STRATIGRAPHY AND HYDROTHERMAL ALTERATION ENCOUNTERED BY MONITOR WELLS COMPLETED AT NGATAMARIKI AND ORAKEI KORAKO IN 2011

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ABSTRACT

As part of the Ngatamariki Geothermal Development, in September – November 2011 Mighty River Power Limited drilled four pressure monitoring wells. These are, two "sentinel wells" ~3 km north of NM4, between the Ngatamariki and Orakei Korako Geothermal Fields (NMM17 and NMM18), and two "monitoring wells" a further 3.5 km to the north, within the Orakei Korako Geothermal Field (OKM1 and OKM2). Each of the monitor well pairs has one deep (~1500 mD) and one shallow (~400 mD) well.

The deep sentinel well (NMM18) was designed to target volcaniclastic sediments, tuff and variably welded ignimbrite of the Tahorakuri Formation, which is a known reservoir-hosting unit at Orakei Korako and Ngatamariki. NMM18 is sited to monitor subsurface pressures in the area corresponding to the inferred overlap of the resistivity boundary zones of the two fields. The deep monitor well (OKM1) was located near the abandoned OK1 exploration drillhole (drilled to 1403.6 mD in 1965), 1 km east of the main thermal area at Orakei Korako, in order to monitor reservoir depth pressures. Both NMM18 and OKM1 show a typically argillic alteration assemblage, characterised by smectite, mordenite, quartz, calcite, leucoxene, pyrite and iron oxides. Indications from drilling and testing results are that these wells are in optimal locations for ongoing subsurface pressure monitoring as part of resource consent requirements.

This paper describes the geology from the wells, and compares the geology and alteration mineralogy logged, with the geology recorded in the Orakei Korako geothermal exploration wells drilled in the 1960's, and at Ngatamariki since the mid 1980's.

1. INTRODUCTION

More than 21 high enthalpy geothermal reservoirs have been identified within the Taupo Volcanic Zone (TVZ), New Zealand (Figure 1). Of these, several systems, including Ngatamariki, are designated for commercial geothermal development by the associated regional regulatory authorities. Development has been prohibited or limited at seven areas, including Orakei Korako, in order to preserve the associated surface thermal features, or because not enough is currently known about the field. The Ngatamariki and Orakei Korako Geothermal Fields are located in the central part of the Taupo Volcanic Zone (TVZ), approximately 25 km and 30 km northeast of Lake Taupo respectively (Figure 1).

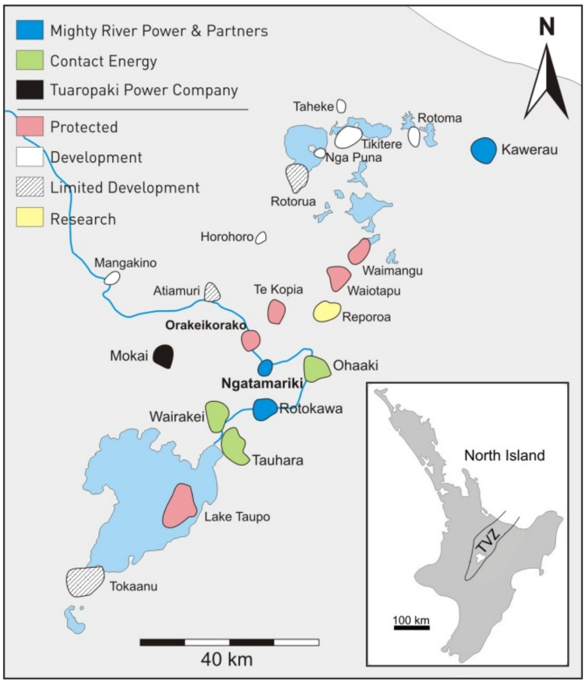

Figure 1: Location map showing Ngatamariki and Orakei Korako Geothermal Fields in the Taupo Volcanic Zone.

As of 2010, Mighty River Power was granted a resource consent to develop the Ngatamariki Geothermal Field with a fluid take of 60,000 t/d and nominally 98% injection. One of the key conditions set out by the resource consent is the avoidance of any induced pressure or temperature response that may cause an adverse effect on surface thermal discharges in the Orakei Korako geothermal system. To ensure compliance with this condition, a monitoring and mitigation strategy was to be established, including the monitoring of subsurface pressures between the two fields.

Coinciding with the commencement of earthworks for an 82 MW ORMAT binary plant at the Ngatamariki site, five monitor wells were drilled from September 2011 (OKM1, OKM2, OKM3, NMM17 and NMM18; Figure 2). This paper will discuss the geology encountered in these wells, and how they compare within the regional context to the geology at Ngatamariki and Orakei Korako.

