THE MATALIBONG-25 COREHOLE AT THE TIWI GEOTHERMAL FIELD

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Abstract

Well Matalibong-25 was core-drilled to 2439 m (8000') in the Tiwi reservoir as a pressure monitoring well in 1992-1993. While core drilling overcame the technical challenge of drilling a deep well into an underpressured reservoir, the scientific results of the recovered rock core have added significantly to the value of the well. Analysis of the core has yielded detailed data on stratigraphy and hydrothermal alteration,, and characterized reservoir permeability and the nature of the reservoir floor. Well test results show that cored slim holes can quickly give stabilized formation temperatures, and when flowed, yield well test parameters and fluid samples comparable to that of a regular-sized production hole.

US DOE-sponsored research on the rock core has provided important insights into the chemistry and evolution of the Tiwi hydrothermal system. Studies of fractures and vein occurrence and orientation show that reservoir permeability is due to secondary faulting and fracturing, without little or no influence of primary lithology. Detailed studies of veins show that the system underwent eight distinct stages of mineral precipitation, culminating in an assemblage of illite-quartz. Geochemical modeling of the present day reservoir fluids shows that they are in equilibrium with this last illite-quartz assemblage, and appear to represent a mixture between fresh and seawater. Fluid inclusion gases, analyzed by quadrupole mass spectrometry, reveal a meteoric character to the early system and higher concentrations of methane than in the present system. $^{40}Ar/^{39}Ar$ *age dating of vein adularia suggests an age of >200 ka for the first 7 stages of veining, and a recent rejuvenation of the system after an extended period of quiescence. Ongoing and future research includes additional age dating, noble gas isotopes of fluid inclusion gases and studies into the nature of porosity in the core.*

1.0 INTRODUCTION

Well Matalibong #25 (Mat-25) was drilled in 1992-93 as a deep, vertical pressure monitoring well in the heart of the productive, western sector of Tiwi geothermal field (Figure 1). In order to avoid drilling problems expected in the underpressured deep reservoir, the hole was drilled by continuous coring through the reservoir interval. Previous Unocal experience with continuous coring showed it to be superior to rotary drilling in maintaining hole stability in low pressure, caving rock formations.

Above the reservoir the hole was drilled by conventional rotary methods, culminating with 17.8 cm (7 inch) cemented casing set to 781 m (2563 ft). The well was then drilled by continuous wireline coring, with CHD 134 (13.4 cm) core drilled from 788 m (2586 ft) to 1524 m (5000 ft) followed by CHD 101 (10.1 cm) core to the targeted depth of 2439 m (8000 ft). Mat-25 was completed with 12.7 cm (5 inch) slotted liner set to 1524 m, and 8.9 cm (3.5 inch) slotted liner set to total depth.

A byproduct of the coring process was a nearly complete rock core through the Tiwi reservoir, available for reservoir and scientific studies. Core recovery was greater than 95% on average, and the core hole remained near vertical throughout drilling, increasing in deviation from 2¼° from vertical at 776 m (2545 ft) to 7%" at bottom. In order to facilitate research on the core, PGI and NPC made the core available to the Energy and Geoscience Institute (EGI) at the University of Utah, for study under contract to the US Department of Energy. This paper presents the geology of the cored section of Mat-25 and a *summary* of the results of this research.

