SUBSURFACE STRATIGRAPHY AND STRUCTURE OF THE ORAKEIKORAKO AND TE KOPIA GEOTHERMAL SYSTEMS, NEW ZEALAND

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ABSTRACT

The Orakeikorako Geothermal System is located about 23km NNE of Taupo, New Zealand, on the eastern margin of the Maroa Volcanic Centre. The Te Kopia Geothermal System is located a further 10km to the NE, 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.

Four wells, a distance of 1 to 1.5km apart, have been drilled at Orakeikorako and two at Te Kopia, to a maximum depth of 1405m. They penetrate Pliocene to Quaternary tuffs, rhyolite lava and several ignimbrite sheets. The Mesozoic greywacke basement was not reached.

Detailed petrographic description of cores and use of point counting techniques has enabled the correlation and differentiation of the Paeroa Ignimbrite, Te Kopia Ignimbrite and Akatarewa Ignimbrite in the six drillholes.

Well logs and a panel diagram are presented and were used to describe subsurface stratigraphy and structure in the Orakeikorako-Te Kopia area.

INTRODUCTION

The Orakeikorako Geothermal field, bisected by the Waikato River, is located about 23km NNE of Taupo, New Zealand (Figure I). The area was investigated in the mid 1960's to assess the electrical power potential of the field; this included the drilling of four wells which are now designated OK1(1403.6m deep), OK2(1155.2m), OK4(1374.6m) and OK6(1219.8m).

Two wells were also drilled at Te Kopia, 10km NE of Orakeikorako, designated TK1(944.9m deep) and TK2(1250.4m).

An extensive set of cores and cuttings, plus well data are available and provide the basis for this and present studies of subsurface stratigraphy and hydrothermal alteration at Orakeikorako and Te Kopia.

About 350 thin sections have been examined and these were supplemented by X-Ray Diffraction data from clay and mineral separates. Fluid inclusion geothermometry and mineral stability temperatures were compared to measured bore temperatures. This paper describes the subsurface lithology and stratigraphy in the Orakeikorako-Te Kopia area. The aim of the present study is to assess the alteration mineralogy, understand the fluid-rock interactions there and recognise any change in reservoir conditions that has occurred.

SURFACE GEOLOGY

Surface manifestations in the Orakeikorako Geothermal Field consists of hot, neutral pH pools, springs and geysers, silica sinter, hydrothermal eruption craters and acid alteration, which occur in an area of about 1.8km^2, predominantly on the east bank of the Waikato River. However extensive deposits of sinter also occur on the west bank.

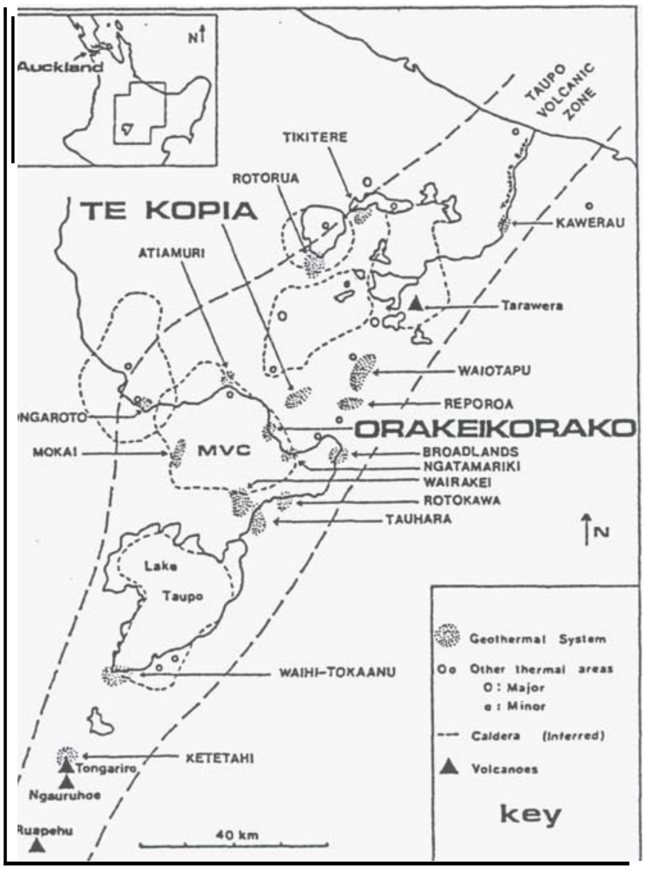

Figure 1 : Location of the Orakeikorako and Te Kopia Geothermal Fields, Taupo Volcanic Zone, North Island, New Zealand. MVC=Maroa Volcanic Centre.

The natural activity at Te Kopia, about 1.5km^2 in area, consists of steaming ground, mudpools, fumaroles and warm acid pools.

The distribution, type and chemistry of thermal features at Orakeikorako is described in detail by Lloyd (1972,1974) and Mahon (1972). Lloyd (1972) also summarised work undertaken in the area before the river valley was flooded in 1961 to form Lake Ohakuri. More recently, geochemical studies have been undertaken by Sheppard and Lyon (1984). Analyses of bore water from the Orakeikorako wells were made in the 1960's (Mahon 1965a,b and 1966).

