DRILLING HISTORY AT WAIRAKEI

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SUMMARY

Exploration of the Wairakei geothermal field began prior to 1950. An overview is provided of the drilling undertaken fiom the initial investigations to the celebration of 40 years of power generation. Changes in drilling methods and equipment are discussed and a summary of the events leading to the classic well failures WK26 and WK204 is provided.

1. INITIAL DRILLING

Prior to March 1950 the Department of Scientific and Industrial Research (DSIR) had drilled a few bores to provide steam for the Wairakei Hotel. These initial wells were drilled without any pressure control equipment, the procedure being to drill until steam was tapped and then withdraw the drilling tools as quickly as possible, hoping that the column of water would not be blown out before the drillstring was withdrawn (McMillan).

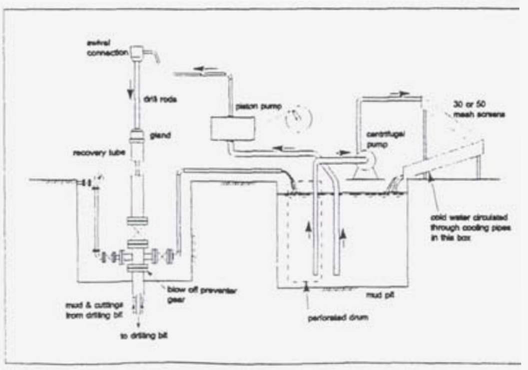
After this initial drilling by DSIR, the Public Works Department (PWD) assumed responsibility. Drill superintendent R McMillan, who was on secondment fiom the Mines Department, prepared designs for pressure control equipment (a stuffing box) which was manufactured in the workshops at Mangakino. Initial drilling was undertaken using three Sullivan 37 rotary drillrigs owned by the PWD. These rigs could drill to 130m (750 ft). Drillpipe was flush joint 2 $^3/_8$" "N-Rod" capable of passing through the stuffing box. The general drilling arrangement is shown in Figure 1. A heavier drillrig, a Failing Holemaster capable of drilling to 450m (1500 ft) was sourced from the Mines Department.

Drilling of WK1 commenced in May 1950 using the Sullivan 37 drillrig. Features of this drilling phase were:

- Wooden Cellars were used.
- Drilling was on a one shift, 5 day week basis.
- All drilling was undertaken with a core barrel.
- When it was considered that the core had sufficient strength the hole was enlarged using a larger core barrel prior to running 6" casing.
- The importance of multiple casing to withstand BPD conditions was accepted.
- Casing was class "C" steampipe.
- Non-return valves were used at the bottom of the drillpipe.
- Wells were not lined.
- The importance of fill cementing of the casing was appreciated at an early stage.

A further two Failing rigs were acquired. In the initial investigation phase some 22 wells were drilled at depths of up to 460m (1506 ft). Two of the rigs remain in service today.

Figure 1 – General Drilling Arrangement



2. DEEPER DRILLING

Even though the Failing rigs were performing very well it became apparent that drilling rigs of a larger capacity were required. Two National Ideal T12 drilling rigs were acquired by the successor to the PWD, the Ministry of Works (MOW). The drilling of WK20 commenced in November 1952.

The features of this deeper drilling were (Craig, 1961; Fisher, 1961):

- Drag bits were initially used to drill the larger diameter upper sections but were soon replaced by tricone drillbits.
- Tricone drillbits were used to drill the lower sections. These were often rebuilt until the bearings wore out.
- The cooling tower was introduced.
- The cementing was done with the Ideal C150B downhole pumps.
- The casing programme was:
  - Surface (13 3/8") to 12m
  - Anchor (10 5/8") to 75m-180m
  - Production (8 5/8") to 300m – 450m
  - Open hole 7 5/8"
  - ie. larger open hole size
- The initial wells were not lined with a slotted liner.
- Liner was introduced on a regular basis during the drilling at WK52 in April 1957.
- Blowout prevention equipment was used as we know it today. This included Shaffer mechanical double gate units and an annular preventor.
- The maximum diameter of casing which could be run through equipment was 10 5/8" O.D. A drilling through valve below the wellhead equipment was also used.
- Drillpipe (3-1/2" diameter) was used with the upset tool joints.
- Casing float shoes on the bottom were used.
- Both liner hangers and the "J-Slot" were initially used but the J-Slot quickly became the preferred method to run the slotted liners.
- If the grout failed to reach the surface the annulus between the two casings was filled with grout through tubing fiom the surface.
- Cement grout comprised construction grade cement, 3% bentonite and a concrete grade plasticiser.