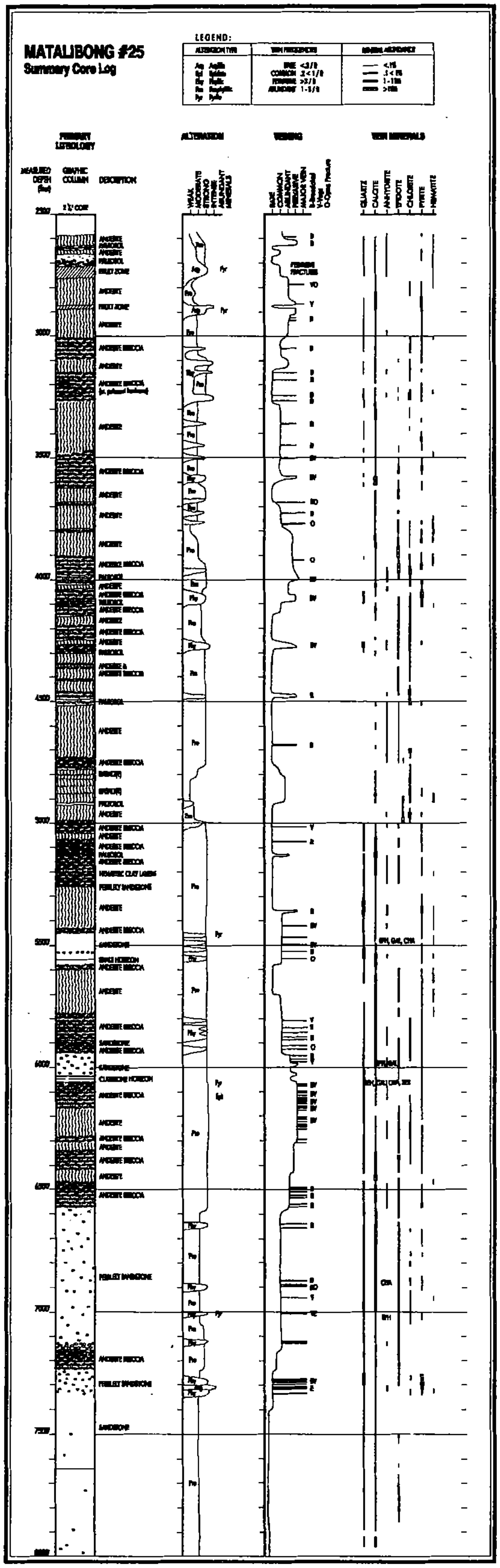


Figure 2. Distribution of lithologies, extent of hydrothermal alteration and veining, and occurance of vein minerals in Matalibong 25.

Primary lithology in the core is dominated by basalt and basaltic andesite lavas, flow breccias and volcaniclastics, suggesting a prolonged and nearly continuous episode of arc volcanism. At **1601** m **(5250 ft)** the depositional environment of the section makes a transition from subaerial to subaqueous marine. Paleosol horizons, which are common in the upper section of the core, give way to intervals of poorly-sorted pebbly sandstones. Below **2012** m **(6600** ft), the core becomes almost entirely sandstone.

The hydrothermal reservoir is characterized by alteration . assemblages containing varying proportions of chlorite, illite, quartz, calcite, pyrite, epidote, anhydrite, adularia and wairakite. Epidote, which is characteristic of propylitically altered rocks, first appears near the top of the core at depths of approximately **900** m **(2950** ft). With the exception of a few short intervals above **1525** m **(5002** ft), alteration intensity is uniformly high throughout the core.

Veins are common and widespread, and can be divided into two types: assemblages characterized by various proportions of calcite, anhydrite, quartz, epidote, and wairalute, and assemblages dominated by illite, quartz, and pyrite. Veining intensity and the distribution of brecciated, vuggy or open veins appears to delineate two separate intervals of fluid circulation; one from the top of the core to **1250** m **(4100** ft) and one from **1646** m **(5400** ft) to **2256** m **(7400** ft). Two steeply-dipping fault zones, whch are the foci of intense pyrite-rich argillic alteration, are found above **914** m **(2998** ft) and may have served as conduits for the downward migration of supergene waters from above the reservoir, and the upward movement of steam condensate.

