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GEOLOGICAL RESULTS OF PRODUCTION WELL DRILLING IN THE WESTERN STEAMFIELD, OHAAKI GEOTHERMAL SYSTEM: 2005 - 2007

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SUMMARY – Drilling of 10 production wells since 2005 in the western Ohaaki steamfield has provided important insights into the deep stratigraphy, including new lithological types, the depth and contour of the greywacke basement and likely influences of basement faults, and the deep hydrological structure. New andesite and dacite subunits of the Tahorakuri Formation have been identified and may be of extrusive or intrusive origin. The depth to the greywacke basement increases towards the northwest, where it lies beyond -2150 mRL, and north (-1724 mRL), with a possible NW-trending horst-like structure. The basement is likely to be faulted by both NW- and NE-trending basement faults, which provide pathways for upwelling fluids into the post-basement volcano-sedimentary sequence where both formational and fault-related permeability are likely to provide pathways for fluid movement. The northwestern part of the steamfield, where greywacke basement is deepest, contains favourable mineralogical indicators for good permeability and high temperatures (>280° C) and is a highly prospective part of the field for steam production.

1. INTRODUCTION

Ohaaki geothermal field, New Zealand, is located approximately 30 km NE of Taupo township (Figure 1). Since November 2005, 10 production wells have been completed in the western Ohaaki steamfield (BR52, BR52A, BR53, BR54, BR56, BR57, BR58, BR59, BR60, BR61; Figure 1). Whereas most of the previously drilled Ohaaki wells have been shallower than -1000 mRSL, these new wells are considerably deeper with the deepest (BR59) being to -2136 mRSL. The results of this 10 well drilling programme has revealed valuable information on the stratigraphy, alteration, basement structure and possible controls on hydrology at depth (i.e., <-1000 mRL) in the western Ohaaki steamfield.

The aims of the drilling programme were to increase steam production and continue resource management. Drill targeting was directed at permeable zones within, and at contacts between, the Rangitaiki Ignimbrite and Tahorakuri and Waikora Formations. Also, any permeability occurring at or close to the greywacke basement surface would be targeted.

The greywacke basement topographic surface, determined previously using seismic, gravity and well data has been considered to be influenced by major NE-trending normal faults, block faulted down to the northwest (Henrys and Hochstein, 1990). However, regional NW-trending structures that affect basement rocks cropping out in the Kaimanawa and Urewera Ranges, east of the Taupo Volcanic Zone, must also be considered as having a strong influence on the basement topography at Ohaaki. The general NW-trending shape of the Ohaaki resistivity boundary and deep isotherms may be accounted for by such structures (Wan and Hedenquist, 1981).

2. STRATIGRAPHY

With the exception of BR15, BR15R and BR48, most of the wells drilled in the western Ohaaki steamfield prior to 2005 are between 1000 and 1500 m drilled depth. Examination of drillcuttings and drillcore from more than 20 wells by previous workers has led to a sound understanding of the Ohaaki stratigraphy to these depths (Table 1; Grindley and Browne, 1968; Browne, 1971; Wood, 1983). The stratigraphic framework to 1500 m is a sequence of lacustrine deposits (**Huka Falls Formation**), rhyolite lavas and breccias (**Ohaaki Rhyolite**), reworked sediments (**Waiora Formation**), variably welded pyroclastic formations (**Rangitaiki Ignimbrite**) along with airfall tuffs, pumice breccias and andesites that have a more limited distribution.

The western steamfield production wells drilled since 2005 have provided important insights into the pre-Rangitaiki Ignimbrite strata overlying the greywacke basement (i.e., >1500 m drilled depth). This sequence, known collectively as the Reporoa Group (Gravely et al., 2006) consists of the Tahorakuri Formation and Waikora Formation (Table 1).

