THE DEEPER STRUCTURE OF THE WAIRAKEI GEOTHERMAL FIELD

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ABSTRACT

Most drillholes at Wairakei are between 600 and 800 m deep, a few extend down to 1000-1200 m where thick impermeable ignimbrites or rhyolites have discouraged deeper drilling over much of the field. Only two holes have penetrated through these ignimbrites. One (W121) in the centre of the Wairakei Field drilled almost 1 km of ignimbrites and bottomed in impermeable andesites and pumice-lapilli tuffs. The other (W219) in the north of the Wairakei Field drilled only 200 m of ignimbrites and bottomed in pumice-lapilli tuff and rhyolite. Re-evaluation of drillhole data indicates that the Wairakei Ignimbrites are composed of three separate sheets, that can be discriminated on phenocryst content. Only the upper sheet extends north from W121 to W219. A major tectonic boundary, probably a caldera margin or NW-trending cross-fault separates these two holes and has been suggested as the target for a deep (2.5-3 km) exploratory hole. Other deep exploration well sites in the southern and western parts of the Wairakei Field are also discussed.

INTRODUCTION

Since 1963, Wairakei Geothermal Field has proved a reliable source of energy, providing a base load of 1200 GW/yr to the New Zealand grid, equivalent to about 13% of the North Island or about 8% of the New Zealand electrical energy consumption. During the life time of the field, field pressures have declined (Bolton, 1971) due to drawdown, although this has been largely offset by recharge from deeper levels as shown by repeat gravity surveys (Hunt, 1977). However at the level of present production (500-800 m) individual wells have fallen in output with the decline in field pressures. To maintain station output, the energy in the waste hot water has been progressively utilised in double-flash separator units. As this option has been used up, it is proposed to pipe more steam and hot water from areas to the west of the present production field, where earlier investigation drilling (200 series wells) has proved high-temperature resources at present production levels. Initially, three wells (207, 206 and 215) will be utilised and the waste water recharged into the reservoir via W219 (Fig. 1). Eventually, it will be necessary to drill to deeper levels to maintain production. This paper discusses potential drilling targets for such a deep drilling operation.

PREVIOUS DEEP DRILLING

Wairakei Geothermal Field consists of a pumiceous pyroclastic reservoir (Waiora Formation) at the crest of an elevated horst, underlain by thick ignimbrites (Wairakei Ignimbrites), and capped by lacustrine mudstones (Huka Falls Formation). To the south, thick rhyolites erupted into the Waiora Formation have depressed the Wairakei Ignimbrites to beyond present drilling depths (Fig. 2 see also Grindley, 1965). Previous deep drilling has been confined to the deep test well W121 in the upper Waiora Valley (Fig. 1) to the southwest of the present production area. This well proved almost 1 km of dense (welded) ignimbrites underlain by 650 m of pumiceous pyroclastics and sediments of the Ohakuri Group with three intercalated flows (or sills) of andesite, similar to the Waiora Valley Andesite erupted above the upper surface of the Wairakei Ignimbrites in the present production area (Figs 3, 4, & Grindley, 1965, fig. 22).

A major fault was encountered within the Wairakei Ignimbrites and associated loss circulation zones severely impeded the drilling of W121, until this zone was cased off. Apart from a small permeable zone at the top of the underlying Ohakuri Group and minor losses in the andesite, W121 was essentially impermeable and non-productive, despite its bottom hole temperature of 275°C. Because of the thick ignimbrites, the small rise in temperatures and the low permeability, further deep drilling in the present production area is unlikely to be recommended. Similarly, the occurrence of thick rhyolite flows to the south is also discouraging for deep exploration, although it has been suggested (Grindley, 1965, fig. 55) that a heat source lay in that direction. Other options need to be considered.