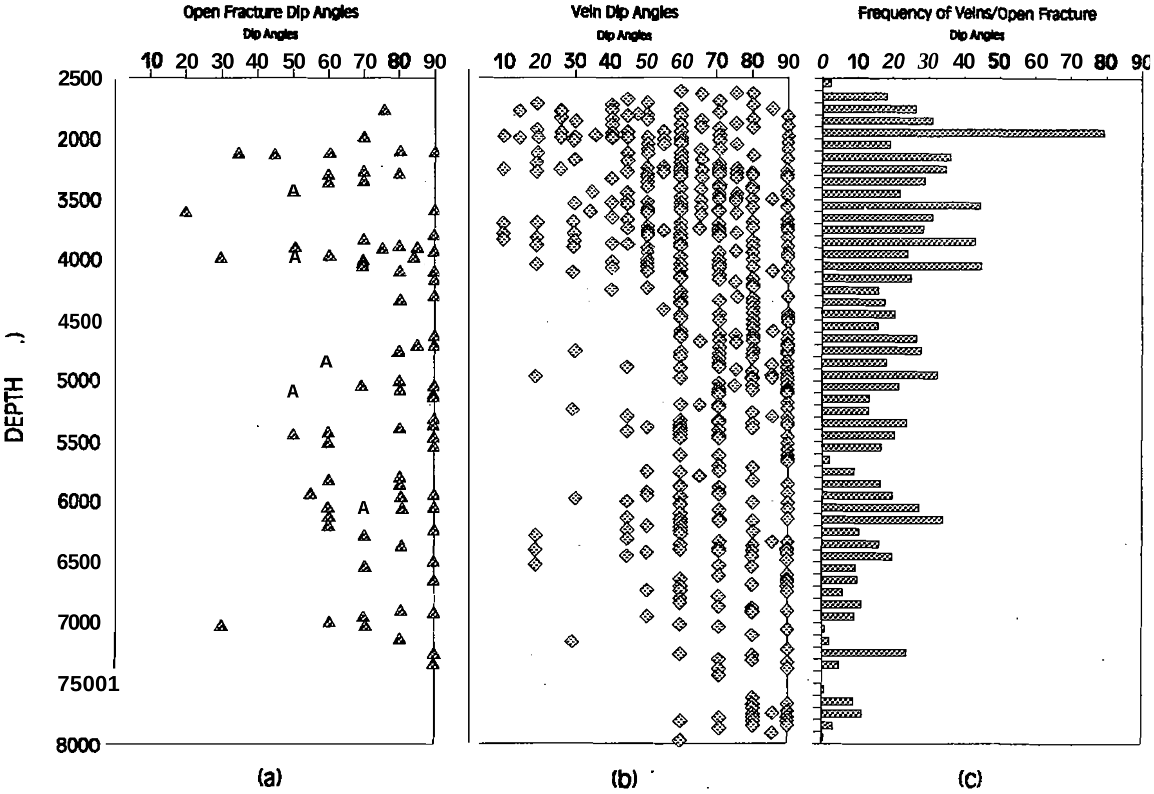
2.1 MAT-25 TEST RESULTS

The well's test results proved to be as good or better than a regular hole. The well heated up to a stable temperature profile in just two weeks. It was successfully flow tested a month later, yielding a stabilized rate of **17.4** kg/s **(138** kph) total mass flow and **4.2** kg/s **(33** kph) steam at **0.63** MPa **(91** psig) flowing wellhead pressure at a maximum enthalpy of **1181 KJ/kg (510** BTU/lb). Geochemical samples showed the well's chemistry to have stabilized after the first two days of the flowtest, probably because of the relatively small quantities of drilling fluids circulated during coring. This was probably also the major reason for well temperatures to rebound quickly after drilling.

Wellbore simulation modeling of a flowing pressure-temperature-spinner survey identified four feed zones in cored section. Fracture zones in the core at these depths tended to show open, vuggy veins containing only quartz, calcite and pyrite in relatively unmineralized planar fractures or brecciated zones. Wellbore modeling also showed that the two deepest feed zones were lower enthalpy (and temperature) than the upper ones, confirming a temperature reversal observed in static temperature profiles.

3.0 RESEARCH RESULTS

US DOE sponsored research on the core has resulted in three publications to date, with others in various stages of submittal and preparation. Nielson et al (1996) studied veins and fractures in the core. They found that fracture permeability in the core was associated with secondary faulting and fracturing, and that primary lithologic features, such as geologic contacts, are sealed and do not contribute to fluid production. Figure 3, taken from Nielson et al, shows the dip angles and frequency of veins and open fractures in the well. While the majority of open and sealed fractures in the core are steeply-dipping (>60°), shallow-dipping fractures (<45°) are abundant above 1300 m (4265 ft) depth and decrease in abundance with depth.



(a) (b) (c)

Figure 3. Dip angles of (a) open fractures and (b) veins in the Mat-25 cores measured with respect to the core axis. Frequency distribution of veins and open fractures (c) is compiled on 100foot intervals.

Comparisons with lithology suggest that rack type exerts little control over fracture and vein intensity and the distribution of major veins. Furthermore, there is no change in lithology that might explain the dramatic decrease in vein intensity below 2256 m (7400 ft), which appears to mark the base of the hydrothermal reservoir.