In the new western steamfield wells the **Tahorakuri Formation** lithology is most commonly a crystal-poor (quartz and plagioclase) lithic breccia containing angular to rounded lithic clasts of pumice, flow banded rhyolite lava, and rare to minor, plutonics, andesite and rounded argillite pebbles. Lithic poor ignimbrite strat are also present. The Tahorakuri Formation has a thickness ranging between 230 m (BR26) and 784 m (BR59). The **Waikora Formation** either underlies, or is intercalated with, the Tahorakuri Formation. It is a pebble conglomerate of abundant rounded greywacke sandstone and

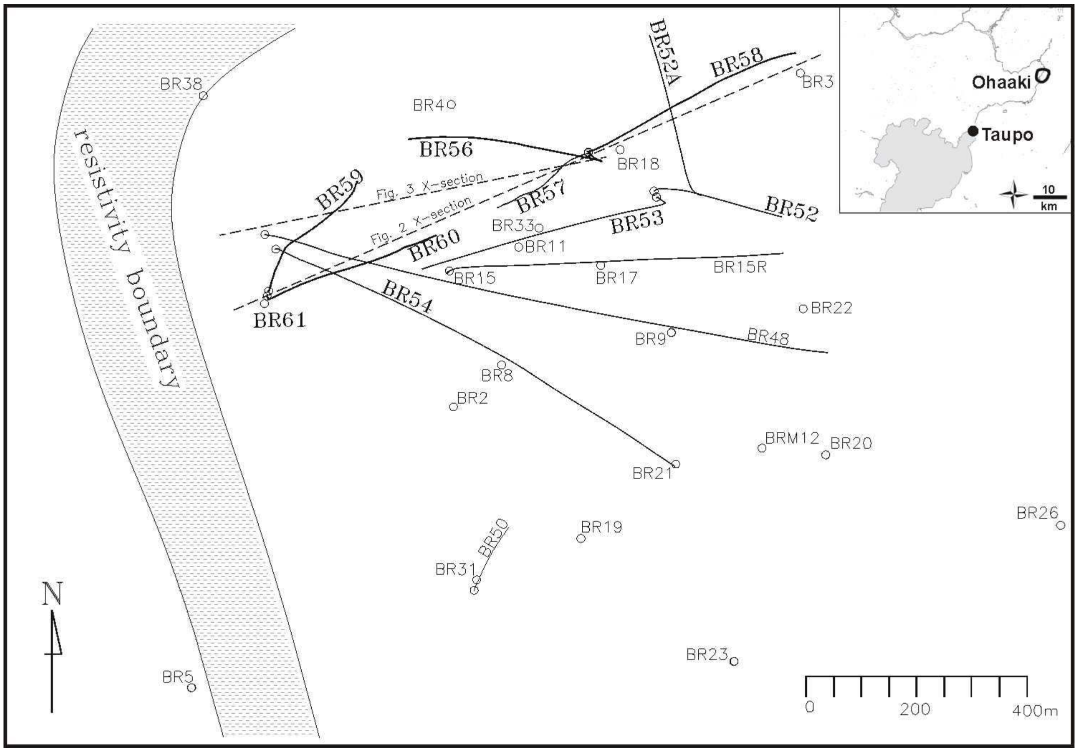

Figure 1. Well location map of the western Ohaaki steamfield showing the western portion of the resistivity boundary. The 10 recently drilled wells are highlighted in bold. The line of cross-sections for Figures 2 and 3 are also represented.

Table 1. Summary and description of the stratigraphic sequence with range of formation thicknesses encountered in the latest production wells drilled in the western Ohaaki steamfield.

