GEOLOGICAL RESULTS FROM DRILLING IN THE POIHIPI (WESTERN) SECTOR OF THE WAIRAKEI GEOTHERMAL FIELD, NZ

I. BOGIE, J.V. LAWLESS AND K.M. MacKENZIE

Kingston Morrison Ltd, Auckland, NZ

SUMMARY - Four wells drilled into the Poihipi Sector on the Western margin of the Wairakei geothermal field have found a similar lithostratigraphy to that encountered in wells previously drilled in the general area. Young pumice breccias overly the Huka Falls Formation, with the latter containing intercalations of the Rautehuia Breccia. This in turn overlies ignimbrites and tuffaceous sediments of the Waiora Formation, which contains flows of Haparangi Rhyolite. This sequence is cut by steeply dipping normal faults which strike to the northeast and for the most part dip towards the northwest. Hydrothermal alteration is virtually limited to the Waiora and Haparangi units where a sequence of interlayered illite-smectite and illite clays are found along with chlorite, quartz, pyrite and calcite. There is a minor occurrence of zeolites. Despite large changes in the area's hydrology in response to exploitation, changes in alteration are limited to a comparatively deep occurrence of kaolinite and minor overprinting of epidote by illitic clay.

1. INTRODUCTION

The Poihipi sector of the Wairakei Geothermal Field is located southwest of the developed portion of the field (Figure 1) and is bounded by Poihipi Rd to the northeast and the field's resistivity boundary to the southwest, thus forming an elongate northwest trending area approximately 500 m wide and 2 km long. It is currently under development by Mercury-Geotherm Ltd with the intention to supply electric power to the grid by the end of 1996.

The wider area was explored by drilling between 1959 and 1963 by the then Ministry of Works with eleven wells (Wk 204, 205, 208, 212, 214, 218, 220, 221, 222 and 223; see Figure 1) drilled within 1 km of the Poihipi Sector, although no wells were actually drilled within the sector. These wells were drilled down to depths of between 335 and 1200 m, with 212 being the deepest. Wk 204 is notable as being the "rogue bore" (Grindley, 1965).

The wells in the western part of the Wairakei field, adjacent to the Poihipi Sector, were not included in the initial development of the Wairakei field, primarily because their location did not justify the costs of their connection with the Wairakei power station. However, with the large scale exploitation of the field, without reinjection, a significant shallow steam resource has now been created (Grindley, 1986). With the introduction of a new legal framework for geothermal development in New Zealand, a private, stand alone power development in this area has now become feasible.

2. DRILLING IN THE POIHIPI SECTOR

Three shallow small diameter bores (GE 1, 2 and 3) were drilled to depths of up to 265 m by Geotherm Exports Ltd in 1988 to provide a source of heat for greenhouses. GE 3 encountered a productive shallow steam zone, providing encouragement for further development. As of August 1995 four full-diameter wells have been completed in the Poihipi sector (Wk 604, 610, 620 and 650; Figure 1). Details of the wells are given in Table 2. Well Wk 604 was drilled to establish the production potential of the shallow steam zone and 620 its extent, whereas 610 and 650 were drilled to establish both the extent of the steam zone and any underlying liquid resource. All wells were targeted to intersect mapped faults (KML, unpublished data) at the appropriate production level. This strategy has generally proven successful, in that zones of enhanced permeability have been encountered at levels which can be correlated with faults mapped on the surface.

