THE HISTORY OF THE OHAAKI GEOTHERMAL FIELD – IN 3D

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ABSTRACT

Geothermal drilling of the Ohaaki Geothermal Field (New Zealand) started in 1965, and subsequently involved several phases of exploration, delineation and production/injection drilling, culminating in the commissioning of the Ohaaki Power Station in 1988. Since that time, exploration, development and monitoring activities have continued, with ongoing collation of geophysical survey and reservoir engineering data, and new geological insights from recent drilling operations. The acquisition of new geoscientific information demands a combined interpretation of the geothermal data sets which can be challenging. As such, 3D modelling has been increasingly used by Contact Energy Ltd. and GNS Science for geothermal data management, analysis and interpretation. To demonstrate the value of 3D modelling and data integration, five 3D geological models of the Ohaaki Geothermal Field have been constructed, for five different stages of field development, using Leapfrog Geothermal 3D visualisation and modelling software. Comparison of the respective 3D models with (historical) interpretations made at each development phase highlights the utility and effectiveness of 3D geological modelling in producing robust and consistent interpretations. We demonstrate how 3D geological models and numerical interpolations can be easily updated and refined, with testing of alternative interpretations accompanying revision of the conceptual and geological models. As a result of increased efficiency and reliability, 3D models can be used on a routine basis to assist in the development of drilling strategies and to advance data integration for field management.

1. INTRODUCTION

The Ohaaki Geothermal Field is located ~30 km NE of Taupo, New Zealand (Figure 1). Exploration drilling began in 1965, following regional electrical resistivity surveys in the Taupo Volcanic Zone (TVZ). Over 45 years of subsequent field exploration and development, 65 wells were drilled for electricity generation and fluid disposal (Figure 2).

Recent field development in New Zealand has used 3D modelling as a routine tool for understanding the 3D geological framework, effectively assisting well planning and field management of geothermal fields. In this paper, we present and assess five 3D geological models developed using the Leapfrog Geothermal software (Carr et al., 2001; Cowan et al., 2002) at different dates of the development of the field; i.e. after completion of 6, 13, 25, 49 and 65 wells, respectively. The first two models correspond to the state of knowledge during initial exploration, with wells reaching ~800 to 1400 mGL (below ground level). During subsequent field delineation, to ~1971, an additional 12 wells were drilled (i.e. 25 wells completed), with drilled depths in the range of ~1000 to 2500 mGL. The "49 wells model" coincides with the end of production drilling (i.e. includes wells drilled between 1973, and commissioning of the Ohaaki Power Station in 1988). The present steamfield layout comprises 65 wells, and includes make-up wells (particularly in the NW part of the field) drilled since 2001 that support recovery of power generation to ~65 MWe from the Ohaaki Geothermal Field, with several wells drilled to 2500 to 3000 mGL depth.

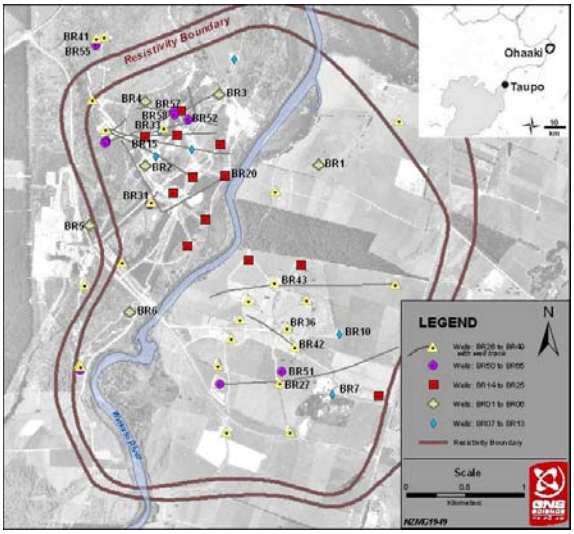

Figure 1: Ohaaki Geothermal Field, with well names mentioned in this paper. The wellhead symbols show the different stages of field development discussed in this paper, after 6, 13, 25, 49 and 65 wells were drilled.

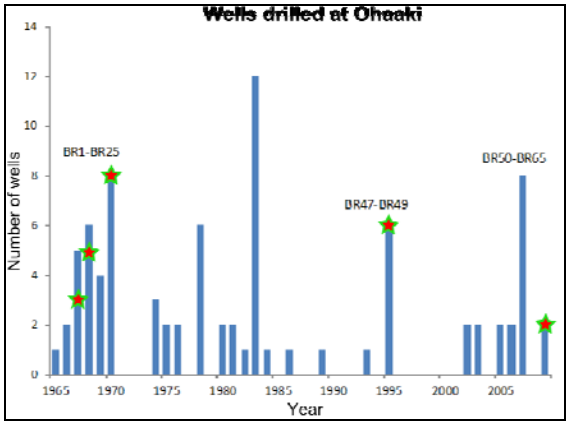

Figure 2: Ohaaki Geothermal Field, with well names mentioned in this paper. The wellhead symbols show the different stages of field development discussed in this paper, after 6, 13, 25, 49 and 65 wells were drilled.

