Recent Subsurface Insights at Rotokawa: Case Study of a New Well

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ABSTRACT

In 2024, an injection well was drilled at the Rotokawa Geothermal Field, targeting feed zones indicated by offset wells. The injection well was designed to replace a previous injection well which had wellbore integrity issues. By re-targeting feed zones from offset wells, the new well provided an opportunity to validate current reservoir models and gather fresh subsurface data.

The well design leveraged learnings from nearby wells to improve the likelihood of success and reduce drilling risk. The planning included both primary and contingency completion options to address potential challenges associated with expected high subsurface temperatures and weak rock strength conditions. With both primary and secondary completion designs prepared in advance, the drilling team was able to “dynamically” install the design that fitted the formation characteristics collected as the well was drilled. The drilling program was completed on schedule and to plan. The target feedzones were successfully intercepted, with excellent permeability encountered. The maximum measured temperature of this well was 338°C after heat-up, possibly the hottest so far recorded in New Zealand.

Although the well was drilled near existing wells, the encountered subsurface conditions highlighted that significant changes in reservoir characteristics can occur over short distances in the field. Data from the new injection well revealed, in particular, more detailed information about the potential nature of the deep reservoir boundary and new insights on stratigraphic and structural controls on reservoir conditions in the injection area. These results will be used to refine the conceptual model and support future well planning at Rotokawa.

1. INTRODUCTION

1.1 Location and subsurface context

Rotokawa is a high-temperature (>300°C) geothermal field located in the central Taupō Volcanic Zone of New Zealand. The field supports two commercial power stations with a combined capacity of over 170 Mwe: Rotokawa (RGEN, commissioned in 1997) and Ngā Awa Pūrua (NAP, commissioned in 2010). The field is operated as a joint venture between Tauhara North No. 2 Trust and Mercury NZ Ltd. In addition to its importance for electricity generation, Rotokawa hosts nationally significant geothermal features, including Lake Rotokawa and its surrounding thermal areas.

Geologically, the reservoir is situated within a NE–SW graben structure and is characterized by a thick volcanic sequence overlying a Mesozoic greywacke basement. Production wells typically tap feedzones between 1000 metres and 2500 metres depth, drawing from permeability within the volcanic sequence. Injection zones are generally deeper, between 1500 metres and 2500 metres depth, with injection below 2300 metres depth within basement greywacke.

1.2 Background

Sustainable development of commercial high-enthalpy geothermal systems depends not only on early-stage exploration and production drilling, but also the ability to strategically add or replace wells as reservoir conditions and surface requirements change. Re-targeting permeable zones of idle or abandoned wells (“twinning”) is a lower-risk approach for scenarios where disruption of production and injection operations carry high financial risk. Despite drilling in a known area of the field, applying updated subsurface interpretations and improved well design practices can still provide opportunities to optimise outcomes and gain new insights into the reservoir.

RK21 was drilled in early 2008 as a deep injection well to support the development of the NAP power station. During high-temperature casing condition (HTCC) testing shortly after drilling, indications of possible casing integrity issues were identified, although no associated fluid movement was observed through these zones at the time. With no immediate evidence of leakage, the well was monitored while NAP was completed. RK21 began injecting brine from NAP following its commissioning in mid-2010, until injection was redirected to another well in late 2010. Over time the casing issues appeared to progress, and in 2012 a workover was undertaken to isolate the affected intervals using a series of cement plugs. The well remained shut-in while options for future use or abandonment were evaluated.

In 2023, the need for an additional deep injection well was identified to support long-term operational flexibility. While options such as side-tracking or repairing RK21 were considered, the condition of the existing wellbore made this approach impractical. Drilling a new well, targeting the same deep permeability intercepted by RK21, was selected as the most feasible and reliable option. This new well, RK41, was drilled in 2024.

2. WELL PLANNING

2.1 Well target and path

The primary objective for RK41 was to intercept the main deep permeable zone encountered by RK21, located at approximately 2400 metres below ground level within the basement greywacke. Completion testing at RK21 indicated that this feedzone had good permeability, and if accessed with the drilling of RK41, would be sufficient to achieve the station requirements for injection capacity. This zone was interpreted to be associated with a high angle fracture system aligned with the dominant NE–SW structural fabric of the Rotokawa reservoir.