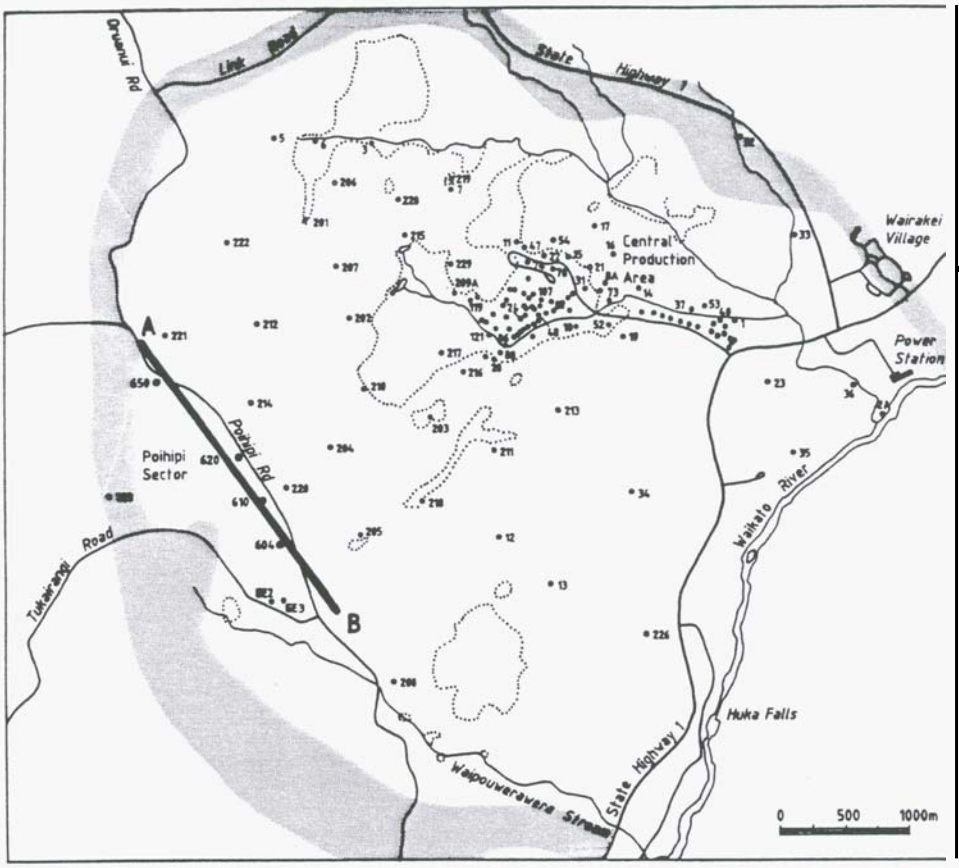
Well	Wk 604	Wk 610	Wk 620	Wk 650
Well Head Elevation (m CHF RSL)	467	503	522	538
Coordinates[a] mN	602235	602666	602975	603581
mE	263886	263691	263432	262804
Total Depth (m)[b]	331	1003	615	1360
Production Casing Depth (m)	214	284	135	686
Cutting Recovery Intervals (m)	0 to 232	0 to 285	0 to 325[d]	0 to 1200
Core Depths (m)	232	291, 496[c], 710, 1003	327	1250

Abbreviations:

[a] Bay of Plenty Maketu Grid
[b] All wells are vertical
[c] Ejecta from hole
[d] Minor deeper returns

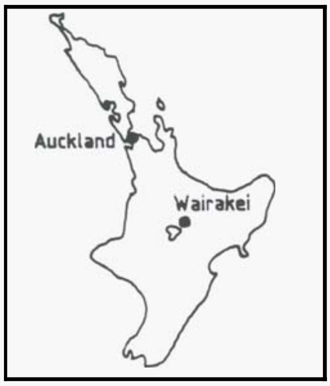
3. LITHOSTRATIGRAPHY

The geology of the previous wells is presented in Grindley (1965) and the petrology is presented by Steiner (1977). There are conflicts between these reports, since Grindley (1965) uses a stratigraphic subdivision scheme whereas Steiner (1977) uses a lithologic subdivision. Subsequent workers (Healy, 1984, ECNZ, 1992 and Wood, 1994) have attempted to resolve some of the problems, but