A chemical survey of the Te Kopia thermal springs was undertaken by Mahon (1965c) and reviewed by Healy (1974).

The geology of the Orakeikorako and Te Kopia Geothermal Fields is greatly influenced by their location near the margin of the Maroa Volcanic Centre (Figure 2), from which much of the pyroclastic material in the drillholes is derived.

The surface geology in the vicinity of the geothermal areas is described by Grindley (1959) and Lloyd (1972) Figure 2) and consists of Holocene Taupo Pumice Alluvium, rhyolite sands and gravel of the Hinuera Formation, plus older lacustrine siltstone, sandstone and pumice tuffs of the Huka Falls Formation and pumiceous breccia, tuff and ignimbrite of the Ohakuri Formation.

The Paeroa Ignimbrite crops out to the north of Orakeikorako, west of Te Kopia and is exposed on the Paeroa Fault Scarp. The Te Kopia Ignimbrite is the oldest formation exposed at the surface, and is encountered at the base of the Paeroa Fault scarp, NE of Te Kopia. Other ignimbrites encountered in the drillholes do not crop out. Intermediate and basalt volcanic rocks in the area are very minor (Lloyd, 1972)

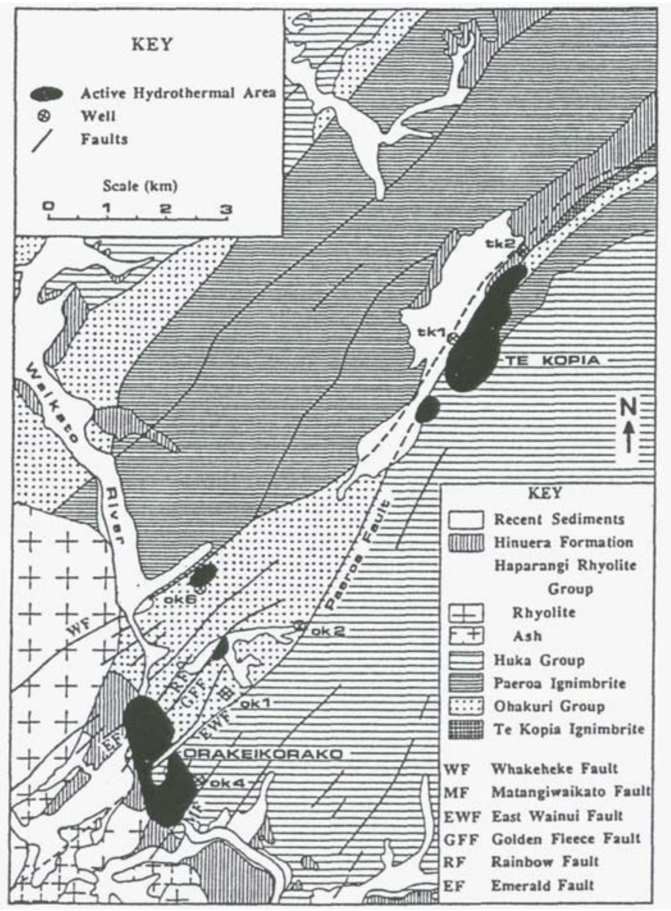

Figure 2 : Surface geology in the Orakeikorako-Te Kopia area After Grindley (1959) and Lloyd (1972).

STRUCTURE

The area of surface hydrothermal activity at Orakeikorako and Te Kopia is intimately associated with a swarm of late Cenozoic to Recent, NE-SW trending normal faults which bifurcate from the Paeroa Fault (Figure 2).

The fault is normal, downthrown to the NW, with a maximum vertical slip of 550m indicated from the topography. It forms the prominent north-west trending scarp of the Paeroa tilted block (Grindley, 1959).

South-west of the Te Kopia hydrothermal area the Paeroa Fault divides, with the Whakeheke Fault marking the northern boundary of the Orakeikorako field and the Matangiwaikato Fault marking its Southern boundary. The swarm of SW trending faults in the Paeroa Fault Zone between the Whakeheke and Matangiwaikato Faults diverge toward the south-west and are downthrown to the north-west. Hydrothermal activity occurs on the bounding faults, and subordinate, steeply dipping East Wainui, Golden Fleece, Rainbow and Emerald Faults and on several numerous unnamed faults (Lloyd, 1972).

Well preserved and comparatively small (4 to 5 metres) surface displacements are encrusted with siliceous sinter (up to 1 metre thick) to form prominent features in the Orakeikorako surface area, and clearly show the close association between faults and hot springs which occur at the foot of the fault scarps.

Many hot springs, area of warm ground and also hydrothermal eruption craters are aligned along SW trending lines. Even though there is no surface displacement these lines may be interpreted as faults.

Intensive faulting affected the rocks penetrated by the Orakeikorako and Te Kopia drillholes, and is indicated by a number of slickenside cores, breccia zones and circulation losses in the drill records (Figure 3). Many cores from the fracture and fault zones show a more intense wall rock alteration due to the higher fluid-rock ratios.