Formation	Lithology	Thickness (m)
SURFICIAL DEPOSITS, inc. Taupo Pumice Alluvium	Pumice gravel, sands and alluvium with interbedded soil horizons.	5-45
HUKA FALLS FORMATION	Pale grey to brown, lacustrine siltstone and intercalated laminated sandstone.	40-90
OHAAKI RHYOLITE	Quartz - biotite phyric, pumiceous rhyolite lava.	350-645
WAIORA FORMATION	Tuffaceous rhyolite siltstone with rhyolite, pumice and siltstone clasts.	absent-240
LOWER SILTSTONE	Pale to dark brown, finely laminated muddy siltstone.	9-94
RAUTAWIRI BRECCIA	Vitric-crystal breccia and laminated siltstone.	79-369
SILTSTONE-SANDSTONE	Pale grey, dark grey and medium brown, siltstone to fine sandstone.	absent-15
ANDESITE C LAVA	Feldspar – pyroxene phyric, finely porphyritic lava.	absent-30
RANGITAIKI IGNIMBRITE	Partially welded, crystal-lithic ignimbrite with embayed, bipyramidal quartz, crystals, pumice and rhyolite clasts.	249-480
TAHORAKURI FORMATION	**Tahorakuri Formation:** Crystal-poor, non to partially welded, lithic breccia and ignimbrite. Clasts of pumice, rhyolite, argillite with quartz and feldspar crystals.	230-784
WAIKORA FORMATION	**Waikora Formation:** Pebble conglomerate, subangular to rounded greywacke clasts with rare volcanic lithics (pumice, rhyolite, andesite).	9-225
ANDESITE	**Andesite:** Weakly porphyritic andesite: plagioclase, chlorite-altered ferromagnesian phenocrysts in a microcrystalline groundmass.	<5-222
DACITE	**Dacite:** Porphyritic dacite: quartz, plagioclase and biotite phenocrysts in a crystalline groundmass.	40
GREYWACKE BASEMENT	Dark grey argillite and pale grey quartzose sandstone.	-

argillite and minor to rare rhyolite, pumice and andesite lava clasts. It ranges in thickness between 9 m (BR52) and 225 m (BR56). Waikora intercalations intersected in the new wells (BR59, BR60 and BR61) are relatively thin (15-60 m) and occur below ~-1600 mRL.

Prior to 2005, pre-Rangitaiki Ignimbrite andesite had been intersected only in BR15 where a 25 m thick unit (at -1698 to -1723 mRL) was identified within the Waikora Formation as well as two possibly dacitic units within the Tahorakuri Formation (Browne, 1971). Recently drilled wells (BR56, BR57, BR59, BR60) intersect a number of weakly **porphyritic andesite** (Figure 2 and 3) units of significant thickness. The rock contains sparse phenocrysts of plagioclase feldspar and chlorite pseudomorphs of a ferromagnesian mineral (probably pyroxene). The groundmass is microcrystalline and contains randomly oriented, fine plagioclase laths in a felsic mesostasis.

The andesites are not strata-bound (Figures 2 and 3) and occur within the Tahorakuri Formation (BR60: <5 m thick), the Waikora Formation (BR57: 20 m thick), at the Waikora and Tahorakuri Formation lower contact (BR60: 25 m thick) and as a substantially thicker unit between the Tahorakuri Formation and the greywacke basement (BR60: 174 m thick; Figure 2). Greatest thicknesses however were encountered in BR56 and BR59, which both terminated in porphyritic andesite after drilling through 175 m and 222 m of the unit, respectively (Figure 3). Petrographic correlation of this andesite strata between wells shows it to be a series of relatively thin units in BR57 and BR60 (Figure 2); each apparently thicken and deepen towards the northwest in BR56 and BR59 (Figure 3). It has not been possible from drillcutting examination to determine an extrusive or intrusive origin, hence multiple extrusive lava flows or microdioritic intrusions (stocks, sills and dikes) are plausible. With andesite intersections in only four wells, the deep stratigraphic architecture remains conjectural. For any future deep production well targeting in the northwestern part of Ohaaki, it will be important to define the spatial extent of the andesite, as significant permeability occurs both within and at the boundaries of the formation.

In BR60, between -1952 m and -1991 mRL (Figure 2) a ~40 m thick interval of **porphyritic dacite** was intersected within the porphyritic andesite. It contains phenocrysts of quartz, plagioclase feldspar and biotite in a crystalline groundmass. Biotite, which has been completely altered to chlorite and epidote, is recognised from relict crystal habit.