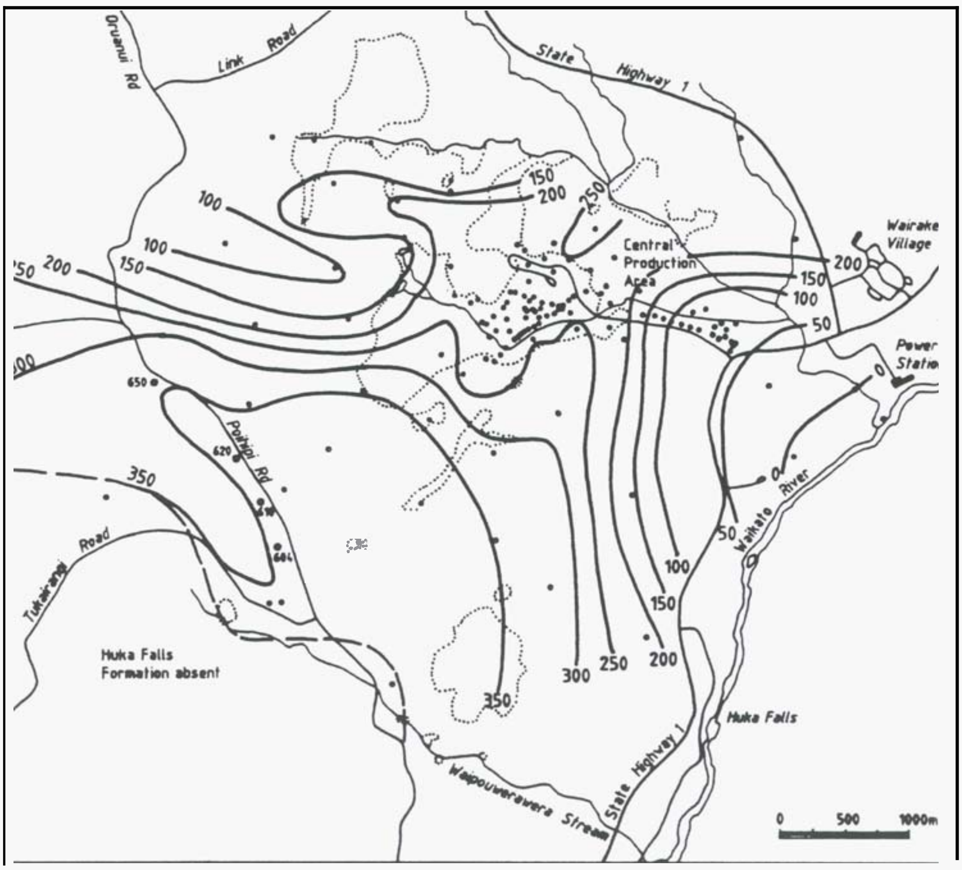
Key

- Geothermal Well
- Extent of surface thermal activity
- Resistivity boundary
- A B Cross-section line



Location map

Fig. 1



Key

- Geothermal Well
- Extentofsurface thermal activity
- Contour m RSL
- South Western limit of Huka Falls Formation

(modified after Healy 1984)

Structural contours on the base of Huka Falls Formation

Fig. 2

despite the wells having regular coring intervals (15 m) the effects of hydrothermal alteration, lithological diversity and lateral facies variation, and the intercalation of some units precludes a definitive interpretation of the area's lithostratigraphy. Consequently, on the basis of precedence and general utility - particularly when logging cuttings megascopically - the stratigraphy of Grindley (1965) has in the most part been retained with some changes in formation names in the shallower formations. The youngest pumice breccias are now assigned to the Arawa Formation (Healy, 1964) which has been further subdivided by Wilson (1993) and the 26 500 year old (Wilson e? *al.*, 1988) pumice breccias, which includes the Oruanui Formation (Vucetich and Pullar, 1969), have now been included in the Wairakei Formation (Self and Healy, 1987). A further informal unit - the Rautehuia Breccia (ECNZ, 1992) - is now recognised as an intercalation within the Huka Falls Formation. The Haparangi Rhyolite units (Grange, 1937) enclosed within the Waiora Formation in the Poihipi sector have now been recognised as flows rather than sills and these have been informally subdivided (KRTA, 1988) following Grindley's (1965) usage of the names "Karapiti" or "Te Mihi" Rhyolite depending on whether or not they contain megascopic quartz.

The lithostatigraphic results obtained from the four wells are presented as isopach and structural contour maps for the two important units: the Huka Falls Formation and the Karapiti IIa Rhyolite (Figures 2, 3 and 4), and as a cross-section (Figure 5). These results are based primarily on cutting analysis; cores were only obtained in "blind" portions of the holes (Table 1). This has limited the correlation of units in terms of textures larger than the cutting sizes.

