RETROSPECTIVE AND PROSPECTIVE VIEWS OF THE DEVELOPMENT OF WAIRAKEI GEOTHERMAL FIELD: 50 YEARS AND COUNTING

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SUMMARY - Even with 50 years of geothermal power from Wairakei field, the thermal resource is still substantial. If new technologies being deployed by the oil industry today become economic for the geothermal industry in the future, developed fields like Wairakei can be considered as "sustainable" energy resources.

1 INTRODUCTION

With the celebration of the 50-year anniversary of Wairakei Power Station, it is appropriate to reflect on both the pioneering years that led to the commissioning of the power plant, and the development possibilities that lie ahead for Wairakei during the next 50 years. A large amount of scientific literature has been written about Wairakei field, including many recent reviews since the mid-1990s in expert witness testimony presented at Resource Management Act hearings. In addition, several papers in the 20th NZ Geothermal Workshop (1998) reviewed the development history of Wairakei field at its 40-year anniversary celebration. This paper therefore makes no attempt to review either the characteristics of the field or its development history. Instead, the first part gives some brief, personal insights on a few notable events during Wairakei's 50-year history. The second part of the paper speculates about the cutting-edge technologies that could influence development of the field during its second half-century.

2 RETROSPECTIVE VIEWS

2.1 The Rome U.N. Geothermal Conference

In 1961, the United Nations sponsored a conference on "New Sources of Renewable Energy" in Rome, Italy. Of the seven volumes published from that conference, the first three were on geothermal topics. This conference was the unveiling to the international geothermal community of the scientific and engineering advances that had been made at Wairakei, and more generally in understanding the resource potential in the Taupo Volcanic Zone (TVZ) during the previous decade. Frank Studt (DSIR) was Chairman of the sessions on exploration and assessment, and Jack Smith (Min. of Works) was rapporteur for the development sessions. As Smith pointed out in his summary, of the 28 papers on electricity generation, the bulk of the papers were from Larderello, Italy (9), Wairakei (13), and The Geysers, California (3), and of these, only Wairakei papers dealt with harnessing wells discharging steam and water. In the exploration volume, 14 of the 39 papers presented N.Z. research results.

The Rome conference was the start of many N.Z. geothermal pioneers becoming world authorities on geothermal development. This continued with major contributions to the Second U.N. Symposium on the Development and Utilization of Geothermal Resources, held in Pisa, Italy, in 1970. Here, 39 papers by N.Z. authors were presented.

2.2 Two scientific leaders emerging from the 1950s

Many of the pioneering scientific and engineering advances during the 1950s were undoubtedly team efforts, with considerable interaction and exchange of ideas. However, in my opinion, two scientists deserve special recognition for the roles they played during those early years, which may now be largely forgotten. In both cases, they went on to play influential roles in later years.

John Banwell, a physicist, returned to the Dominion Laboratory after being part of the research team in England during WWII years that developed new radar technology. His talents as an experimentalist were quickly an asset once the government decided to investigate the possibilities of geothermal power around 1950. Bolton (1998) notes that Banwell was part of the early discussions lead by Sir Ernest Marsden on accelerating the investigations at Wairakei. He subsequently helped with design of a geothermometer to measure downhole temperature profiles; he developed a calorimeter that became standard equipment during the 1950s for measuring the discharge enthalpy of two-phase wells; he quickly understood the control of boiling-point-for-depth and hydrostatic pressures on the subsurface temperature regime, and the implications of the vast stored heat potential at Wairakei; he contributed to the geophysical techniques best suited to subsurface geothermal fluid surveying and was the first to realize that repeat precision gravimetry could detect the development of steam zones; and during the early 1960s he used oxygen and deuterium analyses to characterize geothermal waters. During the 1970s, Banwell became director of the U.N. Development Program for geothermal resources, and co-edited with Bob Fournier the three-volume publication from the San Francisco geothermal conference in 1975.

During the early 1950s Jim Ellis worked with Stu Wilson on the chemical signatures of geothermal discharges. Their paper (Ellis and Wilson, 1955) estimating the natural heat output of Wairakei using chloride as a tracer for geothermal water, is now recognized as a classic. Subsequently, Ellis published trail-blazing laboratory work on the solubility of carbon dioxide and calcite in geothermal waters, and recognized the temperature dependence of cation ratios such a Na/K, which underpinned later development of geochemical geothermometers. He teamed with Tony Mahon to publish what still remains as the premier book on the geochemistry of geothermal systems (Ellis and Mahon, 1977). Ellis built within the Chemistry Division, DSIR, geochemical teams of world renown studying the thermodynamics of geothermal fluids. He became Director of the Division, and subsequently became Director-General of DSIR.