GEOPHYSICAL STRUCTURE OF WAIRAKEI

Gravity surveys and the results of initial drilling (Beck and Robertson, 1955) outlined the Wairakei Gravity High and the Wairakei Block, a horst-like elevation in the Taupo Volcanic Zone of regional subsidence. Preliminary estimates placing basement at c.1.2 km below sea-level

(Modriniak and Studt, 1959), must be increased following deep drilling (-2.1 km+) and the proving of higher density rocks (andesites and ignimbrites) at the deeper levels, than originally anticipated. The latest interpretation of the gravity data (Rogan, 1982) shows a gravity depression north of Wairakei, extending down to c.2.5 km below sea-level and a gravity high over the Wairakei Block (base at -1.0 to -1.5 km). Again, these values are minima depending on the assumed density of volcanic rocks overlying the basement. The gravity depression outlined by Rogan (1982, fig. 4) appears to be part of the Maroa Graben of Modriniak and Studt (1959) an inferred major NW-trending older graben, athwart the general NE-trending grabens and horsts of the currently active Taupo Volcanic Zone. The reality of this structure was questioned by Grindley (1965) on geological grounds.

Caldera-like structures have been postulated at Lake Taupo, Maroa and Okataina by Healy (1962) and are supported by low gravity and high magnetic anomalies (Rogan, 1982). The calderas are thought to result from gravitational collapse following large ignimbrite eruptions and have been the locus of rhyolite dome extrusion until the present day. The relation of Wairakei geothermal field to the Taupo and Maroa Volcanic centres has not been satisfactorily established. Reinterpretation of drillhole data at Wairakei, presented here, may shed some light on this problem.

GEOLOGICAL STRUCTURE OF WAIRAKEI

A south to north cross-section of Wairakei (Fig. 2) based on drillhole data (Grindley, 1965; Healy, 1965; Steiner, 1977) shows stable isotherms, the resistivity boundaries of the field at 600 m depth (Banwell and Macdonald, 1965; G. Risk and P. Macdonald, pers. corn.) and the position of faults at the surface (Fig. 1), some of which extend to depths of 0.5 km as shown by drilling (Grindley, 1965). The isothermal cross-section shows two "thermal highs", one to the south of and one to the north of the present production area, both potential deep drilling targets.

The northern thermal anomaly coincides with a postulated major fault affecting the Wairakei Ignimbrites, but not the post-ignimbrite Huka Group. In W121 the base of the Wairakei Ignimbrites is at -1175 m, whereas in W219, 1.25 km to the north, the base is at only -367 m. An 800 m displacement (down to the south) of the base of the ignimbrite is thus indicated. Such a large displacement in such a short distance makes underlying topographic relief an unlikely explanation.

Further evidence comes from a consideration of mineralogic variations within the Wairakei Ignimbrites. Despite hydrothermal alteration, three separate sheets of ignimbrite can be discriminated on the basis of phenocryst abundance and mineralogy. The upper unit, present in W219 and in many wells to the south, including W121, is a hornblende-hypersthene-quartz-feldspar crystal-rich ignimbrite. An underlying unit, present in W121, W48 and at the bottom of W218 and W54 is a biotite-hornblende-hypersthene-quartz feldspar crystal-rich ignimbrite, the glassy base of which was cored in W48. The basal unit, found only in W121 and W48, is a hornblende-hypersthene-quartz-feldspar ignimbrite with little or no biotite and a lower crystal content. Lithic inclusions of micro-diorite/andesite, microdolerite/basalt, granoblastic quartz (Steiner, 1963) and glassy rhyolite are present in all three sheets.

A geological interpretation shows a steep southward-dipping fault limiting the lower two sheets of ignimbrite and probably truncated by the uppermost sheet. An episode of block-faulting or caldera collapse, probably resulting from the eruption of the thick lower sheets of Wairakei Ignimbrite, is thus indicated. Faulting and collapse did not follow eruption of the uppermost sheet of ignimbrite, possibly because the eruptive vent was further away, perhaps. even outside the caldera occupied by the lower 2 sheets.

The Wairakei Geothermal Field is, therefore, believed to have been established close to the northern rim of a major caldera, produced as a result of collapse following the eruption of almost 1 km of crystal-rich ignimbrites, now almost totally welded from top to bottom. Such a major outpouring of rhyolitic magma must represent the rapid evacuation of a large magma chamber. It is not surprising that a hydrothermal system should become established during such a major volcanic event and that it should continue to be active to the present day. Regional correlation of the Wairakei Ignimbrites has not been clearly established. Phenocryst mineralogy suggests correlation of the uppermost sheet of mainly hypersthene-bearing quartz-feldspar ignimbrite with the Rangitaiki Ignimbrite of the Rangitaiki Plains (Martin, 1961). Broadlands (Grindley and Browne, 1976) extending north to Kawerau. The lower 2 sheets, containing biotite and hornblende as essential minerals may be correlative with the Whakamaru Ignimbrite of western L. Taupo, Mokai and the Waikato Valley (Ewart, 1965; Briggs, 1976).