3.1 Young Pumice Breccias

The youngest pumice breccias of the Arawa Formation have been largely or completely removed during well pad construction. Their remnants are best preserved in Wk 604 where pumice breccias containing a variety of lithic clasts including rhyolite and basalt are found. Pumice breccias of the Wairakei Formation tend to have a pinkish colour to them and are found beneath the Arawa Formation. In addition to pumice they also contain lithic clasts, including rhyolite and basalt. In Wk 650 a basal welded layer is found which does not correspond to the descriptions of the Wairakei Formation provided by Self and Healy (1987). It is uncertain whether this unit is a welded member of the Wairakei Formation or is part of a regional ignimbrite sheet predating the Wairakei Formation. Its limited distribution is suggestive of the former.

3.2 Huka Falls Formation

The Huka Falls Formation consists mainly of grey mudstones and siltstones with brown carbonaceous horizons and intercalated sandstones and pumice breccias. Even given possible fault offsets the upper surface has significant topographic relief and is strongly weathered in places, indicating a change from lacustrine to subaerial conditions with the consequent development of an erosional surface. The base of the formation is also irregular with a suggestion of a deeper depositional basin in the southwest. This feature is shown in Figure 5.

Included within the Huka Falls Formation is the Rautehuia Breccia (ECNZ, 1992). This is considered to be a hydrothermal breccia *sensu lato* consisting of a combination of airfall material and reworked mass flow deposits. It contains altered clasts of formations underlying the Huka Falls Formation enclosed in a grey silty matrix which is indistinguishable from that making up the majority of the Huka Falls Formation. It has a very irregular distribution, suggestive of it mainly being a mass flow deposit within the Poihipi Sector, which has formed a scour channel into older Huka Falls Formation in the vicinity of Wk 620, whereas a thinner bed of breccia in Wk 650 may be airfall material. Its presence as far to the southwest as the Poihipi Sector and its known distribution in the Te Mihi area indicates that a very substantial eruption or eruptions occurred. Given its silty matrix, possibly the closest known analogue to the Rautehuia Breccia - which differs from most substantial hydrothermal breccia deposits reported from other geothermal systems within the Taupo Volcanic Zone (Browne, 1991) which have matrices of communited clast material- is the Rotomahana Mud (Nairn, 1979). The Rotomahana Mud is of phreatomagmatic origin, being associated with the 1886 eruption of Mt. Tarawera. In this context, it is also interesting to note the presence of the K-Trig basalt, along strike just to the south of the area. It is possible that this basalt is penecontemperaneous with the Rautehuia Breccia.

