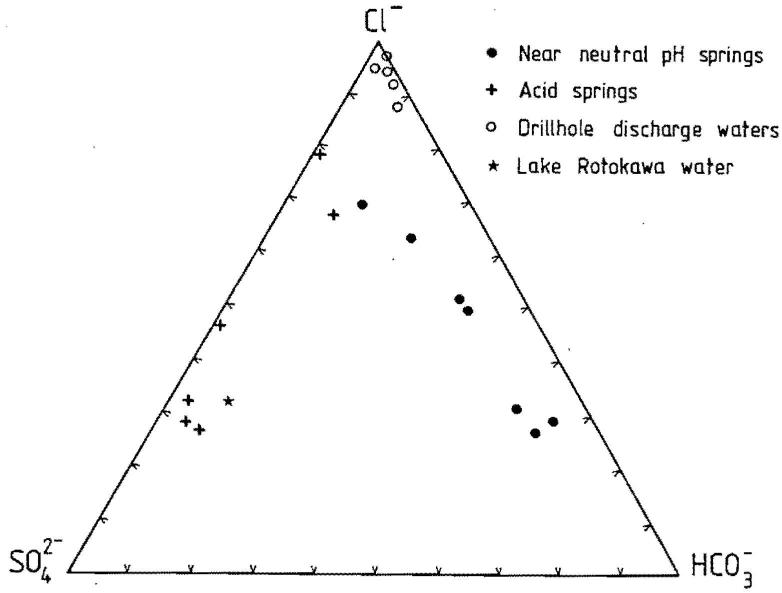

FIGURE 2. Compositions of representative thermal fluids at Rotokawa in terms of C1, SO_4 and HCO_3 end members.

TABLE 1: Composition of representative springs and water discharges from Rotokawa Drillholes

mg/kg

	Enthalpy J/gm	pH (20°)	Li	K	Na	Ca	Mg	Cl	SO_4	B	SiO_2	HCO_3	Reference
Rotokawa Lake		2.4	2.0	32	275	15.7	3.0	383	700	11	195	122	Henley & Middendorf,1985
Rotokawa Spring		2.9	7.5	102	960	20.7	6.9	1518	410	50	355	16	ditto
River Spring 2	(90.0°)	6.57	3.0	32	380	30.0	0.8	477	103	16.3	182	173	Khabar et al, 1986
River Spring 4	(89.5°)	7.74	2.7	35	335	24.8	0.07	438	121	14.7	224	83	ditto
River Spring 6	(71.0°)	7.30	2.4	19	215	11.5	0.63	144	33	2.7	236	315	ditto
RK1 19/4/66	1163	8.45	2.7	120	695	- 3.7 -		1100	54*	95	755	112	Henley & Middendorf, 1985
RK2 20/10/67	2093	7.9	10.4	152	1470	- 4.0 -		2567	96*	84	440	44	ditto
RK3 10/3/78	1260	7.84	16.3	200	1672	37.2	0.36	2864	47	105	505	129	ditto
RK4 5/12/84	1657	7.88	14.8	279	766	4.1	0.31	1614	3	84	1407	48	ditto

* high SO_4 values may be due to H_2S oxidation

TABLE 2: Summary Stratigraphy of the Rotokawa Geothermal Field (from Grindley, et al. 1985)

Formation	Lithology	Thickness (m)	Approx. Age (yr)
Alluvium	river gravels, reworked pumice, rhyolite gravels	~20	<1,800
Taupo Ignimbrite	pumice tephra	~50	~1,800
Parariki Breccia	hydrothermal eruption breccias interbedded with rhyolitic tephras	~50	3,400- to 18,000
Wairakei Breccia	pisolitic vitric tuff	~50	20,000
Huka Falls, Waiora	lacustrine mudstones sandstone vitric, crystal and lithic tuff	70-140 120-370	
Haparangi Rhyolite	flow breccias, locally spherulitic and flow banded	450-750	
Waiora	vitric tuffs	90	
Wairakei Ignimbrite	welded and non-welded vitric crystal tuff	300-350	330,000
Ohakuri	unwelded vitric tuff	650	
Waikora	greywacke and argillite conglomerate	35	
Rotokawa Andesite	porphyritic two pyroxene lava flows	900- >1,200	
Torlesse Supergroup	indurated greywacke and argillite	?	Jurassic