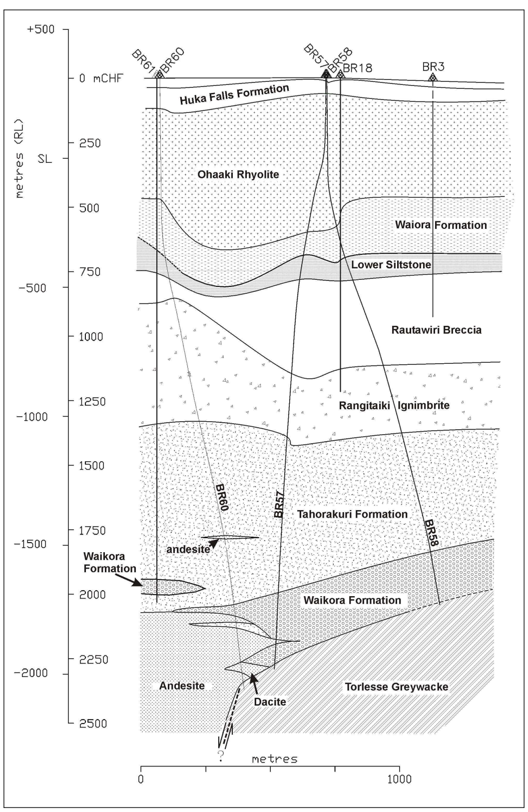

Figure 2. SW-NE cross-section through the western steamfield, with an interpretation of the deep stratigraphic sequence. Line of cross-section shown in Figure 1.

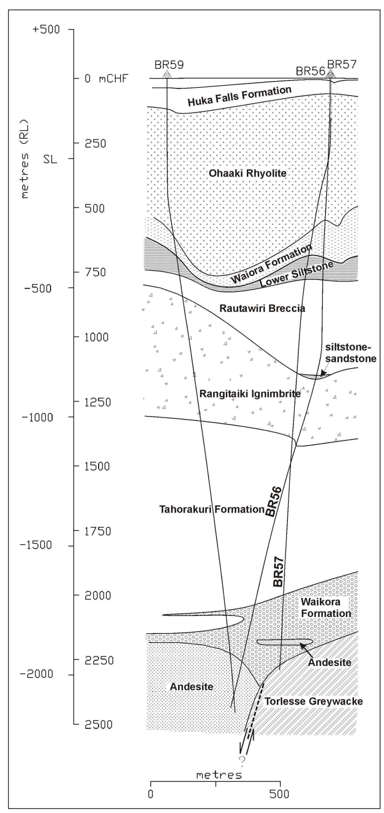

Figure 3. WSW-ENE cross-section through the western steamfield, with an interpretation of the deep stratigraphic sequence. Line of cross-section shown in Figure 1.