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Ideally, the target would position the new well as close as possible to the original RK21 hole to maximise the likelihood of intersecting the same permeable feature. However, trajectory design was constrained by several factors. The first constraint was the need to maintain sufficient stand-off from the idle RK21 to minimise collision risk. Additionally, compliance stand-off requirements from nearby significant geothermal water features (SGFs), as defined by Waikato Regional Council (WRC), further restricted trajectory options. Finally, sufficient stand-off distance from the active injector RK22 was needed to lower the risk of interference.

Another key consideration for targeting was the well profile. RK21 was drilled with an S-type profile, kicking off at approximately 300 mVD (vertical-depth), building to a 20° deviation, holding tangent for ~1500 metres length, then dropping back to near-vertical to achieve its target. While this profile allowed deeper drilling within earlier design constraints, it introduced high lateral forces between the drill pipe and casing in the shallow deviated section, increasing the risk of casing wear. Post-drilling observations suggested that these shallow sections may have experienced mechanical and thermal stresses, potentially contributing to casing damage. For RK41, it was decided that a simpler J-type trajectory could achieve the target. This design had a deeper kick-off point, near 900 mVD, positioning the vertical section of the well on the southeast side of the "blind" Injection Field Fault (IFF) as predicted in the geology model. This allowed the opportunity to test the fault location, as the well path would cross through the IFF at depth towards the target zone, whereas the offset wells passed above the blind fault due to S-well trajectories.

The final J-type well path followed a slightly more northerly azimuth than RK21, intermediate to RK21 and RK22, allowing for safe separations while maintaining a trajectory that would intersect the same fracture system (Figure 1).

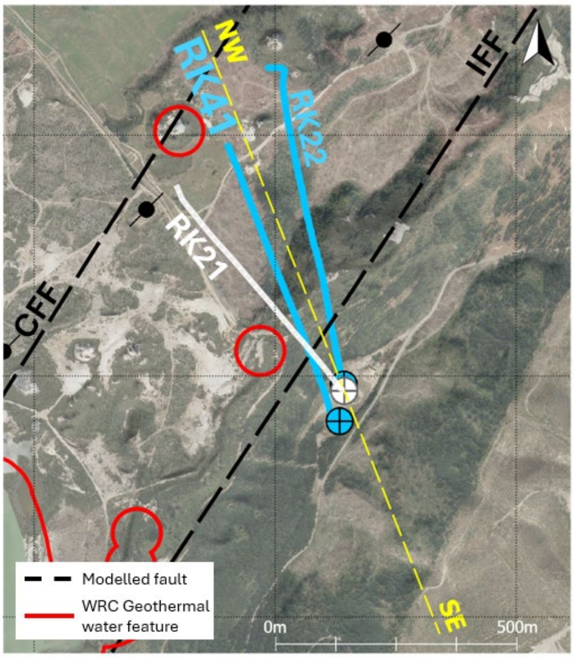

Figure 1. Location of new well (RK41) relative to offset wells. Yellow dashed line shows cross-section location (Figure 4 & Figure 6).

2.2 Casing design

Standard well design and drilling operations require pressure control to prevent uncontrolled flow or blowouts. Each hole section must be engineered so that exposed formations can contain the Maximum Design Pressure (MDP), calculated by the drilling engineer using offset data and analytical methods for each hole size. For RK41, the MDP was based on 100% steam conditions, determined by calculating the saturated steam pressure at the section's maximum static temperature, minus the steam pressure gradient (NZS 2403:2015, New Zealand Standard Code of Practice for Deep Geothermal Wells, 2015).

A range of temperature profiles (P10–P50–P90) was prognosed to guide well design, based on historical data from nearby wells and numerical model simulations. The Rotokawa model predicted that deep "natural state" (pre-production) temperatures of approximately 340 °C were present in the RK41 area. However, by 2024, the model anticipated significant thermal drawdown due to prolonged injection at nearby RK22. These cooling effects informed the P10 scenario, representing the lower bound of expected temperature conditions near the injection source. The P90 case assumed the highest measured temperatures from offset wells RK21 and RK22 during post-drilling heat-up, representing a near-natural state condition.

While considered to be the most extreme and less likely scenario, the P90 profile was used to define the MDP for casing design, ensuring the well could safely contain the highest plausible pressure and temperature conditions. The depth versus temperature (DVT) P90 profile anticipated a spike to 190 °C at circa 400 mVD, followed by cooling to 130 °C at 500 mVD, then a steep increase to 290 °C by 800 mVD. The expected maximum temperature at depth was up to 336°C (Figure 2).