SUBSURFACE STRATIGRAPHY

General Aspects

The subsurface stratigraphy in the Orakeikorako and Te Kopia Geothermal Fields as revealed by drilling is summarized in Figures 4,5 and Table 1.

For the most part, the stratigraphy presented agrees with the initial descriptions of Steiner (1965a,b) and (1977) and Grindley (1965).

Many ignimbrites and tuffaceous rocks recovered fiom the six wells are very similar in appearance. For this reason hand specimen, binocular and petrologic microscope descriptions were supplemented by detailed point counting techniques. Interpretation of this data has enabled the correlation and differentiation of ignimbrite sheets in the wells and facilitated the interpretation of the structural features.

Examination of core and cuttings recovered from the wells show that the field is predominantly composed of generally SE dipping pyroclastic rocks, pumice and crystal tuffs, lapilli tuff, ignimbrite, lacustrine tuffs and intercalated rhyolite lava flows. There are considerable variations in the distribution and thickness of several subsurface formations.

Unfortunately no ideal, widespread and distinctive marker unit was recognised, however, correlation between drillholes is possible, and several units occur in two or more wells.

At shallow levels in all wells pumice, crystal and lacustrine tuffs predominate, but at greater depths distinctive

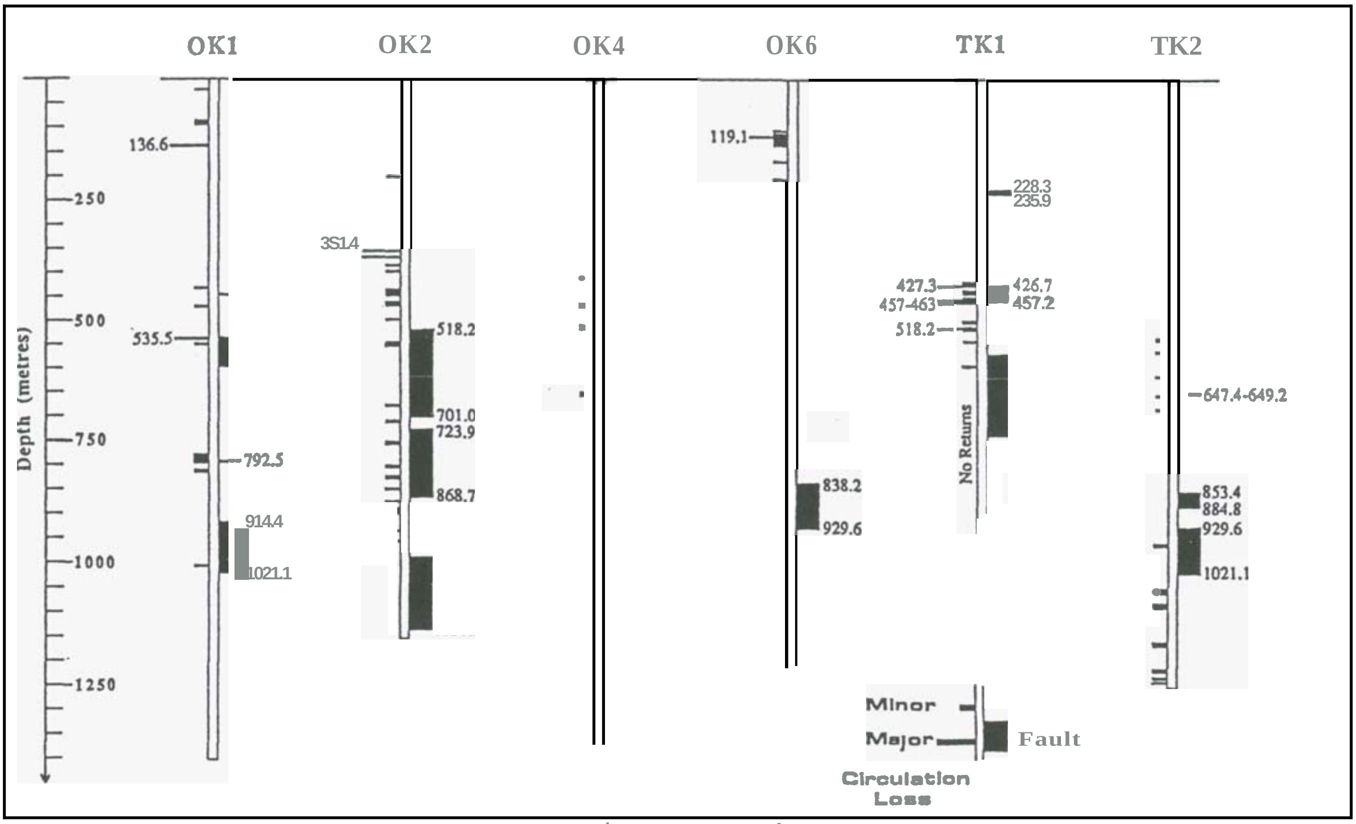

Figure 3 : Occurrence of circulation losses and fault zones in the Orakeikorako and Te Kopia drillholes. Fault Zones inferred from slickenside cores. Circulation losses recorded in drilling records.

ignimbrite units occur. Rhyolite lava flows, which are widely distributed, are not sufficiently distinctive to allow a confident correlation to be ma& between drillholes. For this reason ignimbrite sheets were examined in detail.