2.3 Geothermal Circulars – Publication trends

A tradition that seems to have started in the Dominion Laboratory during the early investigation years of Wairakei field was the use of Geothermal Circulars (GCs). These were short scientific reports which were mailed by the author to a list of geothermal people in different government agencies and academia. The author used his/her initials followed by the number of GCs they had written. John Banwell was up to CJB8 by 1954. The most prolific writers at Wairakei were Tony Mahon (61), Russell James (46), and Dick Glover (43). Although these were not considered publications by DSIR, they frequently have been referenced in other publications. They may now provide the best insights to how scientific thinking evolved during the development of Wairakei field, and steps should be taken to ensure they are appropriately archived, scanned and made more accessible. The practice of putting out GCs petered out during the late 1980s.

Since the early 1990s a considerable amount of valuable scientific material about potential development fields in the TVZ has been presented in the form of expert testimony as part of

Resource Management hearing consents and the subsequent appeals process in the Environment Court. Much of this material does not get published elsewhere in the scientific literature because of time constraints of the authors, and pressure of other scientific contract work. Although the expert testimony is in the public domain, it is difficult to access, and at the moment does not appear to be accessible with standard web search engines. As with the GCs, the N.Z. geothermal community should ensure that this material is more accessible.

2.4 Vertical Discharge Tests

One of the exciting "rituals" at the Wairakei project offices of the Min. of Works and Development and DSIR were vertical discharge tests, especially with the exploration wells that were drilled around the TVZ during the 1980s. Usually an injection test had been carried out at the end of drilling to get a preliminary indication of potential productivity, and the subsequent monitoring of warm-up during the following weeks to months gave an indication of downhole temperature. At the time of well-opening, DSIR geologists from the Rotorua office would lay out a large tarpaulin, hopefully downwind of the expected fall-out zone from the discharge plume, to attempt to catch a sample of mineral ejecta from the feed zones as the discharge built up. Pundits would predict the energy (megawatt thermal) potential of the well both before and during the discharge test. There were times when vehicles parked too close to the discharge plume received a spray of silica laden water that when dry was extremely difficult to remove!

2.5 Thermal Activity Changes

As early as 1954 a hydrothermal eruption occurred in the Karapiti area and raised suspicion that it could have been somehow linked to the discharging production wells some 3 km to the north (Banwell, 1954). Several dozen eruptions occurred intermittently during the subsequent decades, including two in the Pony Club area of Tauhara field. Fortunately, no injuries occurred, despite Karapiti becoming a popular tourist destination, and excited tourists often being the source of information that a new eruption was occurring. Although considerable effort has been spent looking at the timing of the eruptions, a single trigger mechanism has never been proven. Increased steam upflow due to drawdown of the liquid reservoir is the underlying cause of increased steam activity at the surface.

The Rogue Bore also attracted tourist attention for several years, although this feature was the result of uncontrolled steam discharge while drilling well 204 in 1960 (Thompson, 1976). After 3 months of intense dry-steam discharge which created a crater, it evolved into a boiling pool with powerful ebullition. The crater suddenly drained in 1973 and ceased activity.

The gradual decline in geyser activity at Wairakei was not widely publicized during the development years, with a notable exception being the changes described by Thompson (1960). Looking back, it is clear that by about 1954 changes in the flow and chemistry of some features were occurring, and changes became more widespread and pronounced by the early 1960s. By the 1980s, public sensitivity to the environmental impacts of geothermal development became important, and Wairakei became a case study of how surface activity is closely connected to the subsurface reservoir.

3 PROSPECTIVE VIEWS

Statistics N.Z. predicts the N.Z. population will grow by 1.4±1.0 million in the next 50 years. Which energy sources will provide the additional power? It is just as impossible to predict in 50 years time what the state of geothermal development will be, as it was in 1958 to predict where we would be today. We are entering an era of rising energy prices, the likelihood of a carbon emission-constrained world, and there are perceptions of limited future supplies of some traditional energy sources. In 1998, it was inconceivable that the oil price would rise ten-fold within a decade. This price rise has stimulated the development of new drilling, exploration, and production technologies in the oil industry. Today's cutting edge oil industry technologies could be tomorrow's geothermal industry technology. A few of these developments are briefly mentioned below to stimulate thought about geothermal development over the next 30 – 50 years.