Once the design DVT curve was established, the drilling engineer evaluated the Effective Containment Pressure for each section using leak-off test (LOT) data, which provide rock strength and pressure containment estimates. At Rotokawa, LOT data has been collected across multiple wells and casing depths, showing considerable variability, from 1.1 to 0.45 psi/ft. Historically, a conservative 0.50 psi/ft gradient was used for casing design.

Applying this conservative approach to RK41 would require five cemented casing strings to 1330 mVD, including three between 760mVD and 1330 mVD to manage the steep temperature gradient. To maintain a 13-3/8" production casing to the reservoir, this design required setting a 26" intermediate casing in a 28" hole at 760 mVD. This posed challenges: the tight annular clearance increased the risk of hang-up, and this casing size had only been set successfully to a max depth of 320 mVD in previous wells. Furthermore, the 26" casing would fail collapse load conditions near the shoe, complicating cementing.

An alternative design proposed reducing the PCS to 9-5/8", drilling an 8-1/2" hole, and installing a 7" perforated liner through the reservoir. While viable, wellbore flow modelling indicated this configuration would significantly reduce well capacity (up to 40%), making it unsuitable for meeting the power station's requirements.

Next, less conservative assumptions were explored based on LOT values from the two closest offset wells (RK21 and

RK22), located on the same pad. These recorded 0.74 and 0.75 psi/ft near 400 mVD, suggesting stronger formation at that depth. If the 26” intermediate casing could be set at 400 mVD, and a slightly higher rock strength of 0.55 psi/ft assumed below, a four-string design (casing at 100, 400, 820, and 1330 mVD) was feasible.

This design still carried risk, as actual LOT values measured during drilling could prove insufficient. To manage this, the team adopted a primary design based on the higher LOT assumptions, with the contingency that—if actual LOT results did not meet design requirements—the more conservative step-down casing design would be implemented (Figure 3). This approach required full readiness with alternate casing and liner materials, as well as completed contingency design calculations. This flexible strategy introduced a new method to “dynamically” complete the well based on conditions assessed at key decision points during drilling.

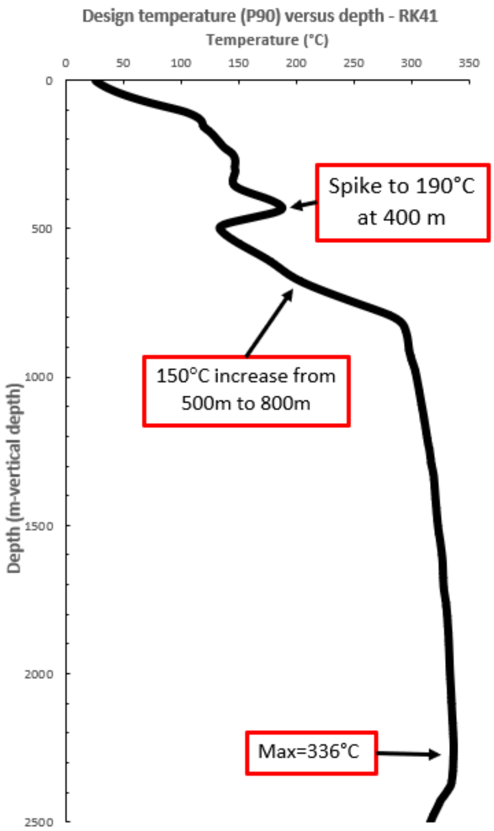

Figure 2. Design temperature versus depth (DVT) for RK41 P90 scenario.

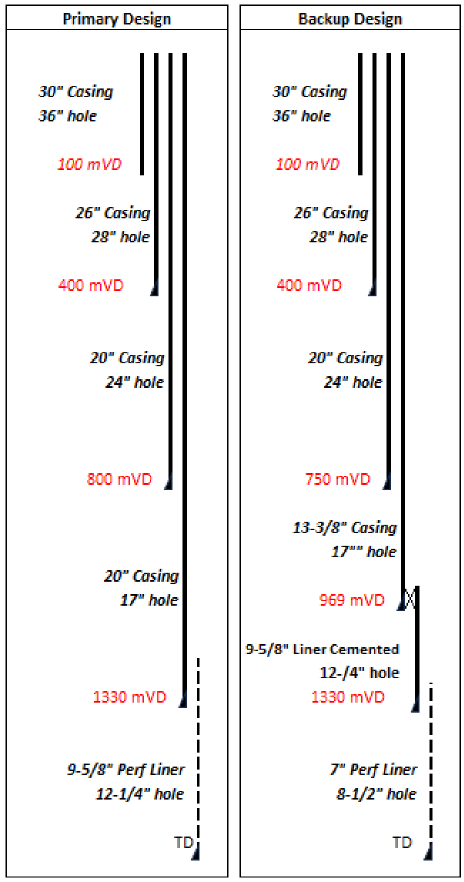

Figure 3. Primary and Backup Casing Design for RK41.