3.3 Waiora Formation (Upper Members)

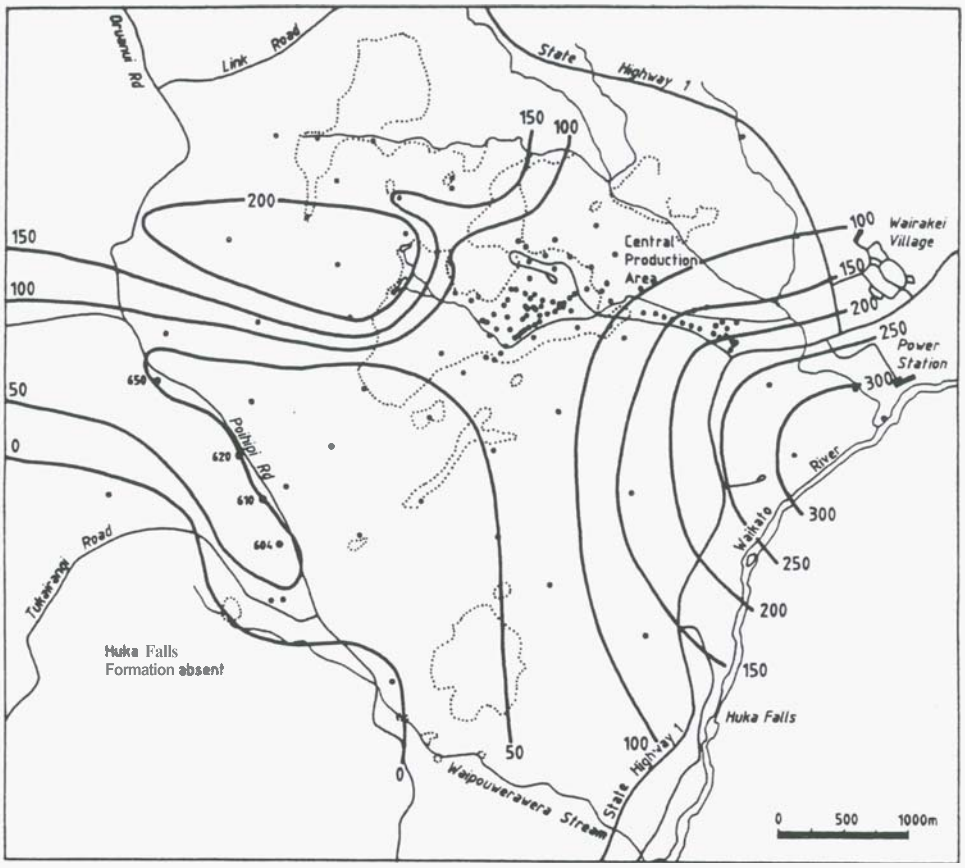
The uppermost member of the Waiora Formation is a 40 m thick grey quartz-feldspar-rich ignimbrite. Below the ignimbrite there are several interbedded tuffs, pumice breccias and sediments which include grey siltstone, white claystone and reworked light brown tuffaceous sandstone.

3.4 Karapiti IIa Rhyolite

The Karapiti IIa Rhyolite consists of medium grained euhedral phenocrysts of plagioclase with subordinate mafics including amphibole and hypersthene enclosed in a groundmass exhibiting variable textures. Near its upper surface it is spherulitic and pumiceous but it becomes darker coloured and banded at depth. Its upper surface, which shows indications of moderate to high permeability, is interpreted to be a flow top auto breccia.

3.5 Waiora Formation (Middle Members)

The middle members of the Waiora Formation consist of an upper 50 m thick unit of quartz-poor pumice breccia which contains siltstone and mudstone lithic fragments, underlain by a dark grey glassy ignimbrite containing dark silicified lithics and minor pumice.