1.1 Geological Context

Ngatamariki and Orakei Korako are located in the central part of the TVZ. Rhyolitic volcanism has dominated the central TVZ for 1.6 Ma, and eight calderas have been identified (Wilson et al., 1995). Deep geothermal drillholes have provided insights into the stratigraphy and geological history of the TVZ. Ngatamariki and Orakei Korako are situated in the northern part of the Maroa Dome Complex (Wilson et al, 1986), with numerous rhyolite domes cropping out at surface.

The subsurface stratigraphy at Ngatamariki has been described by several authors including Wood (1985, 1986), Urzua (2008), Boseley et al. (2010), and at Orakei Korako by Bignall, (1994). With increasing depth the stratigraphy includes a sequence of surficial deposits, including tuff and pumice from the Oruanui Formation (26 Ka eruption at Taupo) which overlies the Huka Falls Formation (HFF) sequence of lacustrine sediments interspersed with volcaniclastic material. HFF overlies a pyroclastic sequence of tuffs and ignimbrites of the Waiora Formation, Whakamaru-group ignimbrite (~330 Ka), and Tahorakuri Formation. Rhyolite and dacite lavas are found interspersed within and between these formations at both fields, with an apparent decreasing abundance of rhyolite from south to north from Ngatamariki to Orakei Korako. At Ngatamariki some of these rhyolite lavas host a confined aquifer beneath the Huka Falls Formation (the formation itself acting as an aquitard) that appears to extend across the field. The Tahorakuri Formation is the main reservoir hosting unit at both Ngatamariki and Orakei Korako.

Beneath the Tahorakuri Formation, particularly in the southern part of Ngatamariki, is a thick sequence of andesite lavas and breccias (collectively referred to as andesite), and volcaniclastic andesite bearing material. The extent of the andesite toward the north is uncertain, although the predominance of volcaniclastic bearing material may coincide with deposits on the distal margins of an andesite volcano centered on the Rotokawa area (Andersen, 2010). None of the Orakei Korako wells are sufficiently deep to intersect andesite at a comparable depth to where it is encountered at Ngatamariki.

NM6 (Figure 3) is the only well at Ngatamariki or Orakei Korako to encounter the greywacke basement. The northern part of Ngatamariki is the only place in the TVZ where a pluton has been encountered by a geothermal drillhole.

2. MONITOR WELLS

Monitoring well pairs north of Ngatamariki and at Orakei Korako have been drilled as part of the System Management Plan required by the Waikato Regional Council.

The purpose of the wells is to monitor subsurface pressures between to the two fields in order to detect pressure or temperature changes outside of natural variation that may be associated with operations at Ngatamariki, and enable the implementation of appropriate measures to ensure that these changes do not cause adverse effects on Orakei Korako surface thermal features. For the sake of clarity, the pressure monitor wells drilled at Orakei Korako are called “monitor wells” whilst the monitor wells drilled between the two systems are commonly referred to as “sentinel wells”. Locations of the wells are shown in Figure 2 below, and in cross section in Figure 3.

The deep (1570 m) sentinel well (NMM18) targets the Tahorakuri Formation, which is the reservoir rock at Ngatamariki. It was designed and located to detect deep pressure drawdown (or build-up) between the two systems in the zone of greatest overlap of resistivity boundaries (not discussed here). An intermediate depth (320 m) sentinel well (NMM17), sited at the same location as NMM18 targets the low resistivity horizon, and was completed in a permeable rhyolite above Huka Falls Formation sediments. It monitors pressure in a possible northward extension of the intermediate aquifer occurring at Ngatamariki in the rhyolite.

The deep (1000 m) reservoir monitor well (OKM1) is near to where Crown exploration well OK1 was drilled in the mid-1960s. Planning for OKM1 was based on information obtained from OK1, in terms of drilling safety and reservoir depth. An intermediate depth (415 m) monitor well (OKM2) was drilled at the same location, targeting an intermediate depth groundwater aquifer in the Waiora Formation.

A 30 m monitor well (OKM3), was drilled on the western side of Lake Ohakuri near the tourist area (Figure 2), in order to monitor the effect of seasonal and lake level changes on the unconfined surface aquifer at Orakei Korako. Monitoring data will be compared with seasonal variations at the Orakei Korako hot springs, with continuous flow monitoring of a spring on the western side of the Waikato River within the thermal area, and continuous temperature monitoring of eruption frequency at the Kurapai Geyser (eastern side of Lake Ohakuri near the tourist area indicated in Figure 2). A better understanding of the natural, near surface seasonal changes influencing the springs will enable differentiation of any trends derived from pressure-temperature changes that may occur in the intermediate and deeper reservoirs.