Dating of these older ignimbrites has been attempted using the fission-track method on glass shards, but is inapplicable to the Wairakei Ignimbrites because of their generally intense alteration and devitrification. Preliminary results on the Whakamaru Ignimbrite of the Waikato Valley gave an age of 330,000 years B.P. while the Te Whaiti Ignimbrite (= the fine-grained distal facies of the Rangitaiki Ignimbrite) has given an age of 310,000 years B.P. (Kohn, 1973, fig. 23). These relative ages are in agreement with their proposed stratigraphic order at Wairakei. Caldera formation presumably could have taken place in the 20,000 year interval between the two Ignimbrite eruptions. A younger age (c.240,000 years B.P.) for the Rangitaiki and Whakamaru Ignimbrites has since been suggested, based on electron microprobe analysis of glass shards and correlation with the Mt Curl Tephra of the lower North Island (Froggatt, in press).

TARGETS FOR DEEP DRILLING

1. If the Wairakei geothermal system originated following major ignimbrite eruptions and caldera collapse, the associated boundary faults may still be potential targets for deep drilling. Accordingly, a site for a deep test well to 3 km has been suggested between W215 and W219 in the north of the field. This well is targeted on the northern boundary fault zone and is expected to bypass the thick ignimbrite sequence encountered in W121 and to obtain permeability in brecciated rocks of the fault zone, provided these have not been sealed by hydrothermal alteration.

2. Another suggested site for a deep test well is on the western side of the Wairakei Field, in the Upper Waiora valley area between wells W207, W215 and W202 where major subsidence of the Wairakei Block took place during deposition of the Huka Group (Grindley, 1965 Fig. 14). Hydrothermal eruption breccias intercalated in the lower part of the Huka Falls Formation (Fig. 2) attain a thickness of 200 m in W215 and include fragments of silicified Wairakei Ignimbrites, indicating eruption of a deep hydrothermal system. Isopachs (thickness contours) on the breccias (Fig. 1) suggest a source in the upper Waiora valley, possibly from the Crater Fault and its intersection with cross faults. From the source, possibly a breccia pipe, a debris flow or lahar flowed west and north beyond the limits of the Wairakei Field (to W224 in the west). Although such a breccia pipe may now be partly sealed by hydrothermal alteration, it still constitutes a potential drilling target. Temperatures of 260-265°C are still present at 1 km depth in this area.

3. An additional site for a deep well has been selected to the south of W121 on the crest of the Wairakei Block between wells W204, W205 and W218, where positive thermal gradients and temperatures of 260°C+ are found at 1 km depth. Because of the thick rhyolites above the Wairakei Ignimbrites, such a well is unlikely to reach basement at 3 km depth. These rhyolites are the northern extension of a major rhyolitic complex, centred on the K Trig area west of Taupo, as shown by large magnetic anomalies (Target Anomaly of Beck and Robertson, 1955) and considered to be a heat source by Grindley (1965, Fig. 55). The downward extensions of the Waiora and Wairakei Faults should provide permeability in this area, as indicated by the "success" of the Rogue Bore W204.