The effects of hydrothermal alteration, which can destroy potentially diagnostic ferromagnesian and feldspar minerals, did not significantly limit correlating between units because their pseudomorphs remain.

No Mesozoic greywacke, 'basement' rocks were encountered during the drilling programme.

The different units encountered in the six Orakeikorako and Te Kopia wells are briefly described below, with their distribution summarized in Table 1.

Akatarewa Ignimbrite

The Akatarewa Ignimbrite (Grindley, 1965) is the oldest unit drilled at Orakeikorako, but does not crop out. At least two sheets, separated by rhyolite, occur in Orakeikorako drillholes.

This quartz-bearing ignimbrite is grey-green coloured where fresh and coarse grained, with a strongly lenticular texture in OK1 and OK2. A massive, pulverulitic texture is developed in Akatarewa Ignimbrite in OK6.

The ignimbrite contains about 25% phenocrysts; consisting of about 80% subhedral plagioclase laths, up to 2mm long; 12% embayed quartz; and 8% mafic minerals which are invariably altered to chlorite and secondary quartz. Almost completely flattened pumice clasts, subrounded tuff and rhyolite fragments also occur in the welded ash matrix.

Te Kopia Ignimbrite

The Te Kopia Ignimbrite only outcrops at the base of the Paeroa Fault Scarp, to the NE of the Te Kopia thermal area. These ignimbrites were first recognised by Grindley (1959), who considered that the formation consists of at least three members. An upper member, about 30m thick, of black to brown vitrophyre, that is highly resistant and is covered by a dark grey tuff. A middle, 15m thick member of tuff breccia that overlies a lower massive unit of hard, dark grey crystal-rich welded tuff.

According to Martin (1961), the Te Kopia Ignimbrite contains about 35% phenocrysts; consisting of plagioclase (72%), quartz (24%) and mafic minerals (4%). Pyroxene is the dominant mafic mineral, with minor amphibole, magnetite and trace biotite.

The Te Kopia Ignimbrite, underlying either Paeroa Ignimbrite or pumiceous tuffs, occurs in all but one (OK4) of the Te Kopia and Orakeikorako drillholes.

The core sample are similar in appearance to the rocks in outcrop, albeit hydrothermally altered. Subrounded quartz grains are typically distinctively embayed and up to 6mm diam.; whilst andesine laths are generally smaller, up to 3mm long. Subrounded pumice and rhyolite fragments, up to 4mm wide also occur.

Ohakuri Group

Subaerial pumice breccias and water-laid tuffs, collectively referred to as members of the Ohakuri Group, crop out to the west of the Paeroa Range, and in the vicinity of Orakeikorako. Grindley (1959) also reported that pumiceous pyroclastics exposed on the Paeroa Fault Scarp underlies the Paeroa Ignimbrite and overlies the Te Kopia Ignimbrite. Pumiceous breccias, tuffs and sandstones are identified in the Te Kopia and Orakeikorako drillholes, overlying the ignimbrites and between the Paeroa, Te Kopia and Akatarewa Ignimbrite sheets.

The various Ohakuri members encountered in core samples are typically petrographically and mineralogically distinct and make correlation difficult. Pumice, rhyolite and ignimbrite clasts, plus quartz, andesine and other subordinate crystal fragments occur in the Ohakuri pyroclastics.