Bruton et al(1997) conducted geochemical modeling on the Mat-25 well fluids to examine the source of the reservoir fluids and to evaluate the chemical and physical processes in vein paragenesis. They found that the downhole reservoir fluids are mildly acidic, with a chemistry suggesting active sericite precipitation in the reservoir. Geochemical modeling was conducted to show the impacts of boiling, conductive cooling and conductive heating on the reservoir fluids. It showed , not unexpectedly, that calcite and anhydrite precipitation were favored by conductive heating, while boiling could be differentiated from conductive cooling by the presence of epidote during boiling, and illite during cooling. Both boiling and cooling favored precipitation of quartz, K-feldspar, wairakite and pyrite. They also suggest that ratios of Na, Cl and Br are indicative a significant component of seawater in the reservoir waters.

Moore et al (1997a) reports on extensive studies of vein minerals in the core. Crosscutting relationships in vein samples to define 8 stages of vein mineralization. These stages are shown diagramatically in Figure 4, taken from Moore et al. Following an initial stage of phyllic alteration, which probably reflects the first heating of the system, the stages define three cycles of boiling and fracturing followed by the influx and heating of cooler fluids. Differing mineralogy suggest a slightly different fluid chemistry for each cycle. The final stage is characterized by widespread illite, consistent with the results of Bruton et al. This suggests a drop in system pH, and they hypothesize that this is in response to an increase in the CO_2 content of the system.

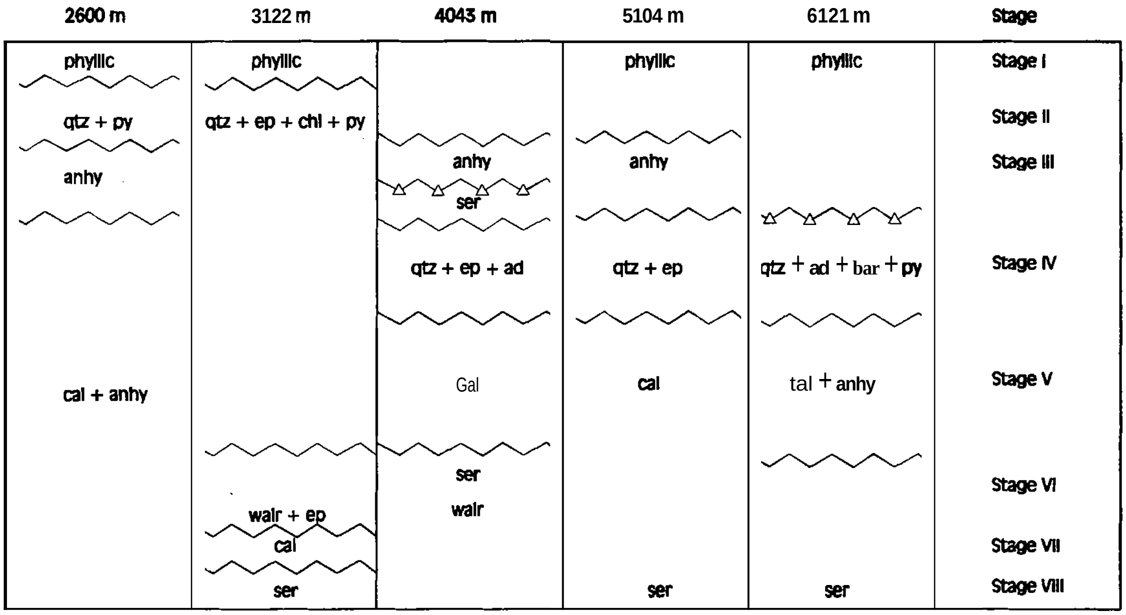


Figure 4. Schematic diagram of stages of mineralization in vein samples from Mat-25:

Fluid inclusion homogenization temperatures and salinities for the vein samples are shown in **Figures 5** and 6, taken from Moore et al. The widespread appearance of vapor-rich, gas-rich and extremely low salinity fluid inclusions confirm events of system-wide boiling suggested by the vein paragenesis studies. An increase in fluid inclusion salinity with depth, to approximately **3.5wt%**, suggests seawater involvement in the deeper levels of the reservoir, as suggested by Bruton. This hypothesis is also supported by an abundance of anhydrite and base metal sulfides' deep in the system.