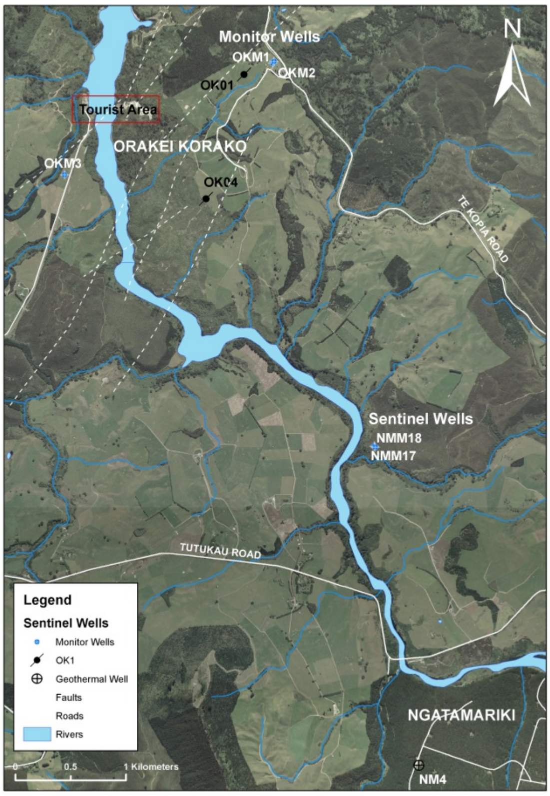

Figure 2: Location map showing NMM17 / NMM18 (sentinel wells) and OKM1 / OKM2 (Orakei Korako monitor wells). White dashed lines are inferred faults.

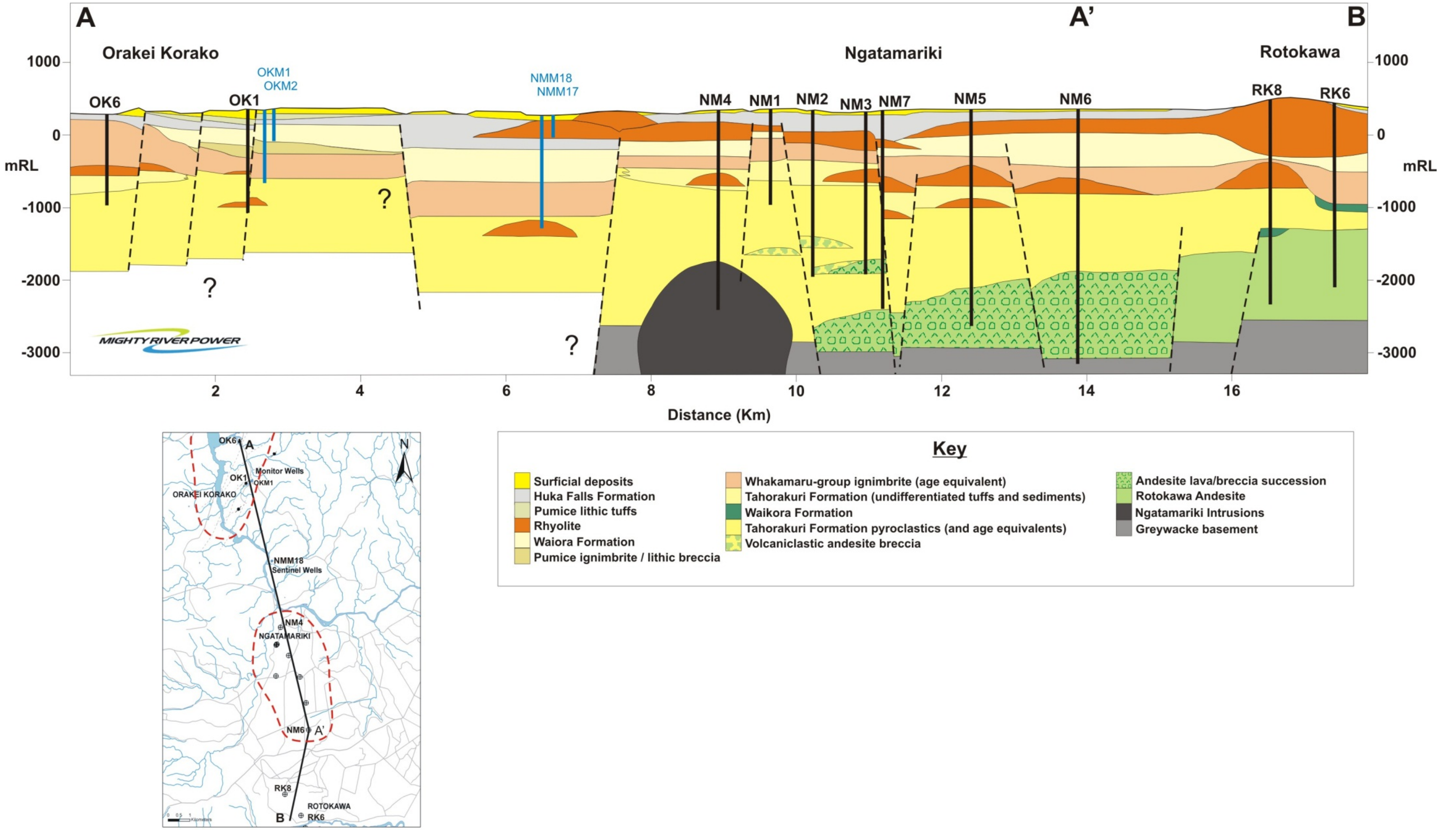

Figure 3: Geologic cross section through Orakei Korako and Ngatamariki Geothermal Fields to Rotokawa in the south.