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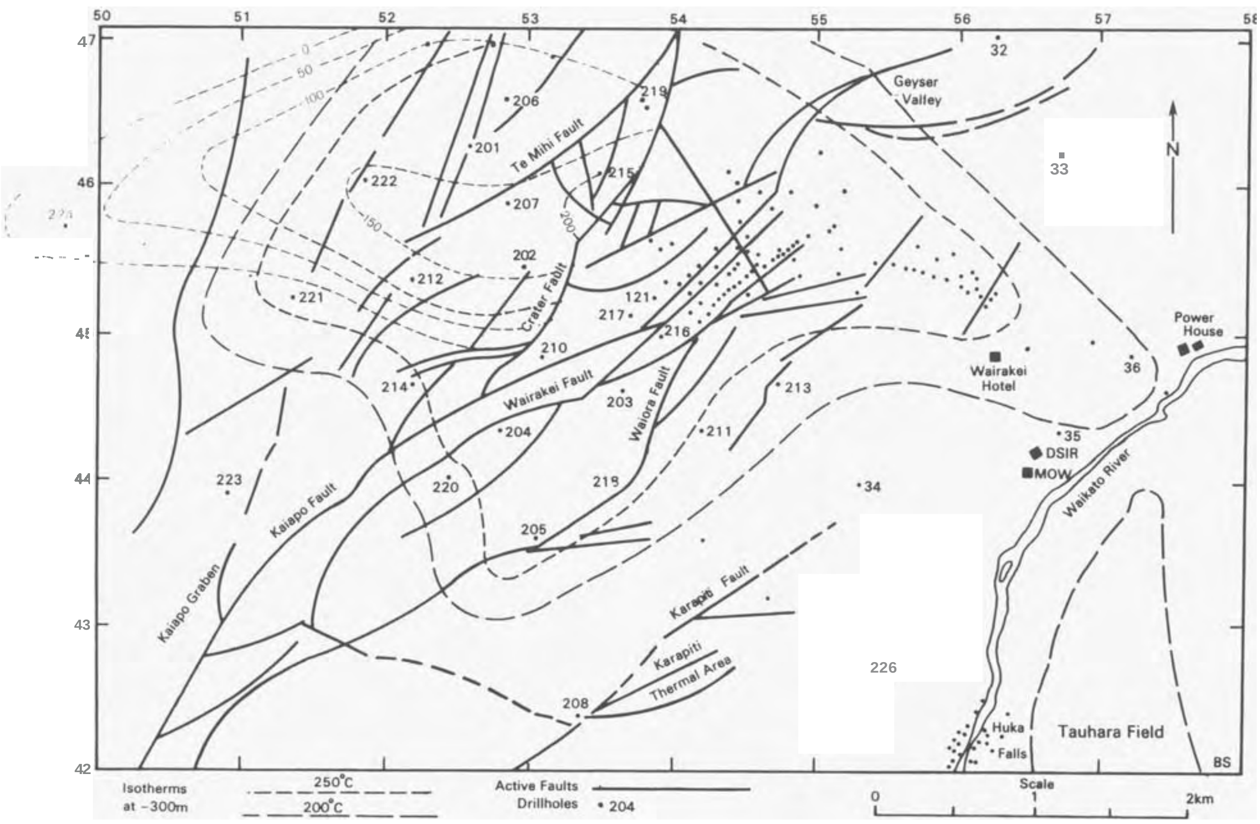

Figure 1. Map of Wairakei Geothermal Field showing drillholes, investigation drillholes (200 series), active faults, and isotherms at -300 m, and isopachs on hydrothermal breccias of Huka Falls Formation (hu_1) at 50 m intervals.