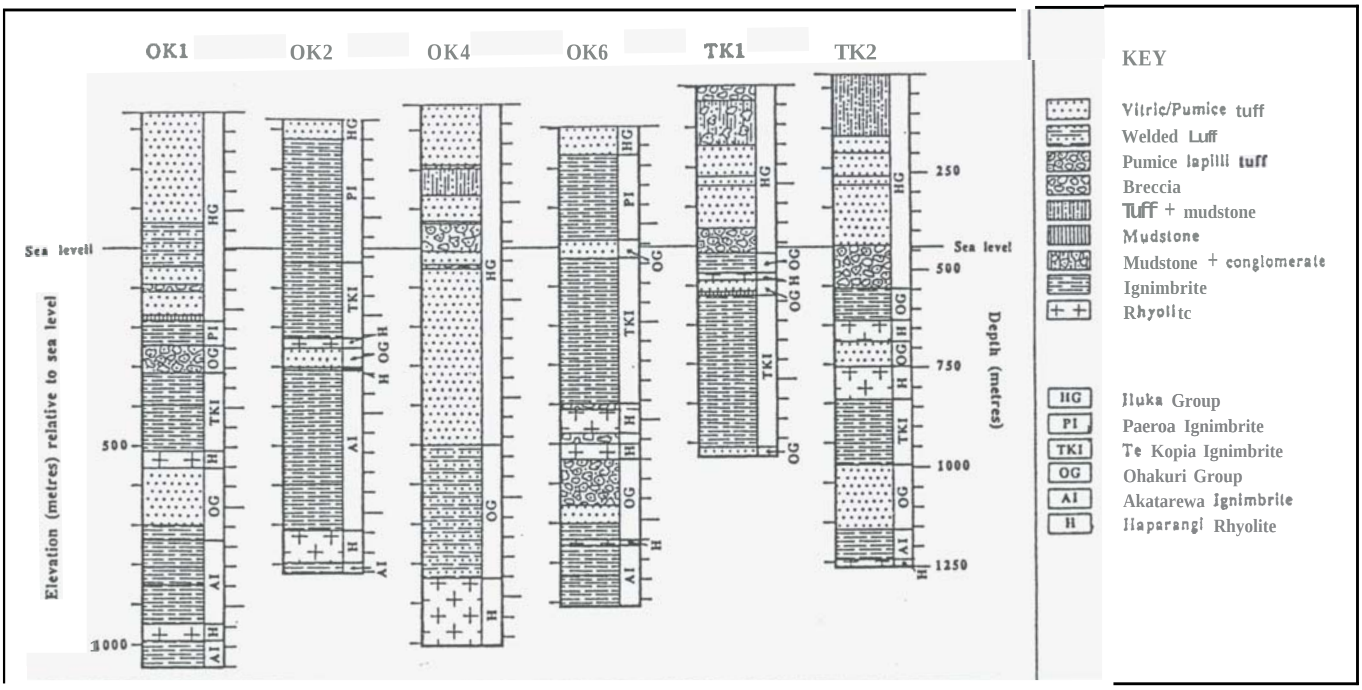

Figure 4 : Lithological logs of Orakeikorako and Te Kopia drillholes.

Paeroa Ignimbrite

The Paeroa Ignimbrite was first named and described by Grindley (1959) from exposures that form the crest of the Paeroa Ridge in the upper part of the Paeroa Fault Scarp. It underlies the Waiotapu Ignimbrite in the Waiotapu geothermal field (Steiner, 1963).

At the type locality the Paeroa Ignimbrite lies unconformably on the Te Weta Ignimbrites, pumice-rich sheets with subordinate sedimentary tuff, not recognised in the Te Kopia and Orakeikorako drillholes.

In outcrop the Paeroa Ignimbrites are light grey to buff coloured, massive, crystal rich and quartz bearing, more welded and compact towards the base of the sheets.

At the SW end of the Paeroa Fault Scarp, in the Orakeikorako area, the Paema Ignimbrite underlies a thick sequence of tuffaceous sediments of the Huka Group.

The Paeroa Ignimbrite contains about 30% phenocrysts by rock volume (Martin, 1961), comprising 40% subhedral plagioclase, up to 2mm long and 40% embayed quartz up to 2mm diam. Biotite is the dominant mafic mineral, with many pyroxene, magnetite and trace amphibole fragments. Pumice, crystal tuff and subrounded rhyolite clasts are also present; subrounded pumice clasts up to 12mm diam occur.

Huka Group

The predominant rocks encountered in the upper parts of the Te Kopia and Orakeikorako drillholes are pumice and basaltic breccias, tuffs and lacustrine sediments consisting of sandstones and mudstones. These are correlated with the Huka Group of Grindley (1959). The Huka Group was subsequently subdivided by Grindley (1965b) into the Waiora Formation and the overlying Huka Falls Formation.

a) Waiora Formation

This includes thick, poorly bedded pumice-tuff, breccias and crystal tuff, and is the main aquifer in the Wairakei Geothermal System, 20km south of Orakeikorako.

Grindley (1959) mapped sediments in the Orakeikorako area which were subsequently included in the Waiora Formation