Description and interpretation of the stratigraphic sequence, and associated hydrothermal alteration assemblages in the four main monitoring wells are based on macroscopic and stereomicroscopic examination of drill cuttings, supplemented by methylene blue testing (MeB; Rosenberg, 2010), x-ray diffraction (XRD), and examination of selected thin sections from cuttings and from core in OKM1. Depths herein refer to measured depth (mD) down the well track from the rig floor (7.86 m above ground level).

2.1 NMM17 and NMM18 Stratigraphy and alteration

NMM17 and NMM18 are located on the same well-pad approximately 3km north of NM4, halfway between Ngatamariki and Orakei Korako. NMM18 was completed with a 4 ½” perforated liner between 1349 mD and 1570 mD. NMM17, which targeted based on findings from NMM18, was completed with 5” stainless steel screens between 278 mD and 320 mD in rhyolite lava.

Drilling results show with increasing depth that the stratigraphic sequence encountered by the sentinel wells is: surficial deposits, rhyolite, Huka Falls Formation, Waiora Formation ($Wa_{3\text{-}4}$, Wa_1) Wairakei Ignimbrite and Tahorakuri Formation (including crystal tuff and rhyolite; Jober et al., 2011; Chambefort et al., 2012). The geology of the wells is illustrated in cross-section in Figure 3.

The surface deposits comprise an unconsolidated heterogeneous mix of pumice, rhyolite lava and crystal-rich tuff. This overlies a porphyritic, glassy, perlitic, pumiceous rhyolite. Below 245 mD the rhyolite is a massive, porphyritic lava with flow banding and spherulitic textures. Below this, the Upper, Middle and Lower Huka Falls Formation tuff and sediments overlie the pumice-crystal tuff and partially welded pumice crystal-rich ignimbrite of the Waiora Formation units ($Wa_{3\text{-}4}$, Wa_1; Jober et al., 2011).

Hydrothermal alteration in the shallow stratigraphy is of weak to moderate intensity and characterised by smectite, chlorite (below 230mD), iron oxide and quartz. Methylene blue tests for swelling clay indicate that smectite abundance is highest in the surficial deposits and in the Huka Falls Formation (up to 20%). A short interval of high intensity alteration occurs at the base of the porphyritic rhyolite in NMM18. Alteration intensity gradually increases from weak in the Upper Huka Falls Formation to strong in the Waiora Formation, possibly due to the lower permeability of the Huka Falls Formation acting as an aquitard and channeling the hydrothermal fluids beneath the sediments. This is also inferred at Ngatamariki where hydrothermal fluids up-flowing from the deep reservoir are confined in a rhyolite hosted “intermediate aquifer” beneath the Huka Falls Formation aquitard (Jober et al., 2011, Boseley et al., 2010).

Below the Waiora Formation is a 475 m unit of partially welded quartz-rich Wairakei Ignimbrite (or the age equivalent, Paeroa Ignimbrite) belonging to the ca. 330 ±10 Ka Whakamaru-group ignimbrite (Wilson et al., 1986), identified by its characteristic abundant embayed (or ‘wormy’) quartz crystals. The ignimbrite overlies a white to pale grey variably crystal-rich to crystal-poor ignimbrite beneath 1400 mD, interpreted to be the Tahorakuri Formation. Lithologically, this interval differs slightly from the upper Tahorakuri Formation to the north of Ngatamariki (and also in OK6 in the north of Orakei Korako) which comprises a moderate thickness (~200-300 m) of interlayered tuffaceous siltstones, carbonaceous mudstones and sandstones overlying deeper tuffs and ignimbrites. Tahorakuri sediments are not intersected by NM5 or NM6 (where rhyolite lava directly overlies the pyroclastic succession of the Tahorakuri Formation) which we infer to reflect topographic differences across the field in the past. NMM18 is completed in a porphyritic rhyolite beneath 1460 mD. Rhyolite is also encountered within the Tahorakuri Formation in NM7 and NM5 in the central part of the Ngatamariki Geothermal Field (Figure 3).