3. RESULTS

3.1 Geology

As RK41 was drilled with a different design than offset wells RK21 and RK22, the well path intersected a subsurface zone not previously explored. Specifically, the RK41 J-shaped trajectory allowed a deeper vertical section compared to offsets, which provided an opportunity to test the predicted location of the high-angle, blind Injection Field Fault (IFF, surface trace on Figure 1). This structure is inferred from a stepped-up basement in a deep vertical injection well approximately 1.5 km to the north but not confirmed locally prior to RK41 drilling.

While the stratigraphy intersected in RK41 was broadly consistent with nearby offset wells and the predicted model, several differences were encountered (Figure 4). Notably, the Oruahineawe Rhyolite (and the Waiora units below) were intersected shallower than expected in RK41 and shallower than in the offset wells. However, the Whakamaru Group ignimbrite was intersected at a consistent depth across all three wells (no offset), so the Oruahineawe and Waiora formations’ shallower occurrences are not interpreted as fault-related but are more likely due to thickening through depositional processes. Beneath this, the well path intersected the Rotokawa Andesite at the modelled depth (stepped up relative to offset wells), supporting pre-drill predictions that the well would intersect the IFF from the eastern side, a feature not intersected by RK21 or RK22. However, rather than the >500 metres of Rotokawa Andesite typically expected, only a 35 -metre-thick interval was drilled. This was underlain by 270 metres of volcanic alluvium, which had not been identified during the original RK21 drilling.

Re-evaluation of RK21 and RK22 cuttings, supported by improved understanding of the field since 2008, led to revisions of several stratigraphic boundaries (Rosenberg & Carson, 2024). These revisions were enabled by the relatively coarser cuttings from RK41, which revealed lithological textures and structures not apparent in the finer cuttings of RK21. In RK21, the base of the Whakamaru Group ignimbrite is now interpreted to be 45 metres deeper than originally logged, and the newly recognised Tahorakuri Formation (108 metres thick) is positioned above the Rotokawa Andesite. RK22 required only minor boundary adjustments, as larger cutting sizes allowed recognition of the Tahorakuri Formation during well logging.

The repeated interception of the discrete Rotokawa Andesite lava suggests a structural offset, indicating that RK41 likely crossed the blind Injection Field Fault – a structure inferred to terminate beneath the Whakamaru Group ignimbrite – en route to the target zone, validating the earth model.

3.2 Hydrothermal alteration

Hydrothermal alteration at RK41 was generally moderate to strong, with locally intense intervals. Kaolinite – a mineral indicative of acidic conditions and commonly observed in the intermediate aquifer zone of Rotokawa – was present in trace amounts to circa 700 metres depth, similar to RK22 and RK21. However, in RK21 the proportion of kaolinite observed was much higher than for both RK41 and RK22, with some samples in excess of 5% kaolinite (Ramirez et al., 2008; Kilgour & Ramirez, 2008). Below 700 metres, hydrothermal minerals indicated formation from water-rock reactions of near-neutral pH chloride waters that likely have a high CO_2 content (Rosenberg & Carson, 2024).

Temperature-sensitive clay minerals at RK41 showed interfingering zones of smectite (25–820 m), illite-smectite (a shallow zone at 275–325 m, and deeper zone at 850–1380 m), and illite (local occurrences from 900 m) (Rosenberg & Carson, 2024). The zone and relative proportion of swelling clays exceeded what was expected based on offset wells (Figure 6).

Below 1690 metres depth, the presence of epidote suggests that fluid-rock interactions involved near-neutral pH fluid with temperatures of ≥240° C (Browne & Ellis, 1970). The depth of epidote's first occurrence was much deeper in RK41 (1690 m) compared to RK21 (circa 1200 m) and RK22 (circa 1000 m) (Rosenberg et al., 2024l; Ramirez et al., 2008; Kilgour & Ramirez, 2008).