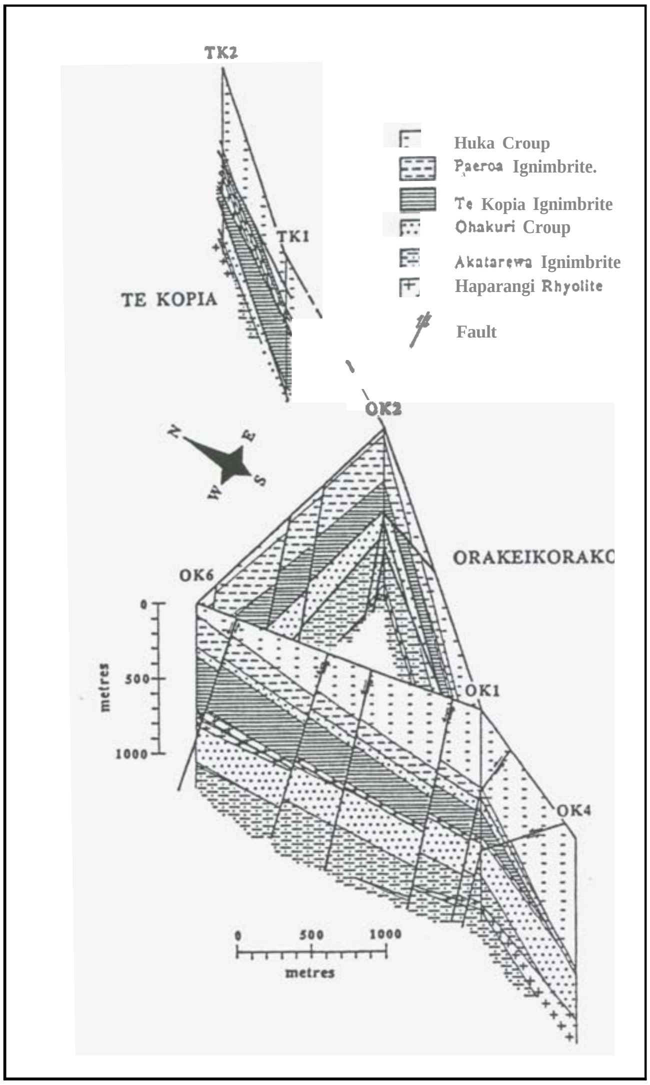

Figure 5 : Panel diagram of subsurface stratigraphy in the Orakeikorako-Te Kopia area.

(Lloyd, 1972), that overlie the Paeroa Ignimbrite. The same relationship occurs in the Orakeikorako drillholes. Lloyd further divided the Waiora Formation at Orakeikorako into two widespread units on the basis of the size of their pumice fragments and degree of compaction; the Orakeikorako Tuff, consisting of poorly bedded pumice tuff, contains pumice, rhyolite and crystal fragments set in a microlitic texture; and the Akatarewa Breccia, consisting of poorly bedded pumice breccia.

b) Huka Falls Formation
Sandstones and mudstones at Orakeikorako and Te Kopia belong to the Huka Falls Formation, which consists of pyroclastic sediments deposited in shallow lacustrine environments. They are comparable to lithologically similar sediments at Huka Falls, Wairakei, although there is no evidence to suggest they were deposited in the same basin.

Correlation between members of the Waiora and Huka Falls Formations in the Orakeikorako and Te Kopia drillholes is difficult since no distinctive marker units were recognised. For this reason the various tuff, breccia and mudstone units are collectively referred to as the Huka Group, although subdivisions based on lithology is noted in Figure 3.

Haparangi Rhyolite Group

The Haparangi Rhyolite Group is the name given by Grindley (1959) for all the young (Huka and post-Huka) rhyolite domes and pyroclastic rocks that they produced.
Rhyolites and dacites of the Haparangi Rhyolite Group occur at different levels in all of the drillholes, but they are most obviously recognised at two main levels; at the base of the Te Kopia Ignimbrite and within the Akatarewa Ignimbrite.
The rhyolites are porphyritic, banded and occasionally spherulitic; andesine phenocrysts predominate, with quartz crystals absent in some flows. The rhyolites also contain minor hornblende, accessory hypersthene, augite, biotite and magnetite. The primary texture of the groundmass is generally microcrystalline or glassy, however the textures are sometimes destroyed in the most intensely altered samples.

Umukuri Sinter

Siliceous sinter deposits at Orakeikorako are named Umukuri Sinter (Lloyd, 1972). The typically ripple-marked sinter occurs in laminated-highly siliceous bands alternating with gritty, less silicified material. The sinter, up to 20m thick, covers an area of approximately 1km^2 on the east and west banks of the Waikato River and is, in places, overlain by the Hinuera Formation and Taupo Pumice Alluvium.
Minor sinter, not previously reported, is present at Te Kopia in an area of steaming ground, fumaroles and warm acid pools. The Occurrence of the sinter here indicate changing thennal and chemical conditions in this area.
At Orakeikorako nodular and mamillary geyserite occurs around geysers and sinter terraces have formed.

Hinuera Formation and Taupo Pumice Alluvium

Current-bedded rhyolite sands and gravels (Healy, 1974) mainly derive from silicic volcanic rocks and Huka Group sediments. These unconsolidated sediments unconformably overly siliceous sinters and rocks of the Huka Group.

The Taupo Pumice Alluvium refers to alluvium pumice breccia deposits, correlated to the last major pumice eruption at Taupo in AD 131.

PERMEABILITY

Following experience of production drilling at Wairakei, intersection with faults at Orakeikorako (and Te Kopia) were initially major target zones to tap hot fluids. However no production zones were found at depths of inferred faulting (Figure 3).