Hydrothermal alteration intensity in NMM18 is greatest in the Wairakei Ignimbrite and underlying Tahorakuri Formation. XRD analyses show smectite persists in rare amounts to around 800 mD, and occurs again at 1200-1500 mD. An inter-layered illite-smectite zone occurs at 510-1110 mD, followed by an illite zone below 1200mD. Other deep alteration minerals encountered in NMM18 include chlorite, calcite, quartz, pyrite, adularia and iron oxide, as well as minor wairakite below 800 mD, and rare, intermittent occurrences of epidote between 1460 - 1570 mD in agreement with the occurrence of illite indicating a relict high temperature assemblage (Jober et al., 2011).

Completion testing results show NMM17 has good permeability with a maximum measured temperature of 16.5°C, and fluid chemistry representative of local groundwater. NMM18 also encountered reasonable permeability and reached a maximum measured bottom hole temperature of 131°C after six months heating (Figure 4).

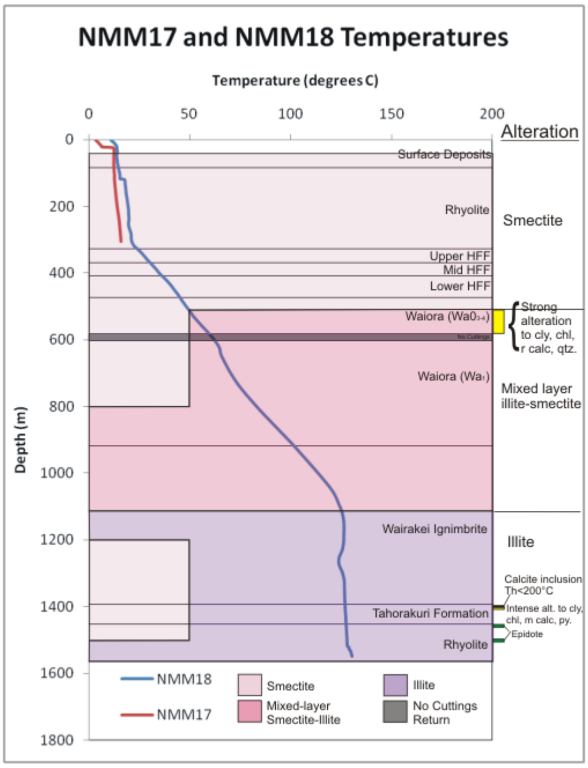

Figure 4: NMM17 and NMM18 temperature profiles (six months heating) showing stratigraphy and annotated with alteration. Shaded zones represent smectite, mixed layer smectite-illite, and illite alteration from XRD.

2.3 OKM1 and OKM2 stratigraphy and alteration

OKM1 and OKM2 are located on the same well-pad, 3.5 km north of NMM17 and NMM18 and ~300 m northeast of OK1. OKM1 was completed to a total depth of 1003 mD, with a 4 ½" perforated liner below 700 mD. OKM2 was completed to a total depth of 415 mD, with continuously slotted 6 ⅞" stainless steel screens back to 388 mD.

With increasing depth OKM1 and OKM2 encountered surface deposits, pumiceous, lithic-rich tuff, lithic-rich tuff, Huka Falls Formation, Waiora Formation, pumiceous ignimbrite, lithic breccia, Whakamaru-group ignimbrite (Wairakei ignimbrite or age the equivalent) and the Tahorakuri Formation. The pyroclastic successions below the Huka Falls Formation match those seen in the Ngatamariki Geothermal Field, seen in the deeper stratigraphic sequence of NMM18 (Figure 3; Jober et al., 2011, 2012). Correlation of stratigraphic units between OK1 and OKM1 is difficult without a detailed reassessment of the OK1 material; however approximate correlation of the regional Whakamaru-group ignimbrite from original descriptions indicates a small localised offset between the two wells, depicted in Figure 3.

Similar to the sentinel wells, the surficial deposits in OKM1 and OKM2 are a mix of unconsolidated lithics including mostly pumice, crystal-rich tuff, minor rhyolite and weakly cemented volcaniclastic sandstone with silicified fragments. However, unlike what was encountered in NMM17 and NMM18, rhyolite does not separate the surficial deposits from the underlying Huka Falls Formation in the OKM1 and OKM2 wells. Instead, beneath the surficial deposits, OKM1 and OKM2 encounter: a homogeneous, vesicular pumice tuff with a glassy groundmass, and a lithic-, crystal-rich tuff breccia with a matrix comprising minor unconsolidated mud and crystals (mainly quartz and plagioclase). Lithics include a mix of tuff, flow-banded rhyolite, porphyritic andesite and silicified fragments (Jober et al., 2012).