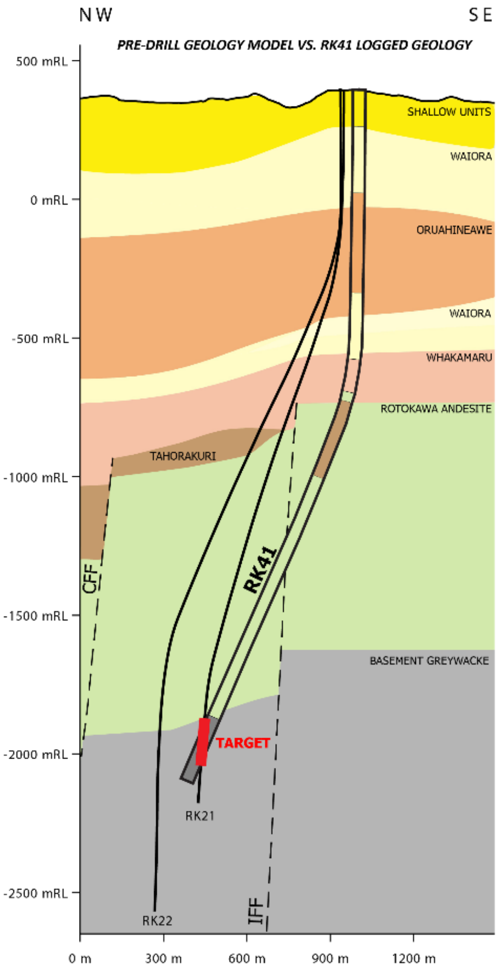

Figure 4. Pre-drilling conceptual geology model and target area, with the actual RK41 logged geology shown along the well path.

3.3 Temperatures

High temperatures were anticipated in the vicinity of RK41 based on historical data from the two offset wells (Figure 2). These measurements, acquired several years prior to drilling, informed a range of thermal scenarios used to guide well design. The high-case (P90) profile assumed saturated steam conditions exceeding 330 °C, which determined the Maximum Design Pressures (MDP) used for casing selection. More conservative (P10-P50) estimates were also calculated. The pressure-temperature-spinner (PTS) survey conducted after 14 weeks of shut-in confirmed that the high-case scenario was realised. A maximum temperature of 338.2 °C was recorded at 2530 m measured depth (MD), validating the design assumptions and confirming excellent thermal conditions (Figure 5).

In contrast to the high temperatures observed at depth, the shallow section of RK41 exhibited significantly lower temperatures than anticipated. Pre-drill estimates based on offset well data suggested up to 190 °C near 400 VD, but post-drill PTS measurements recorded a maximum of only 83 °C. While this result was somewhat surprising, it is consistent with the large variability also observed in the shallow temperature profiles of RK21 and RK22, which created a high uncertainty during the design process. The RK41 data further confirms that significant variation in shallow thermal conditions can occur across short lateral distances—in this case, approximately 70 metres between vertical well sections.

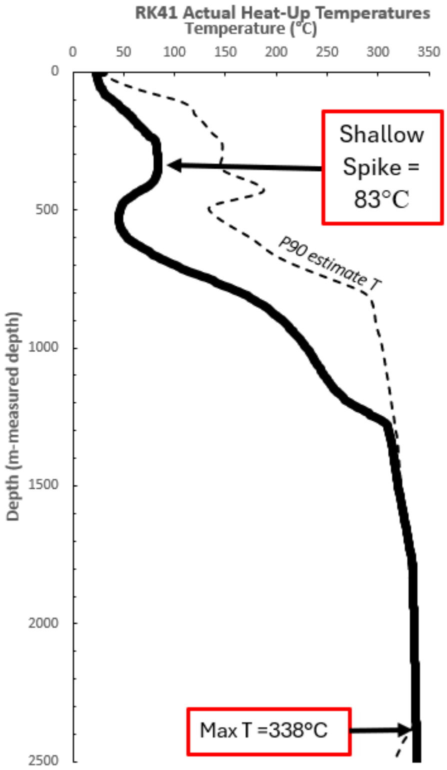

Figure 5. 14-week shut temperature profile of RK41 compared to the estimated P90 profile (dashed).

3.4 Permeability

Injectivity index (II), measured in tonnes per hour per bar (t/h/bar), can be used as a proxy for permeability in injection wells. It quantifies the well's capacity to accept fluid at a given pressure and is a key metric for evaluating well performance.