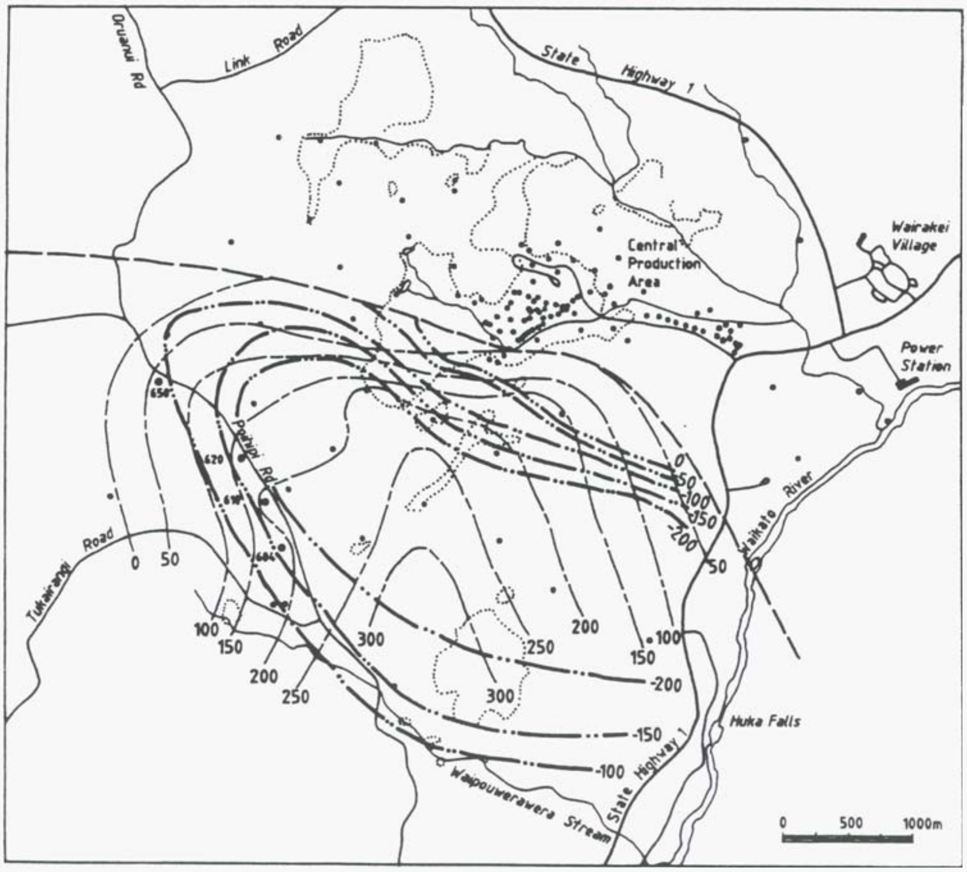
Key

- Geothermal Well
- Extent of surface thermal activity
- Isopach m

(modified after Grindley 1965)

Isopachs on Huka Falls Formation

Fig. 3



Key

- Geothermal Well
- Extent of surface thermal activity
- Northern limit of KIIa Rhyolite
- Contours on top surface of KIIa Rhyolite - m RSL
- Contours on base of KIIa Rhyolite - m RSL

(modified after Healy 1984)

Structural contours on Karapiti IIa Rhyolite flow

Fig. 4

3.6 Karapiti IIb Rhyolite

This unit has only been encountered in Wk 650 but could also have been present in the portion of Wk 610 which was drilled blind. The rhyolite at this level is lithologically identical to the upper rhyolite (ie. Karapiti IIa). The Karapiti IIb Rhyolite is thinner than the upper IIa member and, in contrast to the latter, thins out to the southwest.

3.7 Waiora Formation (Lower Members)

The lower members of the Waiora Formation were reached in Wk 650 and consist of several lithologically distinct pyroclastic units with minor intercalated tuffaceous sediments. The upper pyroclastics are typically much paler and more pumiceous than those at deeper levels, and contain rare phenocryst quartz and a moderate amount of lithic material which include fragments of rhyolite, siltstone and basalt. A core taken at a depth of 1245 m is a lenticular lithic-rich ignimbrite and, although now replaced by secondary minerals, originally consisted of coarsely crystalline phenocrysts of plagioclase, quartz and mafics within a microcrystalline quartzofeldspathic groundmass.

The various members of the Waiora Formation encountered in the Poihipi Sector have not been correlated in detail with those identified by Grindley (1965) or Steiner (1977).

4.0 HYDROTHERMAL ALTERATION

Hydrothermal alteration in the units overlying the Huka Falls Formation is limited to slight chloritisation of the welded unit just above the Huka Falls Formation in Wk 650. As there are no current indications of elevated temperatures at this point in the well, this alteration is considered relict. As it is occurring in the immediate vicinity of a fault exposed during well pad construction, it is possible that in the past this fault has been the conduit for steam or gas into a perched ground water aquifer lying upon the Huka Falls Formation. This alteration would have to have occurred below the zone of oxidation and acid formation, otherwise a more cation leached assemblage would be expected. Hydrothermal alteration within the Huka Falls Formation itself is limited, at least on a megascopic scale (as no petrology was undertaken on the Huka Falls Formation in these wells), to clasts in the Rautehuia Formation and hence is unrelated to hydrothermal processes within the wells.