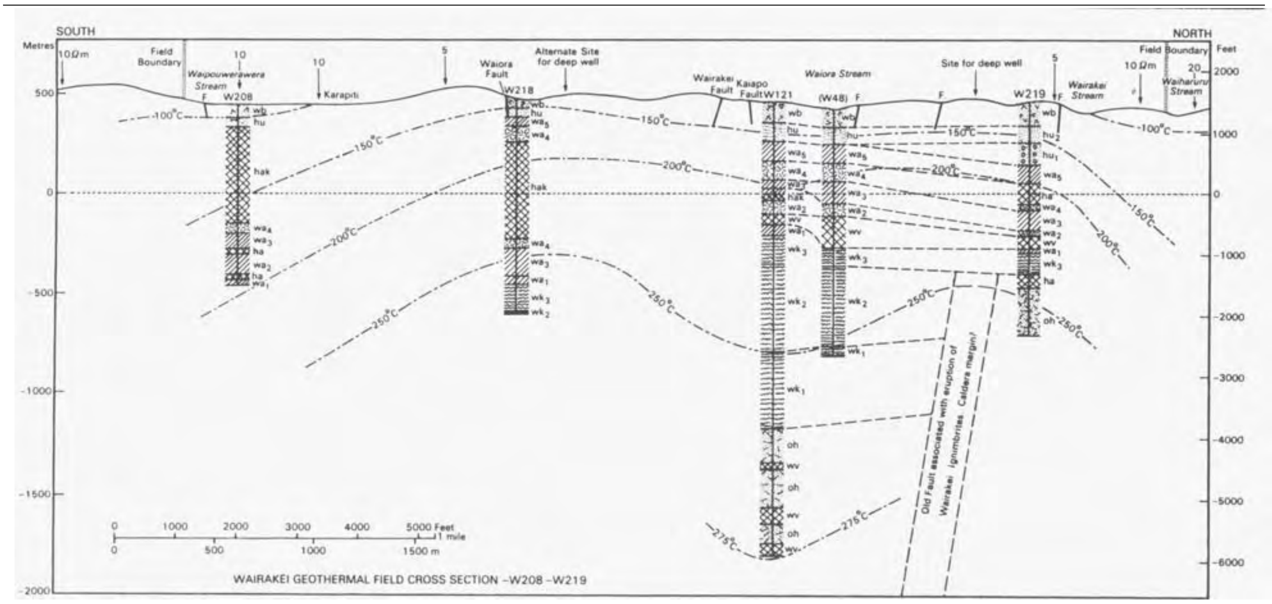

Figure 2. Cross Section between drillholes 208, 218, 121 and 219 showing geological formations, isotherms and potential well sites.