For RK41, the measure of success was to meet a minimum II value based on power station injection requirements. During stage testing, this threshold was set at approximately 10 t/h/bar. However, if RK41 intersected the same fracture zone as RK21—which recorded an II of around 20 t/h/bar at completion—it was expected to perform well above the minimum requirement.

Completion testing of RK41 confirmed excellent permeability, with an injectivity index significantly greater than 20 t/h/bar. The major injection zone, which accepts almost all the injectate, was identified near the bottom of the well and closely aligns with the targeted zone of RK21. Smaller permeable zones were also identified at shallower depths within the reservoir section. Even under injecting conditions during completion testing, these zones were found to persist as inflows, with injecting wellbore pressure significantly lower than estimated reservoir pressure.

3.5 Final Well Design

As planned, leak-off testing (LOT) was conducted at each casing shoe, excluding the surface string. The LOT results, presented in Table 1, confirmed that the measured values were sufficient to proceed with the "Primary Design" schematic. The PCS was ultimately set slightly deeper than anticipated due to the presence of unexpectedly soft and incompetent Tahorakuri Formation, but this did not require any changes to the overall casing design.

Table 1. Design versus actual Leak-off Tests (LOT) for RK41.

Casing shoe	Depth (mVD)	LOT (psi/ft) Plan	LOT (psi/ft) Actual	Result
30" Surface	112	0.43	0.45	*
26" Int #1	**396**	**0.74**	**0.75**	Pass
20" Int #2	821	0.55	0.58	Pass
13-3/" PCS	1308	0.55	0.56	Pass

**No leakoff taken. Mud weight meets requirement.*

4. DISCUSSION

4.1 Drilling strategy and outcome

RK41 offered an opportunity to trial a new well trajectory design (compared to offset wells) and a more flexible design strategy.

Drilling programs and casing designs are typically fixed and approved prior to execution. Changes are only made when operational issues – such as stuck pipe or casing hang-ups – require alternate (usually shallower) casing configurations. In this case, any significant design changes would be implemented only under a strict Management of Change (MOC) process, requiring approval from the engineering and technical teams.

In contrast, the "dynamic" completion method adopted for RK41 required a greater degree of upfront planning. It involved additional design work, contingency casing and liner hanger calculations, and the procurement of alternate materials to be available at site. This approach enabled the preferred big bore design to proceed while relying on the assumption that higher formation strengths – seen in nearby wells – would be confirmed during drilling. The backup casing design served as a risk mitigation measure in case LOT values were lower than expected. Given its success, this flexible method may be considered for future wells with complex offset well temperature profiles.

The considerably higher permeability encountered in RK41 compared to nearby RK21 was somewhat unexpected. This may be attributable to RK41's J-type trajectory, which intersected the fracture zone at a more optimal, higher inclination, allowing it to cut across a greater number of moderate- to high-angle fractures. Fracture logging supports this interpretation. In contrast, RK21's near-vertical path through reservoir may have intersected fewer such features. No fracture log was collected for RK21, and so a direct comparison is not possible. While it is also possible that long-term injection of brine at RK22 may have enhanced regional permeability via thermal stress and mechanical stimulation, the lack of associated microseismicity near RK22 and no measured cooling observed at RK41 suggests that this is unlikely to be the dominant factor here (Sewell et al. 2015). Overall, the RK41 well design and trajectory appear to have been more effective at intersecting key structures and achieving the desired permeability.

These outcomes highlight the value of both adaptable well design and detailed trajectory planning in optimising well performance in structurally complex geothermal fields.

4.2 Reservoir conditions

Temperature measurements from RK41 confirm that the reservoir in this area remains hot, with no significant thermal decline despite prolonged injection nearby at RK22. This sustained high temperature is interpreted to result from the area's proximity to the inferred upflow zone located to the west of the well pad, where fluids are estimated to reach ≥340 °C.

The measured temperature profile from RK41 was more consistent with the model's predicted natural state, rather than the cooler conditions anticipated under prolonged injection. This indicates that thermal drawdown from RK22 is more limited than expected, likely due to anisotropic flow paths directing injected fluids northeast, away from RK41 and as predicted by the conceptual model. In contrast, shallow temperatures (around 400 mVD) were significantly overestimated, with actual values far below the predicted 190 °C from the model's upper-bound (P90) case. These discrepancies highlight opportunities to improve how the model represents both the shallow thermal structure and subsurface flow dynamics. The RK41 dataset provides valuable new calibration points to support these refinements.