Due to circulation losses during drilling, the full sequence of Huka Falls Formation was not identified in the Orakei Korako monitor wells. The Huka Falls Formation comprised interbedded layers of tuff and soft carbonaceous mudstone in an unconsolidated mud matrix, with abundant rhyolite lava and pumice. Unwelded, lithic-rich tuff of the Waiora Formation ($Wa_{3\text{-}4}$; 200-445mD) is identified below the Huka Falls Formation. Total circulation losses during drilling were intermittent throughout this unit, indicating primary permeability in the unwelded tuff.

Unlike what is seen at the sentinel wells, two units separate the Waiora Formation from the Whakamaru-group ignimbrite in OKM1 and OKM2. These comprise a quartz and lithic-rich, partially welded pumice ignimbrite and a crystal-lithic breccia. Examination of thin sections from the pumice ignimbrite reveals similarities to the Waiora (Wa_1) Ignimbrite. Very fine grained cuttings returned from 575-610 mD have limited the lithological interpretation of the crystal-, lithic-rich breccia, and this may or may not form part of the Waiora Formation (Jober et al., 2012; Lewis et al, 2012).

Whakamaru-group ignimbrite has been described in OKM1 between 610 – >870 mD, while the equivalent Paeroa Ignimbrite in neighbouring OK1 is encountered at ~660 mD (Steiner, 1965), potentially indicating a localised offset. Cuttings throughout this interval in OKM1 were extremely fine grained which made identification of the primary lithology somewhat tenuous, particularly between 700 – 770mD, and 870 – 950 mD. Returns were of a grey, quartz-rich welded ignimbrite with commonly embayed quartz crystals. Thin sections of cuttings from 675 m are a weakly altered, partially welded, quartz and plagioclase-rich ignimbrite with a glassy and partially devitrified matrix. Thin sections of fine grained cuttings from 755 – 760 mD and 780 mD are similar to that at 675 mD, however show increased welding and relict vitriclastic textures (Lewis et al., 2012).

In OKM1 a core cut between 1000-1003 mD (at well TD) intersected a plagioclase-rich, partially welded breccia tuff described as the Tahorakuri Formation. Due to poor quality cuttings returns and total circulation losses below 870 mD the exact formation contact depth between Whakamaru-group ignimbrite and Tahorakuri Formation remains uncertain. The tuff included pseudomorphs of amphibole, pyroxene and rare embayed fragmented primary quartz, associated with common coarse, angular lithics of rhyolite and lesser andesite (Jober et al., 2012). The core showed moderate alteration intensity to minor clay, rare disseminated pyrite and minor chlorite. Thin sections of the core confirm the presence of adularia and randomly oriented calcite filled micro-fractures. Zones of locally intense devitrification may be associated with less welded zones (Lewis et al., 2012). Fractures are common in the core and typically coated with iron oxides. Two fluid inclusions samples in calcite were taken from cuttings samples within the Tahorakuri Formation at 1405 and 1410 mD, indicating vein formation from low temperature, dilute fluid.

Hydrothermal alteration in OKM1 and OKM2 is of weak to moderate intensity, with a secondary mineral assemblage consisting of clay (smectite), iron oxides, rare chlorite, quartz, and disseminated pyrite. XRD analyses and methylene blue testing (Rosenberg, 2010) of the cuttings shows smectite is the dominant clay mineral, most abundant in the Huka Falls Formation, with the first occurrence of illite-smectite (indicating temperatures >140°C) at 905 mD (Jober et al., 2012; Lewis et al., 2012).

A zone of strong hydrothermal alteration intensity identified in the upper Waiora Formation, directly below a zone of total circulation loss, is characterised by pervasive smectite clay. A second zone of strong hydrothermal alteration intensity occurs in the middle of the Whakamaru-group ignimbrite, defined by an increase in clay and chlorite veins. A general increase in silicification in the cuttings was noted between 745 – 775 mD.

Pressure transient analysis of completion (injection) test data shows OKM1 and OKM2 are relatively permeable, with maximum temperatures of 185°C and 55°C and respectively following three months heating (Figure 5). OKM1 is a Na-K-Cl type water with chloride concentrations typical of waters on the periphery of a geothermal system (Giggenbach and Goguel, 1989). The temperature profile of both OKM1 and OKM2 to 400 m is similar to the temperature profile from the nearby well OK1, and reflects the existence of permeability through the Waiora Formation (primary permeability through the unwelded tuff). Temperatures below 400 m depth in OKM1 however are cooler than OK1, and this is discussed in section 3.2 below.