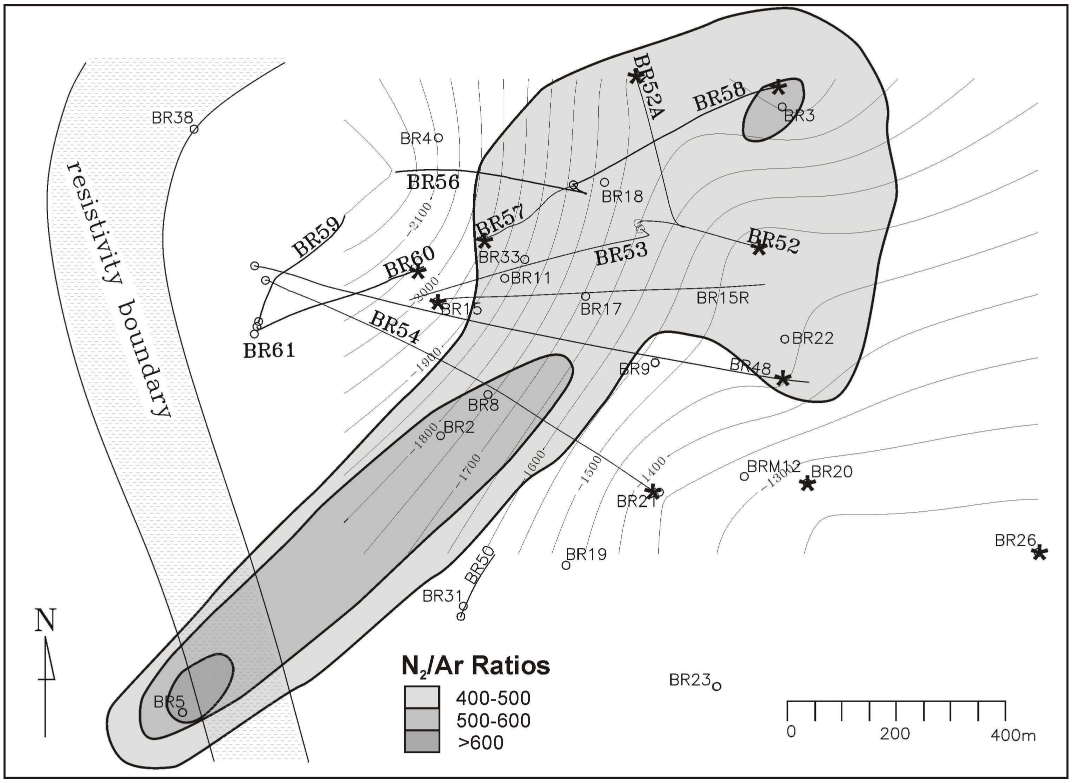

Figure 4. Overlay of N_2/Ar isopleths for the western steamfield (from Christenson et al., 2002) and greywacke basement surface contours to illustrate possible structural influence on fluid/gas upflow. Asterisks indicate the locations of basement intersections. The deepest contours reflect wells BR56 and BR59 which reached respective total depths of -2131 and -2136 mRSL without intersecting greywacke. N_2/Ar ratios were calculated from data collected prior to the drilling of the 10 new wells (highlighted in bold).

The latest drilling has provided important constraints on the depth to the greywacke basement in the western steamfield. Six of the ten recent wells intersected the greywacke (BR52, BR52A, BR54, BR57, BR58 and BR60). Incorporating data from previously drilled wells, contouring of the greywacke basement intersections shows a north and northwest deepening separated by a north to north-westerly plunging ridge or horst-like structure (Figure 4). Deepening to the northwest is likely to be the cumulative downthrow on northeast trending normal faults, close to the TVZ margin (Henrys and Hochstein, 1990). One such fault is inferred between wells BR56/BR59 and BR57 (Figure 3). There is compelling chemical evidence from N_2/Ar ratios for these NE-trending basement faults being pathways for upwelling geothermal fluids (Figure 4; Hedenquist, 1990; Christenson et al., 2002).

However, NW-trending basement faults (Wan and Hedenquist, 1981) cannot be ruled out as a cause of or influence on the basement topography. NW-trending faults may explain the 45 m deepening to the east of BR52A and define the NNW-plunging horst-like ridge between wells BR3 and BR18 (Figure 4). The widening and slight SE elongation of the N_2/Ar isopleths below the area that includes BR58, BR52 and BR22 (Figure 4) is possibly the result of upwelling geothermal fluids exiting NW-trending basement faults and dispersing in the post-basement volcano-sedimentary stratigraphy either via the same faults or through formation permeable horizons.