2. GEOLOGICAL FRAMEWORK AND DATASET

The Ohaaki Geothermal Field is composed of a series of sedimentary and volcaniclastic units, and intercalated rhyolite domes and lavas, deposited over a faulted basement (Rae et al., 2007). The stratigraphic sequence to about -1000 masl (meter above sea level) was initially revealed by wells drilled in the 1960's, and confirmed by later drilling. It consists of 1) lacustrine deposits (Huka Falls Formation, undifferentiated siltstone), 2) pyroclastic formations (Waiora Formation (re-worked in places), Rautawiri Breccia, Rangitaiki Ignimbrite, Tahorakuri Formation (including Waikora Formation)) and 3) rhyolite/dacite lavas and breccias (Ohaaki Rhyolite, Broadlands Rhyolite, Broadlands Dacite). The basement comprises Torlesse low grade metamorphosed siltstones and sandstones (greywacke).

The geological models presented in this paper are based on the geological interpretation of the 65 wells drilled at the Ohaaki Geothermal Field, in the chronological order of their drilling. The two first models (i.e. 6- and 13-wells) integrate seismic refraction studies performed before the drillings. Results of other geophysical surveys (resistivity, MT and gravity) were also integrated, as well as surface observations and regional geology.

3. OHAAKI AT THE EARLY STAGES OF DEVELOPMENT

The first model (i.e. after 6-wells completed) of the Ohaaki Geothermal field are based on the stratigraphic sequence determined during the drilling of the wells (Healy, 1968a), and the interpretation of seismic refraction profiles (Banwell et al., 1967), which defined the extent of two intrusions: the Ohaaki Rhyolite and the Broadlands Rhyolite. Discrepancies were observed between the two data sets, which led to a re-intrepretation of the seismic profiles (Mac Donald and Hatherton (1968)). At that stage, the basement has not been reached, and no definite evidence for faulting has been found. The model is therefore composed of sub-horizontal sedimentary and volcaniclastic layers, crossed by two intrusions (Figure 3a).

A cross-section based on this first exploration stage was produced by Healy (1968a), and is in good correspondence with the 3D-model at the location of the cross-section. Due to the scarcity of data, only few discrepancies could be expected at that stage; however, the 3D model is already a 3D generalisation of the cross-section over the entire field and insures the consistency between all data available.

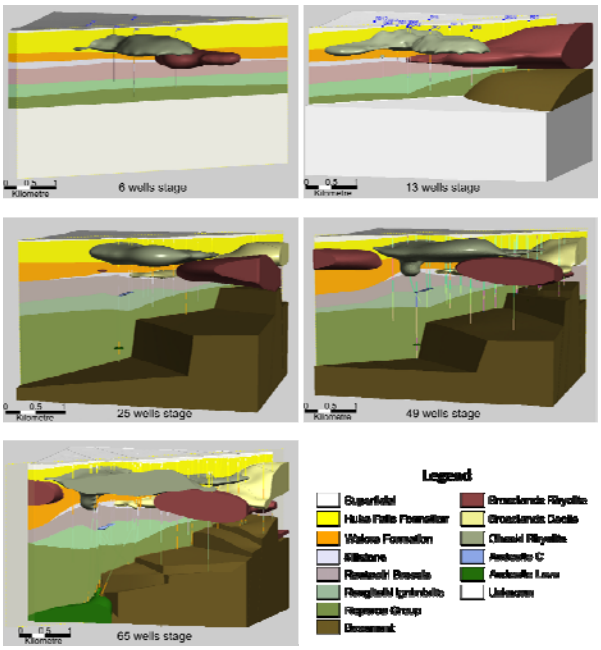

Figure 3: NE view of the Ohaaki 3D geological model, at five stages of field development. All models have similar lateral and vertical extents.

4. EASY UPDATING OF THE OHAAKI MODEL

4.1 Refinement of the geological framework

The first model (6-wells) represented only the post-basement stratigraphy, as the basement has not been reached. In the 13-wells model, only two wells cross the basement in the SE part of the field where it is shallower (Figure 3b). The first wells deeper than -1100 masl were completed near the end of the exploration phase (25-wells model, Figure 3c). The well data reveal lateral thickness variations of the unit overlying the basement. Small variations may be due to the paleo-relief existing at the time of deposition, but major variations are likely to be due to fault displacement, despite no definitive evidence of faulting in the wells, either in redundancy of stratigraphic layers or in the texture of the rocks.

At the 6-wells stage, only two intrusions were encountered by the wells: the Ohaaki Rhyolite and the Broadlands Dacite. The following drillings defined several other major intrusions, such as the Broadlands Rhyolite, and smaller lavas (e.g., the Andesite C). The Ohaaki Rhyolite plays an important role in the permeability of the field, and the presence of a large, broad sheet with two domes has been suggested even before drilling thanks to seismic interpretation. This global frame geometry has been preserved in subsequent stages of development. In the 13-wells model, more wells crossed the rhyolite and geological data are in better agreement with the re-interpreted seismic data set. The major modifications of the shape of the lava in the latter stages concern the eastern extent, which happened to be further to the East and has been accurately defined at the 49-wells stage. Further drilling refined the shape of the

rhyolite, but did not modify it considerably. The latest development phase was focused on the deep NW parts of the field and refined the extent of several lavas (Figure 3e).