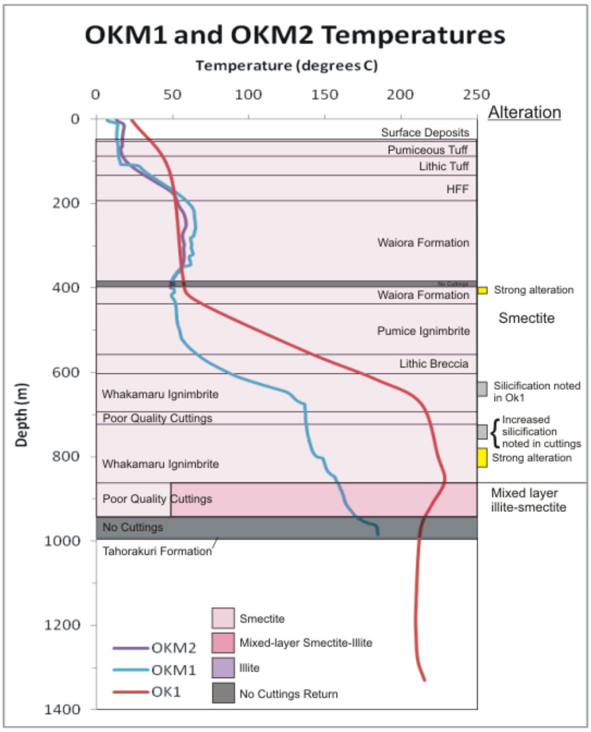

Figure 5: OKM1 and OKM2 temperature profiles (three months heating) showing stratigraphy and annotated with alteration. Shaded zones represent smectite and mixed layer smectite-illite alteration from XRD. The OK1 profile is shown for comparative purposes.

3. DISCUSSION

3.1 Stratigraphy

Regional similarities and field-specific differences of the subsurface geology exist between Ngatamariki and Orakei Korako. The recently drilled Ngatamariki sentinel wells and Orakei Korako monitor wells provide further insight into the geology between the two fields. Local uncertainties remain on the relationships and stratigraphic correlations between the lithologic units of the two fields, and within the Orakei Korako field itself. These uncertainties could be resolved with further detailed examination of the cuttings from the Orakei Korako wells drilled in the 1960s. Stratigraphic relationships inferred from available information are discussed below.

The shallow stratigraphy encountered by NMM17, NMM18, OKM1, and OKM2 is similar to what is seen in NM1 and NM4 in the northern part of the Ngatamariki Geothermal Field. Rhyolite lava in the sentinel wells occurs at a similar depth to rhyolite lava that hosts the intermediate aquifer at Ngatamariki, although it occurs above Huka Falls Formation sediments, rather than below as seen at Ngatamariki. Although the Huka Falls sediments might not have been deposited in the same shallow lake, this does suggest that the rhyolite extrusion was ongoing during the existence of the lake(s), and that the rhyolite in NMM18 rhyolite may be younger than the rhyolite found in NM4.

Shallow rhyolites that host the intermediate depth aquifer are not encountered in any of the Orakei Korako wells, limiting their extent to the Ngatamariki area. This is consistent with the district setting where discrete rhyolite domes of the Maroa Volcanic Complex (associated with the Whakamaru Caldera; Wilson et al., 1986; Figure 4) mainly occur at surface west of the Waikato River. Another key difference in the shallow stratigraphy between the fields is the occurrence of pumice and lithic tuffs above the Waiora Formation, and the tentatively identified pumice ignimbrite and crystal-lithic breccia below the Waiora Formation observed in OKM1 and OKM2. The breccia seems to correspond with descriptions of a pumice breccia above the Paeroa Ignimbrite (age equivalent of Whakamaru-group ignimbrite) in OK1 (Steiner, 1965); its absence in the sentinel wells indicates localisation to the Orakei Korako area.

Differences in the deeper stratigraphy include a greater thickness and depth of several units in the sentinel wells compared to those at Ngatamariki and Orakei Korako. The ~450 m of Waiora Formation in NMM18 occurs at 100 m greater depth, and is twice the thickness of that intercepted in northern Ngatamariki wells, and in the Orakei Korako monitor wells. Similarly, nearly 500 m of Whakamaru-group ignimbrite was drilled by NMM18 compared to about 300 m encountered in the NM1 area, and around 260 m in OKM1. The Whakamaru-group ignimbrite was encountered at 250 m lower elevation in NMM18 than in NM4 and OKM1. These differences can be accommodated by fault constrained basin development (Figure 3), which would also account for the deeper occurrence of the Huka Falls Formation in the sentinel wells.

The Taupo Volcanic Zone is actively rifting and this extension is taken up by significant normal faulting along the Taupo Rift system (Wilson et al., 1995; Figure 6). Even without fault surface expressions, we commonly see stratigraphic offsets (in both thickness and elevation) between wells within many TVZ geothermal fields, including Ngatamariki and Orakei Korako. Tentative correlation of the top of the Whakamaru-group ignimbrite between OKM1 and OK1 Figure 3) is also suggestive of an offset between these two wells, consistent with Paeroa Fault splays that transect the Orakei Korako geothermal area (Lloyd, 1972; Figure 6).