2.1 Vertical and Horizontal Drilling

Most wells at Wairakei field are less than 1.5 km depth, and we know relatively little about the field below 2 km depth (Figs 1, 2). Fig. 1 is a Utah example of how economics directly affect drilling depths: it shows how a large increase in the oil and gas price has doubled the rate that wells are being drilled, and greatly increased the number of deep wells (345 wells drilled below 2900 m in 2008 compared to 6 in 1998). There are land-based gas wells in the US that now produce from 6 – 7 km depth (Wyoming, Oklahoma). A producing oil well drilled by Statoil in the North Sea recently

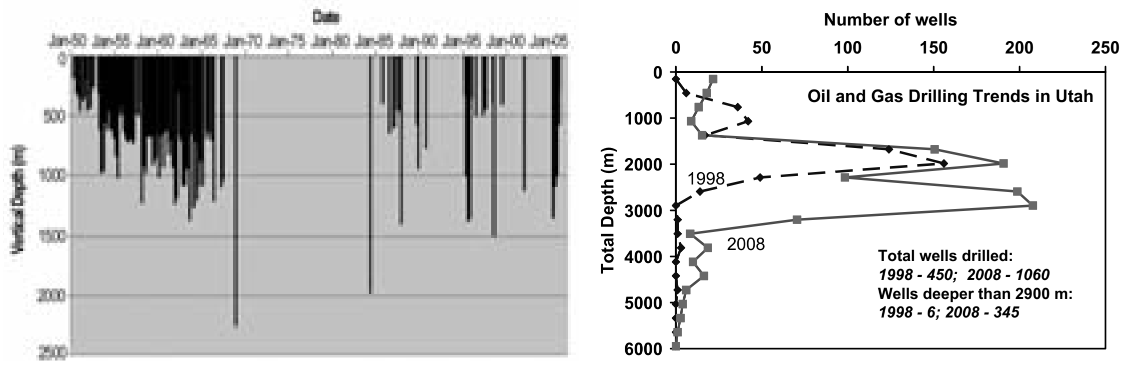

Figure 1. (Left), Drilling depth history of Wairakei Field (Clotworthy, 2006); (Right), Increase in drilling depth in Utah in the last decade as a result of a ten-fold increase in oil and gas prices.

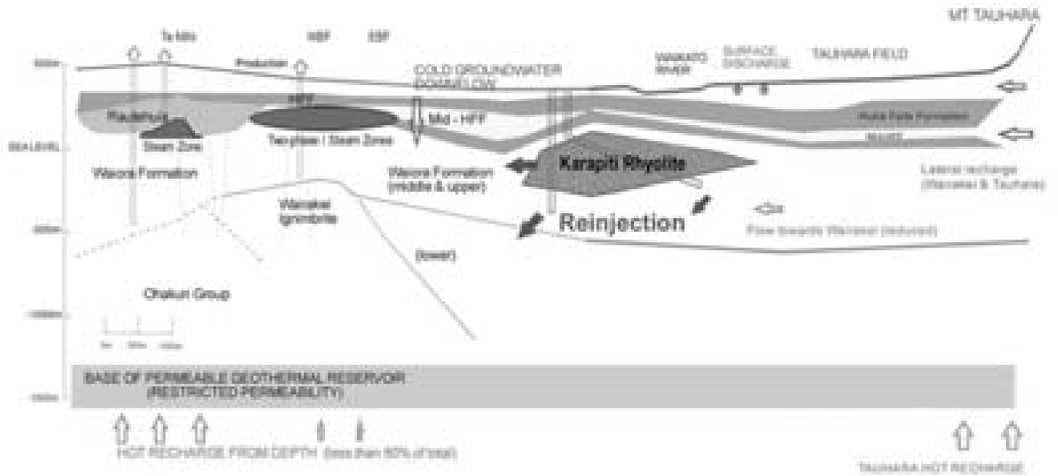

Figure 2. Stylized NW-SE section across the Wairakei-Tauhara system showing flow regime since injection began in 1997. Very little is known about the thermal regime and geology below 2 km depth (Clotworthy, 2006).