Drilling datum above sea level (m)		OK-1 342	OK-2 336.2	OK-4 361.5	OK-6 304.8	TK-1 406.6	TK-2 436.8
Huka Group	m(R.L.)	342 to -184	336 to 286	362 to -508	305 to 233	407 to -18	437 to -107
	Depth (m)	0 to 526	0 to 50	0 to 870	0 to 72	0 to 425	0 to 544
Paeroa Ignimbrite	m(R.L.)	-184 to -248	286 to -25		233 to 17		
	Depth (m)	526 to 590	50 to 361	Absent	72 to 288	Absent	Absent
Ohakuri Group	m(R.L.)	-248 to -319	-244 to -293	-508 to -845	17 to -41	-18 to -67	-107 to -189
	Depth (m)	590 to 661	580 to 629	870-1207	288 to 346	425 to 474	554-626
	m(R.L.)	-559 to -742			-544 to -745	-85 to -128	-244 to -308
	Depth (m)	901 to 1084			849 to 1050	492 to 535	681 to 745
	m(R.L.)					-513 to base	-558 to -721
	Depth (m)					From 920	995 to 1158
Te Kopia Ignimbrite	m(R.L.)	-319 to -518			-41 to -401	-128 to -513	-391 to -558
	Depth (m)	661 to 860	361 to 556	Absent	346 to 706	535 to 920	828 to 995
Haparangi Rhyolite	m(R.L.)	-518 to -559	-220 to -244	-845 to base	-416 to -477	-67 to -85	-189 to -244
	Depth (m)	860 to 901	556 to 580	From 1207	721 to 782	474 to 492	626 to 681
	m(R.L.)	-951 to -992	-293 to -300		-504 to -544		-308 to -391
	Depth (m)	1293 to 1334	629 to 636		809 to 849		745 to 828
	m(R.L.)		-708 to -790		-745 to -760		-796 to base
	Depth (m)		1044 to 1126		1050 to 1065		From 1233
Akatarewa Ignimbrite	m(R.L.)	-742 to -951	-300 to -708		-760 to base		-721 to -796
	Depth (m)	1084 to 1293	636 to 1044	Absent	From 1065	Absent	1158 to 1233
	m(R.L.)	-992 to base	-790 to base				
	Depth (m)		From -819				
Well Bottom (Base)	m(R.L.)	-1062	-819	-1013	-915	-538	-814
	Depth (m)	1403.6	1155.2	1374.6	1219.8	944.9	1250.4

Table 1 : Distribution of units in the four Orakeikorako and two Te Kopia drillholes.

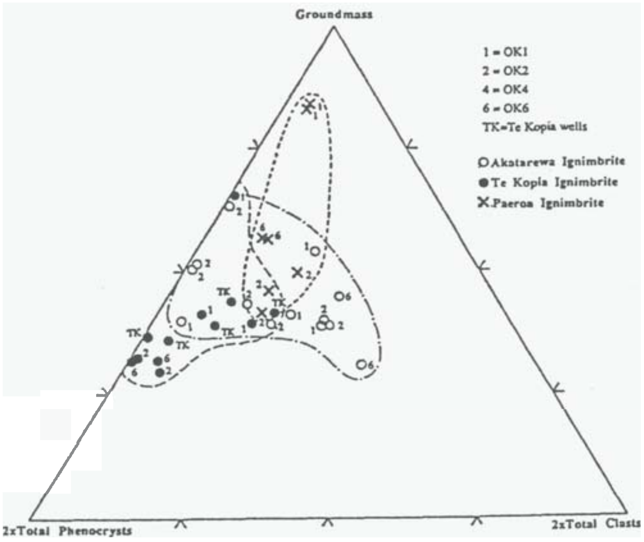

Figure 6a : Ternary diagram based on point counting data from ignimbrites in Orakeikorako and Te Kopia drillholes. Groundmass v Total phenocrysts v Total clasts.

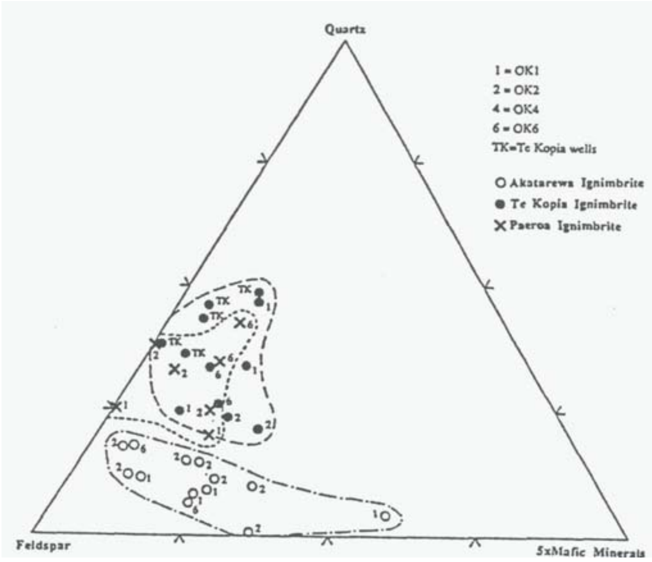

Figure 6b : Ternary diagram based on point counting data from ignimbrites in Orakeikorako and Te Kopia drillholes. Quartz phenocrysts v Feldspar phenocrysts v Total mafic phenocrysts.

Fractures in the pyroclastic rocks outside the fault zones at Orakeikorako and Te Kopia are not common, with only rare, thin (up to 1mm wide) veinlets present in a few of the cores. Usually the veinlets comprise quartz or quartz +calcite, however, at depth rare epidote and epidote+quartz veinlets occur. Some fractures, particularly at shallow levels, are open.

Many workers have indicated a control on the deposition of hydrothermal minerals due to permeability. A knowledge of the mineralogy of the cores can be used to interprets the subsurface permeability. Adularia and albite occur at deep levels in the Orakeikorako and Te Kopia wells, but not always at depths at which the drillholes intersected fracture and fault zones.