The Waiora Formation exhibits considerable variability in the intensity of alteration. The upper ignimbrite member, for instance, is only very weakly altered with minor clay and calcite. Conversely, tuffs and tuffaceous sediments below this unit are intensely chloritised and overall there is a general increase in intensity of alteration with indications of increasing permeability which include partial losses of circulation. The Karapiti Rhyolite is moderately altered with a secondary mineral assemblage consisting predominantly of quartz, albite and illite-smectite, with minor amounts of calcite, chlorite, leucoxene and pyrite. Superimposed upon this pattern are intensely argillised zones just above total losses of circulation which correspond to faults. Cores taken at the loss of circulation show decreasing intensity of alteration with depth indicating that there is much thinner footwall zone of alteration. The dominant alteration minerals are interlayered illite-smectite and illite, with a general increase in the proportion of illite interlayering with depth. Adularia is found in the immediate vicinity of faults. As a steam zone has formed in the shallow part of the sector, much of this alteration is now relict, but there are no obvious changes in mineralogy.

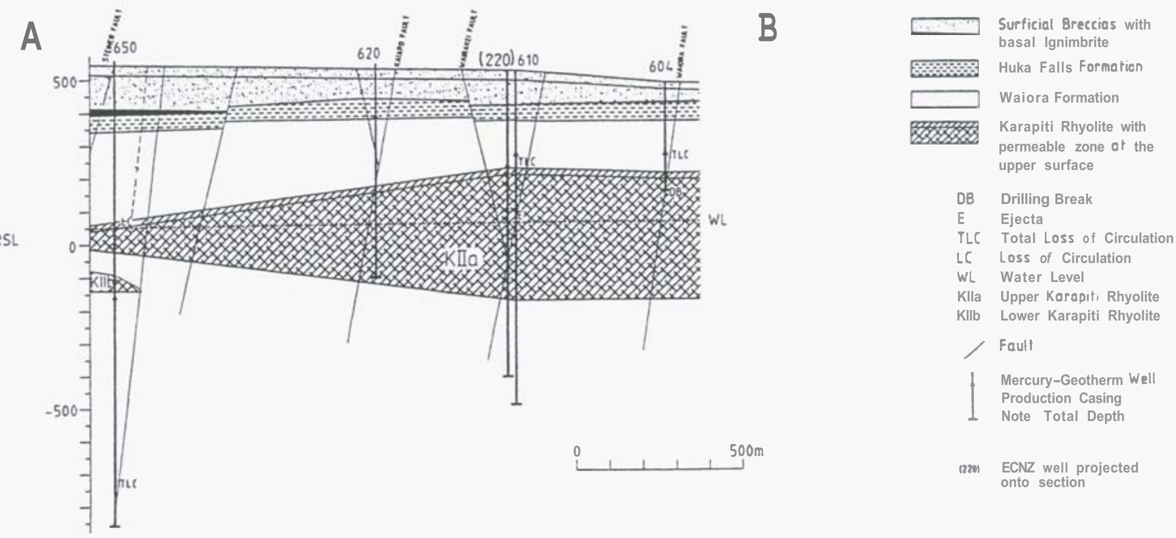
A slightly more complex mineralogy is found in Wk 650. Kaolinite occurs with interlayered illite-smectite and calcite just above the water level in the well. The zeolites, mordenite and natrolite, are found with smectite near the base of the Karapiti IIb Rhyolite and epidote is found with interlayered illite-smectite at the circulation loss at 1250 m. In the fust instance the presence of interlayered illite-smectite is suggestive of the water level being previously higher, with the subsequent kaolinite formation from water-rock interaction involving a condensate fluid of bicarbonate composition which formed as a layer over the declining deep water level. The presence of the zeolites with smectite are indicative of a cold inflow at the base of the rhyolite, a phenomenom noted in other wells towards the centre of the field (Healy, 1984a). The presence of illite-smectite replacing epidote is believed to be the fust occurrence of retrograde alteration at Wairakei given that Steiner (1977) notes its absence.

5.0 STRUCTURE

The various lithostratigraphic units, whilst exhibiting a degree of topography at their surfaces, are generally flat lying. They are cut by a series of northeast striking normal faults which mainly dip to the northwest at an average angle of 80". Southeast dipping splinter faults are also found. Offsets on the faults are less than the variation in topography of marker horizons and hence whilst not quantifiable are in most cases not substantial. However, the top and bottom of the Huka Falls Formation in Wk 620 occur at levels between 15 and 20 m shallower than that inferred from stratigraphic information obtained from the other wells. Whilst this may be due to deposition upon an irregular surface and post depositional erosion, it is likely that there has been some minor fault displacement. However, the sense of displacement is opposite to that expected from the Kaiapo Fault (Healy, 1965) which was the target for Wk 620.