Reservoir pressure measurements in RK41 align with natural state expectations and indicate no abnormal drawdown or pressure breakthrough. Together, the temperature and pressure data suggest that the upflow continues to supply hot fluid and buffer the thermal and hydraulic effects of long-term injection in this part of the field.

4.3 Geologic context and conceptual understanding

Drilling results from RK41 have improved the geological and conceptual understanding of the Rotokawa Field, particularly around the Injection Field Fault (Figure 6). While the pre-drill earth model correctly predicted that RK41 would intersect the fault, the stratigraphy and structural features encountered suggest that the structure is both more complex and likely further southeast than previously assumed. The revised structural position of the IFF aligns with a strong deepening of the conductor zone as observed in magnetotelluric (MT) geophysical data.

Above the deep reservoir, RK41 encountered a thicker sequence of colder-than-expected conditions and more clay-rich formations relative to RK21 and RK22. Swelling clays were identified at greater depths than anticipated, providing independent verification of the MT model and helping to confirm the likely field boundary. The absence of pervasive acidic alteration minerals in RK41 suggests that shallow acid-sulphate fluids may be confined to narrow, localised fractures rather than being widespread across this part of the field. Together with the lower shallow formation temperatures measured, this data suggests that the well may be at a reduced risk of external casing corrosion relative to other Rotokawa wells.

Despite encountering relatively low shallow temperatures, reservoir temperatures measured at RK41 are the hottest on record at Rotokawa (338°C). Measured temperatures well exceed those inferred from alteration mineralogy below 1250 metres depth. Some of these findings may be explained by the high concentration of CO_2 in reservoir fluids, which can suppress the formation of epidote (high-temperature indictor mineral), but other minerals, such as smectite and chalcedony, are present at depths where formation temperatures far exceed their expected stability ranges. These findings highlight the complex multi-stage evolution of the Rotokawa geothermal system (Rosenberg et al., 2024).

5. CONCLUSION

The results from RK41 offer valuable insights for reservoir understanding and future development. The "dynamic" casing design method proved effective, providing flexibility while maintaining well integrity. Findings from RK41 will inform ongoing improvements to both the geological and numerical reservoir models. Sustained high temperatures and excellent permeability indicate a strong connection to the deeper upflow, reflecting positively on the long-term sustainability of the resource. This well demonstrates that even in-field drilling for replacement wells can still yield meaningful contributions to field development and understanding.

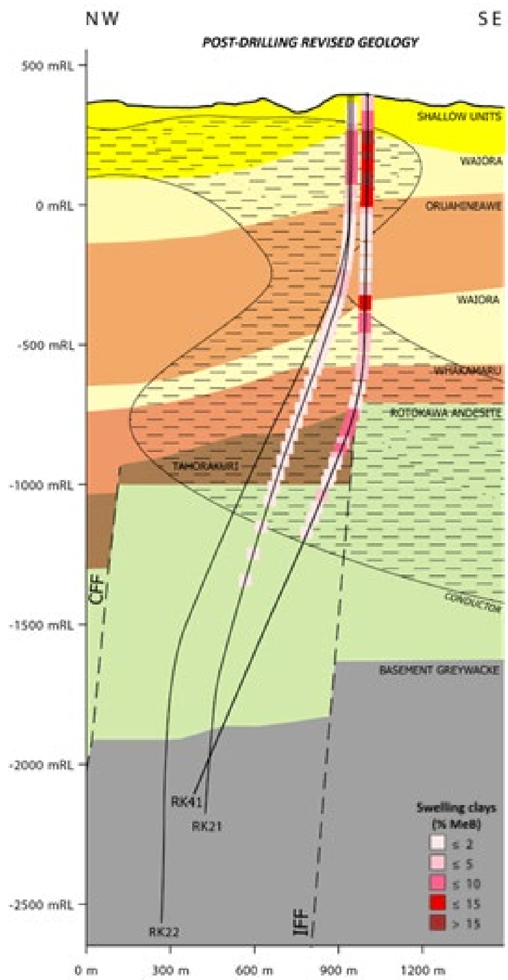

Figure 6. Post-drilling conceptual interpretation of geology with measured MeB content of RK41 & RK21. Conductor is defined by the ≤5 Ω·m zone from geophysical surveying.

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