3. HYDROTHERMAL ALTERATION

The general pattern of hydrothermal alteration types consist of intermediate argillic (illite and/or illite-smectite, chlorite, calcite, quartz, pyrite) above propylitic (chlorite, illite, calcite, epidote, quartz, tremolite-actinolite, wairakite, adularia). The transition between the two types typically occurs between 1000-1500 m drilled depth. Adularia is typically present in rare to minor abundance as a replacement of primary feldspar, but can rarely occur lining veins and cavities (e.g., BR59, BR60). Wairakite has been recognised as a vein mineral in only BR59. Both minerals are considered signs for favourable permeability (Browne and Ellis, 1970; Reyes, 1990). Epidote is present in all of the latest wells drilled, usually in rare to minor amounts as a replacement of plagioclase feldspar and primary ferromagnesian minerals (e.g., pyroxene). Its occurrence implies formation temperatures >260° C (Browne and Ellis, 1970). Tremolite-actinolite is not a typical component of the propylitic alteration and has not been previously reported at Ohaaki (Browne and Ellis, 1970; Browne, 1971; Wood, 1983; Hedenquist, 1990). It occurs in only one of the ten new wells (BR60) in minor abundances below -1800 mRL, as a replacement mineral of primary ferromagnesian minerals. The presence of tremolite-actinolite indicates the highest formation temperatures yet recognised at Ohaaki, with likely formation temperatures in excess of 280° C (Browne, 1978).

Evidence for active faulting during the lifetime of the Ohaaki geothermal system is provided by drillcuttings from the andesite in BR59, below -1750 mRL, that contain deformed vein calcite crystals. The deformed texture shows that active fault movement maintained open pathways for fluid migration, at least through the andesite.

Propylitic alteration intensity is conspicuously highest in Waikora Formation intercalations, where zones of chlorite and epidote are common. The relatively thin units of greywacke pebble conglomerate are likely to be primary geothermal fluid aquifers. Present feed zones in a few of the latest wells occur within these intercalations, or at their boundaries with the Tahorakuri Formation. However, the lack of a spatial correlation between active feed zones and intensely altered Waikora Formation in other wells implies that whilst initially permeable, these pebble conglomerates can become sealed by hydrothermal mineralisation.

4. CONCLUSIONS

The latest drilling in the western Ohaaki steamfield has intersected previously unrecognised lithologies below 1500 m depth. The new strata include an extensive complex of intermediate composition (andesite/microdiorite–dacite/granodiorite) volcanic or hypabyssal rock. The igneous rock is not strata-bound and thickens and deepens to the northwest, on the downthrown side of an inferred NE-trending basement fault. It is not known whether it is of intrusive or extrusive origin and could represent a series of multiple andesite lava flows or microdioritic intrusions (stocks, sills, dikes). They are included here as subunits of the Tahorakuri Formation, but further work is required to constrain the spatial extent and define the whole rock chemistry. Future deep production drilling in the western steamfield should target the deep andesite, as major permeable zones occur either within the unit or at formation boundaries. There is evidence that permeability within the andesite is along fault structures.

New contouring of greywacke basement refines previous models of a northwest and north deepening surface likely to be influenced by both NE-and NW-trending basement faults. A NE-trending basement fault is inferred to occur between BR56/BR59 and BR57. There is geochemical evidence that such faults act as a major pathways for geothermal fluids upflowing through the basement. The northwest of the Ohaaki resource is highly prospective below 1500 m drilled depth as hydrothermal alteration mineralogy implies the highest temperatures (i.e., >280° C) and good permeability in cuttings from wells BR59 and BR60, both of which are proximal to the inferred basement fault.

The NW-trending faults appear to define a NNW-plunging ridge or horst-like basement structure in the northern part of the western steamfield. Geochemical evidence also implies these faults have provided conduits for upwelling fluids, but mineralogical evidence is less encouraging for deep exploration of this part of the field.

Permeability in the post-basement stratigraphy appears to be of both formational and inter-formational origin. However evidence for active faulting in this sequence during the lifetime of the geothermal system, implies the faults are likely to maintain open pathways for fluid movement. Therefore, it is likely that as upwelling geothermal fluids in the northwestern and northern parts of the steamfield move from greywacke basement faults into the post-basement volcano-sedimentary sequence they will utilise available aquifers, be they formational or fault-related.

These new insights from our geological investigations of the stratigraphic and hydrological relationships, provide confidence for future well targeting in the western part of the Ohaaki Geothermal Field. The northwestern part of the steamfield, a region of deep basement faults and wells with high temperature hydrothermal mineral indicators and good permeability should be considered highly prospective for deep production wells at Ohaaki.

5. ACKNOWLEDGEMENTS

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