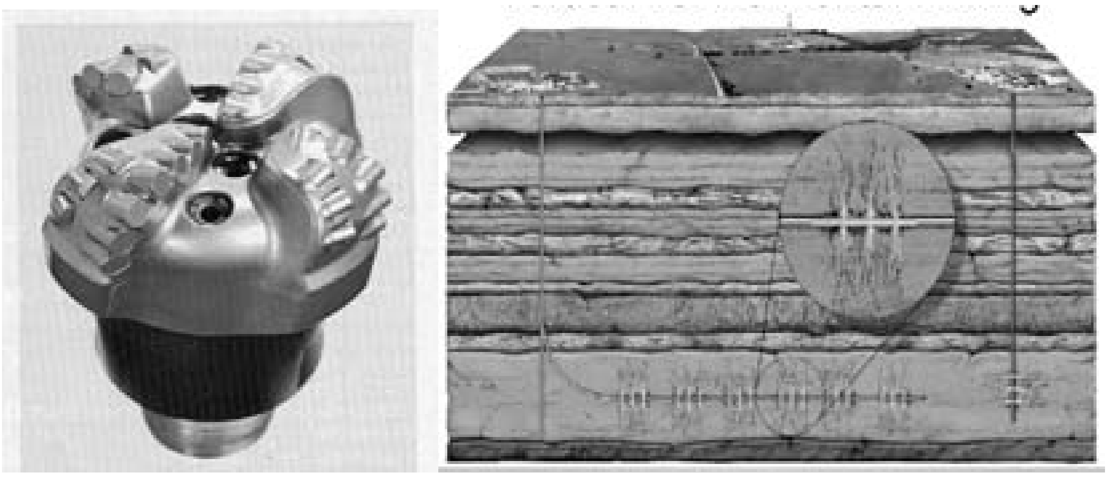

Figure 3. (Left), New design of drill bit capable of drilling 2 km in one run (Reum et al., 2008); (right), hydrofracturing with 5 – 20 stages is now common in tight gas reservoirs (IOGAP, 2008).

set a record of 10 km of lateral offset. Air was used as a drilling fluid, (Statoil website, 9/2008). New drill bit designs are dramatically reducing drilling costs (Fig. 3), with bits capable of 2 km of drilling without pull-out (Reum et al., 2008). These examples show that if the future electricity price in N.Z. rises substantially and technology costs decrease, the opportunities for harnessing the vast geothermal resource at depth beneath the TVZ will increase greatly.

2.2 Hydrofracture Technologies

Large volumes of relatively impermeable, hot rock are frequently encountered at depth beneath production reservoirs in many fields. Technologies for developing tight oil and gas reservoirs have evolved rapidly over the last decade. In particular, multi-stage hydrofracturing of both vertical and lateral legs is now common in such reservoirs (Fig. 3). Fracture stages, each no more that several hundred m in length, may total from five to >20 in a well, and have been found to greatly improve well productivity or injectivity (Pinnacle Technologies, 2006; Eberhard and Mullen, 2004). Although very expensive for the geothermal industry at the moment, these technologies have the potential to greatly expand reservoir volume, and therefore accessible heat.

2.3 Engineered Geothermal Energy

What used to be called hot dry rock, or today is known as engineered geothermal systems (EGS), involves artificially enhancing rock permeability so that cooled fluid from a power plant can be forced through hot rock to extract the heat. So far, demonstration projects have been limited to short connections at depth between several wells, and modest, short-term electricity generation. In many developed geothermal systems around the world, injection wells are typically located in a few places around the margins of the field, and it is hoped that cool injection water does not short circuit to production wells along a few major fractures. The examples of today's engineered oilfield reservoirs may be models for future EGS developments, which may be used to extend the life of traditionally-produced fields. Fig. 4 shows the well layout of a large oilfield in Utah (Monument Butte, 3.4 million barrels oil/year, DOGM, 2008). The number of injectors and producers are about equal, and injection rates per well average about 1 tonne/hour. Each well is typically hydrofractured at seven depths to ensure oil and water flow throughout the reservoir.

4 CONCLUSIONS

In the late 1950s and early 1960s Banwell (1961) recognized that the Wairakei resource had ample energy to sustain the power plant for several decades. Although subsequent drilling confirmed that high temperatures extended farther west than originally appreciated, it was the magnitude of the pressure drawdown in what we now recognize as relatively shallow production wells that caused the size of the plant to be restricted to 160 MW. Half a century later, the power plant is generating at capacity, and the thermal regime at about 1 km depth (Fig. 5) is similar to what existed prior