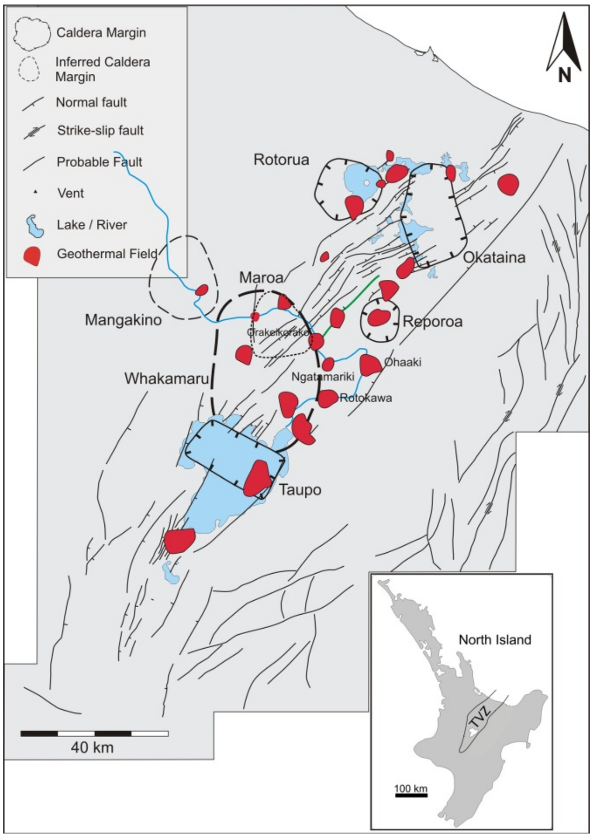

Figure 6: Map showing locations of the geothermal fields, caldera margins and the dominant NE-SW strike of faults in the Taupo Volcanic Zone. Paeroa Fault is indicated in bold green.

3.2 Hydrothermal Alteration

Hydrothermal alteration in OKM1 and OKM2 shows relatively low alteration intensity, characterised by low rank alteration minerals that include smectite and mordenite to around 860m depth, where mixed layer clays are first identified by XRD. This is consistent with the measured temperature profile from OKM1 (five months post drilling) showing that temperatures of >150°C are encountered from about this same depth (Figure 5). OKM1 reached a maximum bottom hole temperature of 185°C, which is slightly cooler than expected, as data collected from nearby Crown exploration well OK1 in the 1960s recorded maximum temperatures >200°C. This may suggest that OKM1 is located closer to the edge of the Orakei Korako reservoir.

Despite temperatures >200°C, no high rank alteration was noted in the OK1 petrology (Steiner, 1965; Bignall, 1994). Steiner (1965) suggests that the medium rank alteration coinciding with the top of the Whakamaru-group (Paeroa) ignimbrite is consistent with fluid flow ascending along a fault intercepted by the well between 909 mD and 1000 mD (indicated by slickensided core). This model could also explain the small zone of moderate intensity alteration in the Whakamaru-group ignimbrite in OKM1, however no faults or interpreted fault zones are confirmed that would indicate structurally-controlled hydrothermal fluid circulation below 1000 mD.

Hydrothermal alteration in the sentinel wells provides interesting insights into the thermal history of the area between Ngatamariki and Orakei Korako. The NMM18 temperature profile (six months post drilling; Figure 4) shows the well is relatively cool, with a maximum bottom hole temperature of about 130°C, consistent with the presence of smectite at depth. However, strong to intense alteration and veining in the Tahorakuri Formation at depth in NMM18 are indicators of hydrothermal fluid flow in the past, and microscopic observations coupled with XRD results show that high temperature (>~240°C; Browne, 1978) minerals such as illite, wairakite and epidote coexist with the smectite (which is stable up to around 150°C; Browne, 1978) below 800 mD. This suggests thermal overprinting has taken place and that the area previously experienced a much higher temperature regime than at present (Jober et al., 2011).

4. CONCLUSION

The drilling of four monitoring and sentinel wells in 2011 to the north of Ngatamariki and at Orakei Korako has provided new insight into the stratigraphy and thermal history of the area between the two fields. High temperature minerals at depth in NMM18 indicate that this area was under a hotter thermal regime at one time, however overprinting by low temperature alteration minerals, consistent with measured temperatures in the well, indicate that the area is slowly cooling down. Significant increases in the thickness, as well as a difference in elevations, of the Whakamaru-group and Waiora Formation regional units in the area of the sentinel wells, indicates that the transitional area between Ngatamariki and Orakei Korako may have been experiencing basin development up to the time of their deposition, and has likely been influenced by significant faulting since. The Orakei Korako monitoring wells show similarities to the Crown exploration well OK1, however further detailed analysis would be required to correlate units across the field more accurately.

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