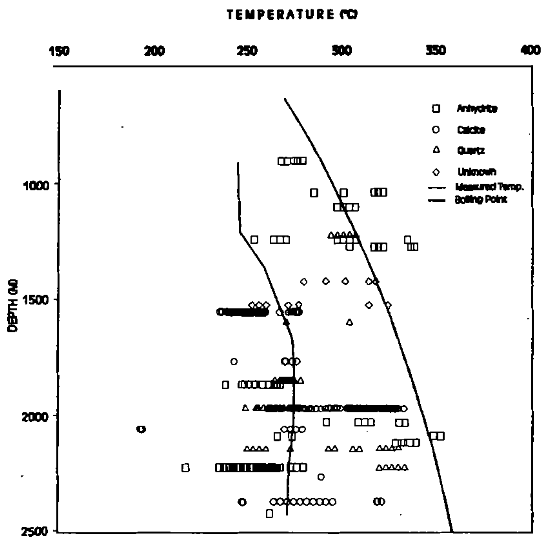


Figure 5. Fluid inclusion homogenization temperatures.

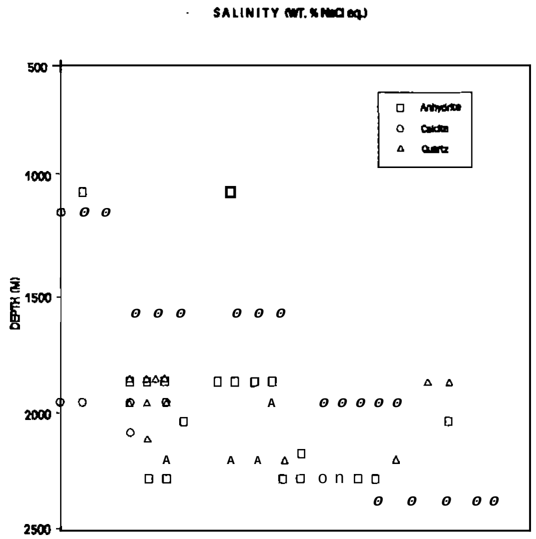


Figure 6. Fluid inclusion salinities.

The results of fluid inclusion gas analyses, found using a relatively new technique, are shown in Figure 7. The fluid inclusion gases are predominantly mixtures of meteoric and crustal gases, with only a few samples showing N_2/Ar ratios suggestive of magmatic input. The fluid inclusions were also found to be richer in CH_4 and other **hydrocarbons** than the present day fluids.

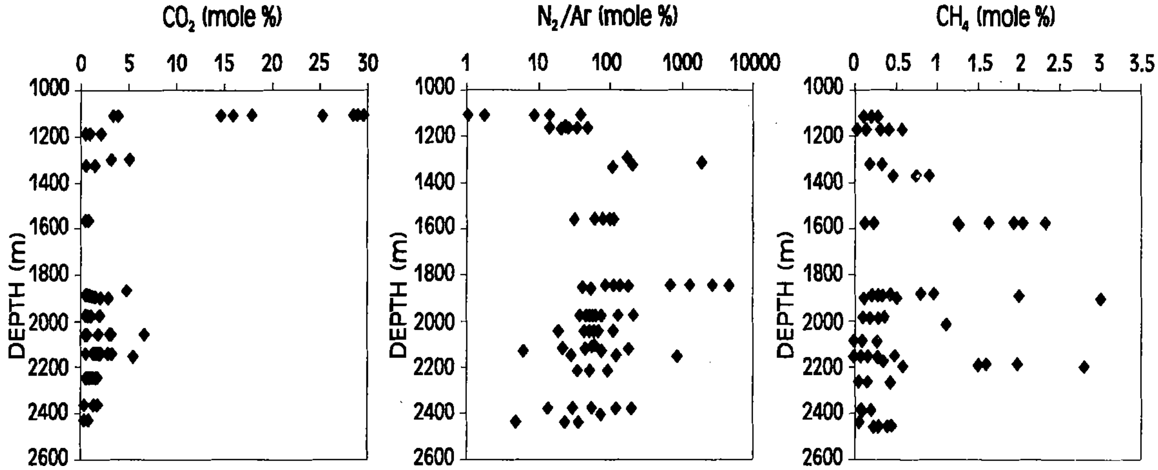


Figure 7. Distribution ofjluid inclusion gases CO_2, N_2, Ar and CH_4.