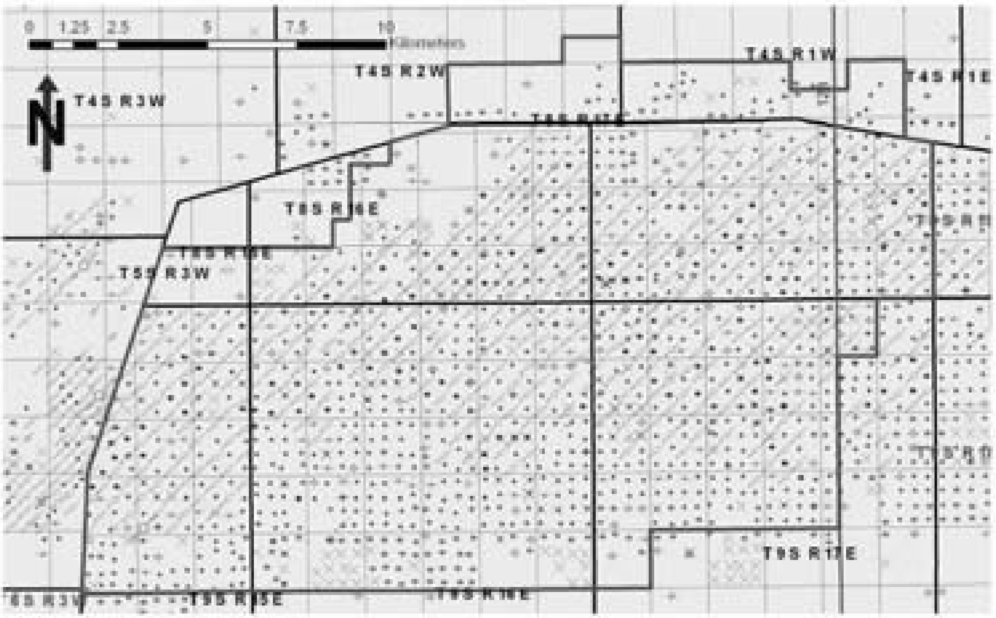

Figure 4. Example of oil field (Monument Butte, Utah) engineered for optimum sweep of oil from relatively tight reservoir using injected water. Most wells are hydrofractured in seven stages. Each injector (open circles with diagonal arrow) typically receives only about 1 tonne/hour of water. In many parts of field, the numbers of producers (small dots) and injectors are about equal. Map supplied by Utah Division of Oil, Gas, and Mining.

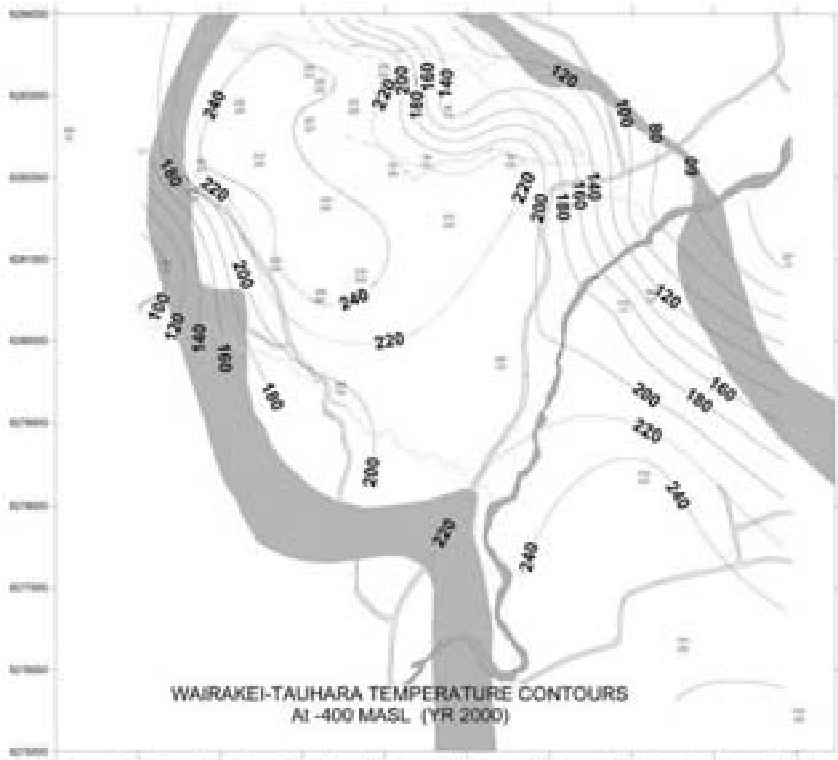

Figure 5. Isotherms (°C, in 2000) at about 1 km depth in the Wairakei-Tauhara system (modified from Clotworthy, 2006). Shaded zone is resistivity boundary at about 500 m depth. Small numbers are well numbers (upper) and temperature (lower).

to production. The 220°C contour is about 90 % of its original area, and the 240°C contour is about 60% of the original area (Clotworthy, 2006). Temperature declines at shallower depth are generally larger, but at greater depth, the declines are generally smaller. When we consider the technological possibilities of deep drilling available today, and the technologies likely to be available in the future, the Wairakei resource can still be considered as vast. I am convinced that in 50 years, Wairakei field will still be producing electricity, and there will still be a substantial thermal resource at depth. If we accept that "sustainability" means not compromising the needs of future generations, Wairakei will be a shining example of how geothermal power is indeed a sustainable energy resource.

5 ACKNOWLEDGEMENT

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