6.0 CONCLUSIONS

Other than the presence of a previously unreported minor welded pyroclastic unit overlying the Hika Falls Formation in the northern part of the sector, the lithostratigraphy of the Poihipi Sector is in accordance with that previously reported in the general area.



Geologic cross section through the Poihipi Sector Fig. 5

The hydrothermal alteration pattern is, with some minor differences, similar to the pre-exploitation pattern despite the creation of a steam zone in response to exploitation of the field. The differences are found in the northern part of the sector where a deep Occurrence of kaolinite appears to have formed as a result of a drop in the deep water table, allowing a bicarbonate rich condensate layer to form. There is also some retrograde alteration with illitic clay replacing epidote in one deep sample, which has not previously been reported.

The same structural pattern of faulting reported from the northeast of the Poihipi Sector continues into it, and provides zones of major permeability.

ACKNOWLEDGMENTS

The authors gratefully acknowledge the permission of Mercury-Geotherm to publish this paper with special mention to Minoru Fredericksens and Alistair McLachlan.

REFERENCES

Browne, P. R. L., **(1991).** Hydrothermal eruptions in New Zealand: Review and Lessons. *PNOC Geoscientific Conference. Manila.*

ECNZ, **(1992).** Resource consent application for reinjection, Wairakei geothermal field. *Discharge permit application and impact assessment.*

Grange, L. I., **(1937).** The geology of the Rotorua-Taupo Subdivision. *NZGS Bulletin* **37.**

Grindley, G. W., **(1965).** The geology, structure, and exploitation of the Wairakei geothermal field, Taupo, New Zealand. *NZGS Bulletin* **75.**

Grindley, G. W., **(1986).** The Te Mihi steam reservoir, Wairakei. *An* exploitable geothermal resource. *Proc. 8th NZ Geothermal Workshop,* **165-170.**

Healy, J., **(1964).** Stratigraphy and chronology of late Quaternary volcanic ash in Taupo, Rotorua, and Gisborne Districts. *NZGS Bulletin* **73.**

Healy, J., **(1965).** Geology of the Wairakei geothermal field. *8th Commonwealth Mining and Metallurgical Congress.* Paper No. **218.**

Healy, J., **(1984).** Wairakei geothermal field in review. *Geothermal Circular,* **JH/10.**

Healy, J., **(1984a).** Temperature inversions in Wairakei geothermal field. *Wairakei Geotheml Seminar.*

KRTA, **(1988).** Review of the Wairakei Geothermal Reservoir. Tukairangi Valley Geothermal Project. *Report prepared for Geothenn Energy Ltd.*

Nairn, I. A., **(1979).** Rotomahana-Waimangu, **1886:** base surge and basalt magma. *NZJGG* **22,363-378.**

Self, **S.** and Healy, J., **(1987).** Wairakei Formation, New Zealand: stratigraphy and correlation. *NZJGG* **30, 73-86.**

Steiner, **A., (1977).** The Wairakei geothermal area, North Island, New Zealand, its subsurface geology and hydrothermal rock alteration. *NZGS Bulletin* **90.**

Vucetich, C. G. and Pullar, W. **A., (1969).** Stratigraphy and chronology of late Pleistocene volcanic ashbeds in central North Island, New Zealand. *NZJGG* **12, 784-837.**

Wilson, C. J. N., **(1993).** Stratigraphy, chronology, styles and dynamics of late Quaternary eruptions **from** Taupo volcano, New Zealand. *Phil. Trans. R. Soc. Lond.* A **343, 205-306.**

Wilson, C. J. N., Switsur, R. V. and Ward, **A.P., (1988).** A new ^{14}C age for the Oruanui (Wairakei) eruption, New Zealand. Geol. *Mag.* **125, 297-300.**

Wood, C. P., **(1994).** The Waiora Formation geothermal aquifer, Taupo Volcanic Zone, New Zealand. Proc. *16th NZ Geothermal Workshop,* **121-126.**