4.2 Evolution of the structure of the Ohaaki Geothermal Field

Geophysical (Gravity and seismic) studies suggested a ~20° deepening of the basement to the NW, without evidence for faulting. However, regional structure trends such as the scarp striking NE-SW marking the edge of the Kaingaroa plateau (to the East of Ohaaki), NE-SW alignment of hot springs and aerial photographs and Bouguer gravity anomalies (Banwell et al., 1967, Mac Donald and Hatherton, 1968) suggest a general structure of the field. At the 6-wells stage, there is no definite evidence of faults, from stratigraphic displacement or texture identification, but the wells did not reach the basement. Volcanic and volcaniclastic deposits mask the deep structure of the field, which makes the role and geometry of faulting in the Ohaaki Geothermal field difficult to frame.

Two of the wells drilled between the 6- and 13-wells stage intersected the basement in the SE part of the field, but did not determine the presence or absence of faults (Figure 4a). It is only from the 25-wells stage that deep faults were identified from major displacement of the top of the basement, crossed by 6 wells (Figure 4b). For example, a deepening of the top of the basement of ~375 m is observed between BR7 and BR16, the latter located ~400 m SE of BR7, therefore incompatible with a deepening of the basement to the NW as indicated in geophysical measurements. At that stage, four fault blocks were discriminated, separated by NE-SW striking faults, the direction inferred from the regional settings.

The next stages of field development involved deep wells, which helped refining the deep structure of the basement by précising the location, orientation and deepening of the faults (Figure 4c and 4d). Most recent field development has occurred in the NW part of the field, with deep wells exceeding 2000 m, which has allowed the basement structure to be defined with more accuracy.

Before the drilling of deep wells, the geophysical measurement provided a general structural trend of the Ohaaki Geothermal Field, but the resolution was not high enough to resolve the complexities of the field, as subsequently revealed by deep drilling. The complexity of the fault network at the current stage (65 wells) is now high, and further drilling may indicate the presence of additional faults with small displacement and/or redefine the location and orientation of existing faults. Resolving such network while integrating geological knowledge and experience without the help of a 3D modeller would be of great difficulty and would lead inevitably to inconsistencies between data through the field.

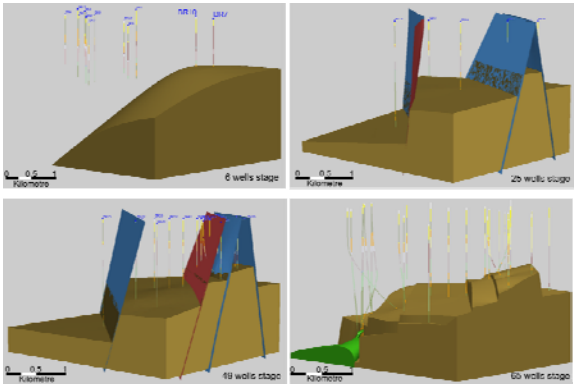

Figure 4: Greywacke basement, associated faults and wells intersecting the basement, at different stage of the development of the Ohaaki Geothermal Field, looking NE. For clarity, in Figures 3b, c and d, only wells that actually intersect the basement surface are shown.

5 CONCLUSION

The evolution of the geological and structural framework through the history of the development of the Ohaaki Geothermal Field has been evaluated by five Leapfrog Geothermal 3D geological models. Each of them corresponds to exploration, resource delineation and production drilling phases of the field.

The first stage of exploration presented a simple geometry for the volcano-sedimentary stratigraphic pile, but the incorporation of geophysical data already allowed the delineation of two of the intrusions. Integration of seismic data during the exploration phase provided invaluable information on the geometry of rhyolite bodies, particularly where it could be combined with drillhole data in the 3D model. Further drilling refined this representation, and especially the geometry of the intrusions. Resolving the role and geometry of faulting in the Ohaaki area is not straight-forward, in part as faults are buried and have no (or rare) surface expression. The first wells drilled were too shallow to intersect the basement, and it is only at the 25-wells stage that the presence of faults was proven. The fault network has then been refined with subsequent deep drilling, becoming increasingly complex. As more drill-hole data are acquired, 3D modelling provides best means of updating and visualising the structural relationships and geological framework of the field. This reduces the risk involved in targeting formational, inter-formational and fault permeability zones.

3D geological models geological models can highlight incoherencies in source data but also help with calibration processes and interpretation. The implicit modelling technique used by Leapfrog Geothermal is particularly efficient in ensuring consistency within and between data sets; it also provides flexibility to update the 3D model after each new well is drilled (as well as the integration of different data sets, such as well logging, geophysical measurements, and geochemical data). It is also possible to test quickly different interpretation scenarios, by enabling the modeller to develop different models simultaneously. 3D models can be continuously interrogated, providing quickly 3D views, elevation maps, cross-sections or the expected stratigraphy of a planned drill-hole, for efficient well targeting and field management.

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