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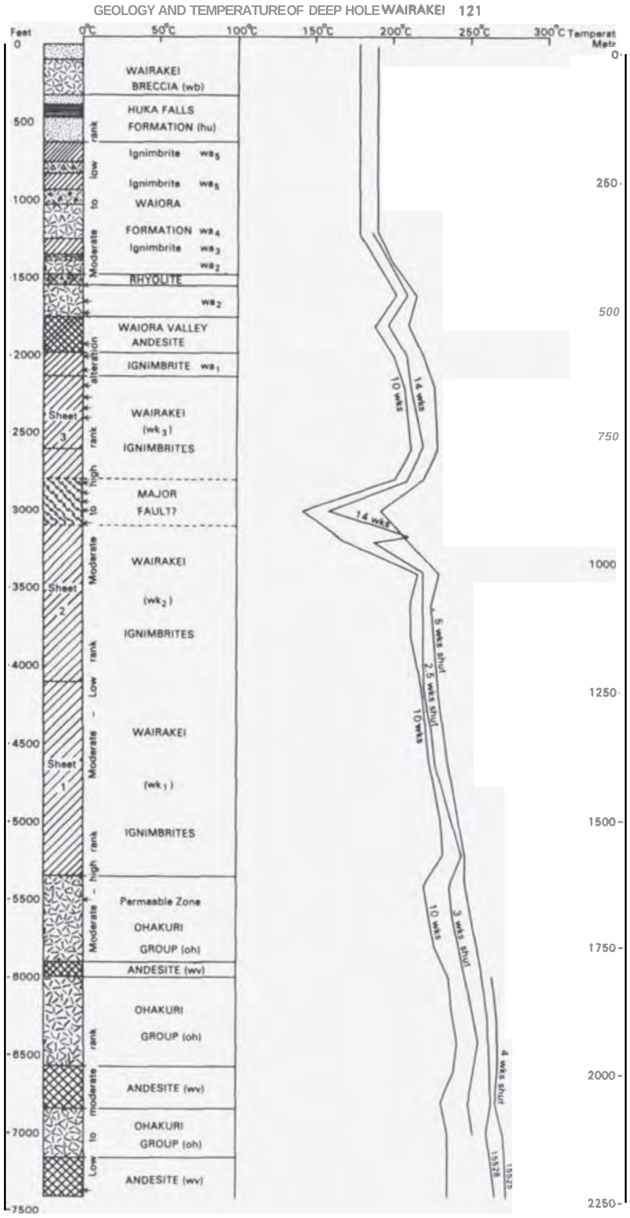
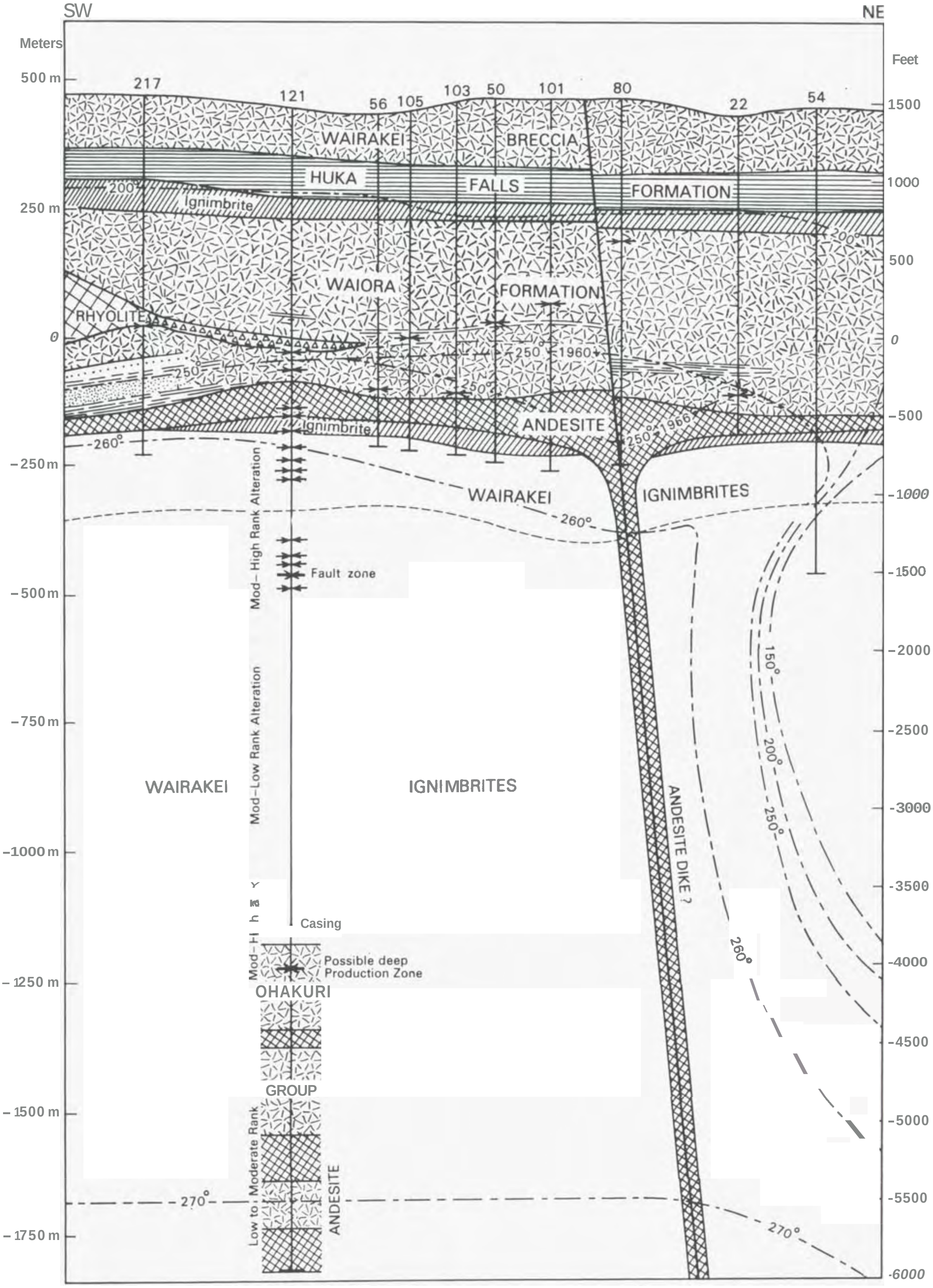


Figure 3. Geological log and temperatures in the deep drillhole at Wairakei (B121). Rank of hydrothermal alteration and loss circulation zones (arrowed) shown alongside log.

Figure 4. (overleaf) Cross Section through Production Area of Wairakei Geothermal Field showing relation of deep well W121 to production wells. Note sharp fall in temperatures to the northeast. The andesite dike is inferred from the geometry and thickness of Waiora Valley Andesite flows in the Production Area. Rhyolite in the southwest is the northern edge of thick rhyolites erupted from the K Trig area west of Taupo. The approximate boundary of the uppermost sheet of Wairakei Ignimbrites (= Rangitaiki Ignimbrite?) is shown by the dashed line.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