However, it is interpreted, after examination of cores at Orakeikorako-Te Kopia, and particularly due to a higher intensity of hydrothermal alteration, that the most permeable zones in the drillholes do occur at depths of fault intersection.

STRATIGRAPHIC CORRELATIONS

The ternary diagrams below (Figures 6a and b), based on standard point counting techniques, were used to correlate the different ignimbrite sheets encountered in the four Orakeikorako and two Te Kopia wells.

Over 50 thin sections (5.0cm x 7.5cm) of different cores were prepared. Between 2000 and 4000 counts were made and primary mind abundances tabulated (Table 2).

Core data plotting in the same regions on the ternary diagrams are interpreted to be form the Same ignimbrite sheet. Where original minerals are hydrothermally altered the primary mineralogy is inferred from the shape of the phenocrysts.

The lithology of most ignimbrite sheets in the Orakeikorako-Te Kopia drillholes varies laterally and vertically, however, correlation based on the identity and abundances of mineral and rock fragments can still be made with reasonable confidence.

		Qt	Plag	Bio	Amph	Py	Mag	Volc	Pumice	Tuff	Grnd	G :2P :2C	Q : P : 5M
Paeroa Igm.	OK2-275.8m	7.3	13.4	0.3	tr	tr		6.7	4.8	1.6	65.9	49.2 :31.3 : 19.5	32.8 :60.4 :6.8
	OK2-335.3m	7.3	16.7	0.5	0.4	tr	tr	1.2	9.3	1.1	63.6	46.7 :36.5 : 16.8	25.2 :57.8 : 16.9
	OK6-229.5m	8.3	12.2	0.6	0.1	tr	tr	0.8	0.5	5.1	72.5	56.8 :33.2 : 10.0	34.8 :51.5 : 13.7
Te Kopia Igm.	OK1-791.3m	18.5	15.7	tr	0.8	0.2	tr	1.7		3.7	59.2	42.0 :50.3 :7.6	46.7 :39.5 : 13.9
	OK1-855.0m	8.5	21.7	0.2	0.2	0.4	tr	0.8	1.0	10.3	56.8	39.7 :43.4 : 16.9	24.5 :62.5 : 13.0
	OK2-503.8111	14.0	33.2	tr	0.8	1.7	tr	0.4		0.3	49.6	33.0 :66.1 :0.9	23.5 :55.6 :20.9
	OK6-365.8m	17.4	28.1	tr	0.4	0.9		1.7		1.9	49.7	33.0 :62.2 :4.8	33.4 :54.1 : 12.5
	OK6-698.6m	14.4	30.5	tr	0.4	1.6				0.3	52.8	35.9 :63.8 :0.4	26.4 :55.8 : 17.8
	Tk1-548.6m	13.7	21.6	tr	0.3	1.7	tr	0.7		7.0	56.5	39.4 :49.9 : 10.8	36.2 :57.2 :6.6
Akatarewa Igm.	OK1-1280.2m	2.9	19.3	tr	0.5	0.2	tr	7.1		13.9	56.7	39.1 :31.7 :29.3	11.6 :76.5 : 12.0
	OK2-976.3m	4.1	22.7	tr	0.5	1.3	tr	2.8		12.0	56.7	39.5 :39.9 :20.6	11.5 :63.4 :25.1
	OK2-1136.9m	2.8	18.6		0.2	0.2		2.6		19.3	56.3	39.1 :30.4 :30.4	12.0 :78.6 :9.3
	OK6-1219.2m	1.7	18.5	tr	0.4	0.8		17.6		12.5	48.6	32.1 :28.3 :39.7	6.5 :70.6 :22.9

Table 2 : Representative point counting data from ignimbrites encountered in the Orakeikorako and Te Kopia drillholes.

Phenocrysts: Qt=Quartz, Plag=Plagioclase, Bio=Biotite, Amph=Amphibole, Py=Pyroxene, Mag=Magnetite,

Clasts: Volc=Volcanic, Pumice, Tuff

G :2P :2C = Ratio Groundmass:2xTotal Phenocrysts:2xTotal Clasts

Q : P : 5M = Ratio Quartz Phenocrysts:Plagioclase Phenocrysts:5xMafic Phenocrysts

CONCLUSIONS

- Four wells have been drilled at Orakeikorako and two at Te Kopia to a maximum depth of 1405m. They penetrate generally SE dipping, Pliocene to Quaternary tuffs, rhyolite lava and several ignimbrite sheets.

- Many ignimbrites and tuffaceous rocks recovered from the drillholes are similar in appearance. However, hand specimen, binocular and petrologic microscope descriptions, supplemented by point counting, has enabled the correlation and differentiation of at least three major ignimbrite sheets; Paeroa Ignimbrite, Te Kopia Ignimbrite and Akatarewa Ignimbrite.

- Interpretation of this data has assisted the construction of well logs and a panel diagram showing the subsurface stratigraphy and structure of the two fields.

- Several fault zones, indicated by slickenside cores and circulation losses, have been intersected by the six wells. Fractures associated with the faulting are inferred to control permeability and has resulted in the occurrence, in the active hydrothermal areas, of numerous hot springs and geysers located at the foot of many fault scarps.

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