$^{40}Ar/^{39}Ar$ age dating of vein adularia, reported in Moore et al (1997b), constrains the first 7 stages of mineralization to have taken place prior to 200 ka. The age date *spectra* of the vein samples, an example of which is shown in Figure 8, further suggest that the system subsequently cooled to below **250°C** and has **been** at its present day temperature of **270°C** for less than **50 ka.**

Ongoing and future research on the core includes additional $^{40}Ar/^{39}Ar$ age dating by **Matt** Heizler at New Mexico Tech, noble gas isotopes of fluid inclusions, underway by Mack Kennedy at Lawrence Berkeley Laboratory, and petrographic imaging analysis of porosity by **EGI.**

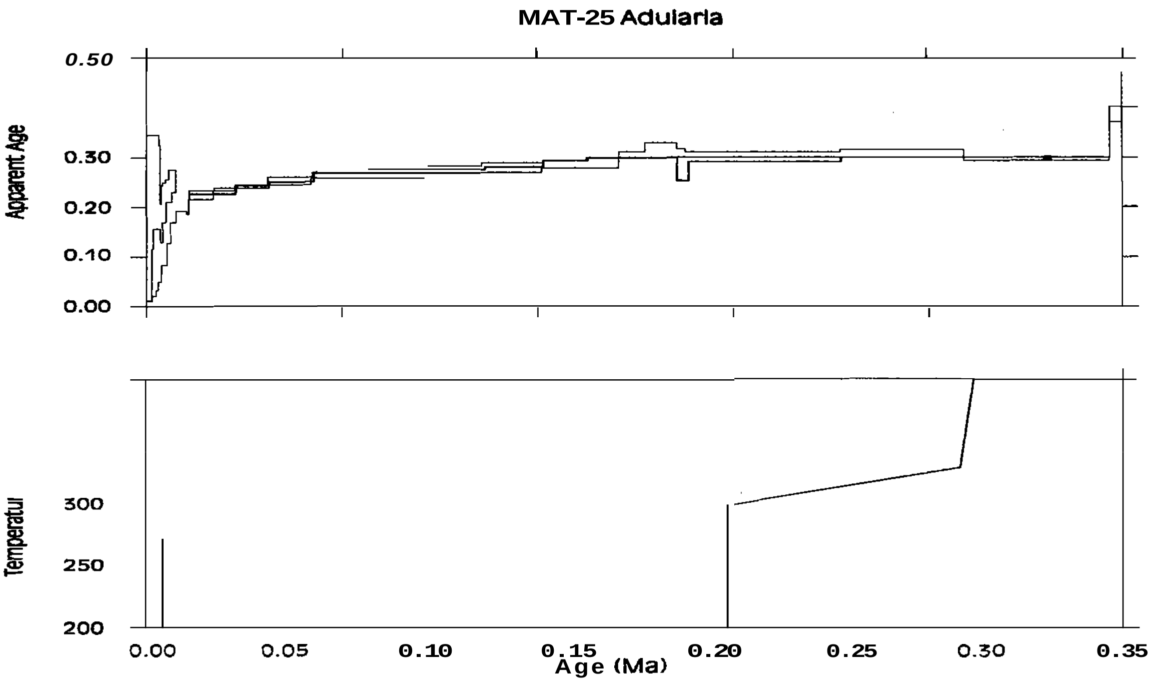


Figure 8. ^{40}Ar/^{39}Ar age dating of vein adularia from Mat-25 cores.

4.0 CONCLUSIONS

The scientific results of the Mat-25 corehole have added significantly to its original value as a pressure monitoring hole. Besides giving a detailed stratigraphy of the reservoir, the geology of the core has revealed the nature of permeability in the reservoir, the zonation of hydrothermal alteration and the nature of the reservoir floor. Well test results show that cored slim holes quickly yield stabilized formation temperatures, and when flowed, yield well test parameters and fluid samples comparable to that of a regular-sized production hole. Comparisons between the down hole logs and the core allow the added feature of actually being able to see the fractures and veins that are wellbore feed zones.

A continuous core through a hydrothermal reservoir also provides material for extensive research into the chemistry and evolution of the system. Research on the core has shown that permeability in Tiwi is due to secondary faulting and fracturing, without any apparent influence of primary lithology. Detailed studies of veins in the core shows that the system has had a complex chemical and thermal history, culminating in a long period of quiescence and recent rejuvenation. Geochemical modeling studies of produced fluids confirm many aspects of the vein studies, adding support to their findings. Future research should further elucidate the history of this complex geothermal system.

5.0 ACKNOWLEDGMENTS

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