Drilling in 1984-86

During this period four deep (>2km) wells were drilled and a great deal more was learnt about the field although some is still proprietary information. Drillhole RK4 (2569m) penetrated a thick (about 900m) sequence of two pyroxene andesite lava flows that at a depth of 2200m rest upon greywackes and argillites of Jurassic age; the latter are the 'basement' rocks for the North Island so that their discovery here had important geophysical significance. No subsequent well reached the Jurassic rocks but elsewhere the andesites are even thicker (>1100m in RK5) and have obviously a major effect on the hydrology of the field; however, except where fractured they are of low permeability. Well temperatures are high, exceeding 330° in RK5 which makes Rotokawa the hottest geothermal field in New Zealand. Fluid inclusion homogenisation temperatures even indicate slightly higher temperatures (340°) and show local cooling has occurred, but elsewhere there has been slight heating.

Drillholes RK4 and 5 have mass flows of about 90 and 135,000 kg/hour respectively, at high wellhead pressures and power output equivalents of about 4.5 and 7MWe. Fluid from these wells had enthalpies of 1500 (RK4) and 1300 (RK5) Kj/kg (Grant, 1985) but vertical permeability was deemed to be poor although horizontal permeability is moderate but discontinuous. Drillhole RK6 was productive but RK8, the northernmost well, was unproductive (Grant, 1987).

The salinity of the water discharged from RK4 and RK5 is much less than that from RK2 and 3 (Table 1); this led Henley and Middendorf (1985) to suggest that the shallow water tapped by RK2 and 3 is a boiled derivative of a deeper alkali chloride water. RK1, however, is less saline than both RK2 and 3 water and appears to be related to RK4 water by both boiling and dilution. Note, also that both RK4 and 5 produce fluid from greater depth than any other wells in any New Zealand geothermal field and production seems to derive from joints associated with normal faults.

Recently, Hedenquist (1985) described the formation of corrosive CO_2 -rich steam heated waters in the subsurface rocks at Ohaaki but also mentioned that they occur in several other gassy New Zealand systems. A possible model for the hydrology of Rotokawa consistent with observations and measurements involves dilute alkaline chloride water, probably originally meteoric, ascending along fault generated joints below the field. As at Ohaaki , this occurs in two upflow regions, here north and south of the Waikato River. The ascending fluids boil and become more saline but near the surface, both north and south of the river, are diluted with shallow steam-heated meteoric water to form the bicarbonate-chloride waters that discharge at river level. Separated gases condense near and at the surface to form acid sulphate fluids from oxidation of H_2S while the corrosive CO_2 -rich waters form in the subsurface from condensing CO_2 : Near the lake ascending alkali chloride water is also hydrolysed by the sulphur beds to produce the observed acid sulphate-chloride springs.

PRESENT STATUS

The Rotokawa geothermal field represents an important resource with an assessed (Grant, 1987) potential of 49 MW (proven), 100 MW (probable) and 200 MW (possible). This is probably optimistic. Further exploratory drilling is needed, especially on its north side but this will not be undertaken in the near future. The main development problems, at this stage seem to me to be:

(a) encountering good subsurface permeability
(b) identifying and combating corrosive CO_2 -rich fluids
(c) determining the most favourable reinjection conditions; this is a problem, ironically enhanced by the hot temperatures and the consequently high silica contents of the thermal fluids
(d) establishing an acceptable development plan for the field which accommodates the requirements of both the sulphur mining interests, the power producers and especially the Ngati Tahu maori owners of the land.

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