Consolidation of the drill sites was introduced in the very early stages for wells drilled by the T12 drillrigs. The pattern adopted remains essentially the same today. Concrete cellars were introduced at about the same time.

Problems fiom collapsed casing were encountered with water being trapped between casings, eg. at WK20.

Deep cellars were used so as to provide sufficient room for the BOP equipment. Deep cellars were a safety hazard and shallow cellars were introduced in 1966, ie. after all the initial production drilling was completed.

Problems were encountered with the short round thread casing pulling out of the coupling and becoming misaligned. The problem was solved in October 1958 at WK58. A sleeve was welded to the top of the coupling, and the bottom of the coupling welded to the casing. If the casing was going to part, the lower end was constrained by the sleeve of the protruding coupling above the lower length of casing and this allowed drilling tools to be run in the well.

Long round thread was used initially at WK68 in January 1961, still with extended sleeves. Problems were still encountered with the long round thread couplings but they were not as bad as the short couplings.

Buttress threaded casing was introduced in a composite production casing string at WK71 in June 1962. This composite string ran both short and long threaded casing still with welded sleeves. Although used in a number of wells in 1962, generally as a composite string, it was not regularly used until 1965 and, in fact, was used in only eight wells including WK121, the deep well.

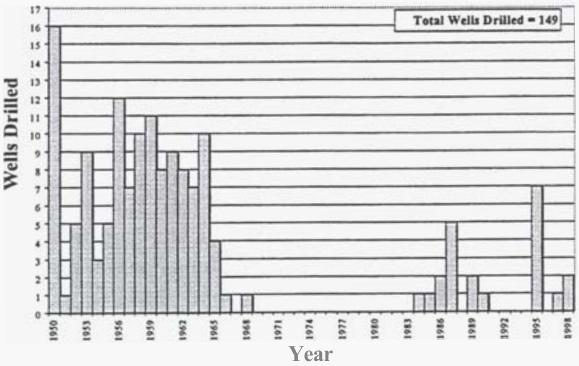
18"/13 3/8" casing was introduced at WK72 in January 1961. 22" casing was introduced at WK65 in October 1964 and used only at WK109 and WK121 in the initial drilling. 22" enabled an additional string of cemented casing to be run without requiring a large BOP system.

Perforating of unproductive wells was attempted with limited success despite the upgrading of the equipment in 1966.

Pilot wells were often drilled adjacent to the main well to depths of 216m (710 foot) in the 200 series wells (from January 1961 to April 1964) before it was realised that they were of limited value.

Drilling activity is shown in Figure 2. This shows that up to 12 wells per annum were drilled and production drilling was completed in 1965 as the drilling resources were deployed to other investigation fields.

Figure 2 – Wairakei Borefield Drilling History



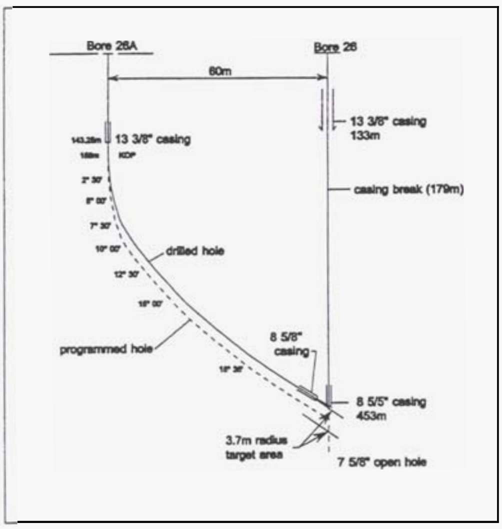
3. THEFAILURES

3.1. WK26

The 8 $^5/_8$" casing failed at 179m allowing well fluids to enter the formation and find their way to the surface. An extensive area surrounding the well was displaced in a series of eruptions. The blowout threatened a number of wells which had been drilled but not connected into the steamfield.

Eastman from the USA was commissioned and, after acceptance of the proposal, deviation equipment including whipstocks, monel drillcollars and downhole survey equipment were acquired. A new site, WK26A, was prepared some 60m fiom WK26. This well was drilled in 25 days in November 1960. The well was a success with WK26 intersected within the 3.7m window. Water containing fluorescent tracer was pumped into WK26A and detected in the surface fissures. Refer Figure 3 (Craig, 1961). Grout was then pumped into WK26A to the well bore area of WK26 and the well successfully sealed.

Figure 3 – WK26 and WK26A



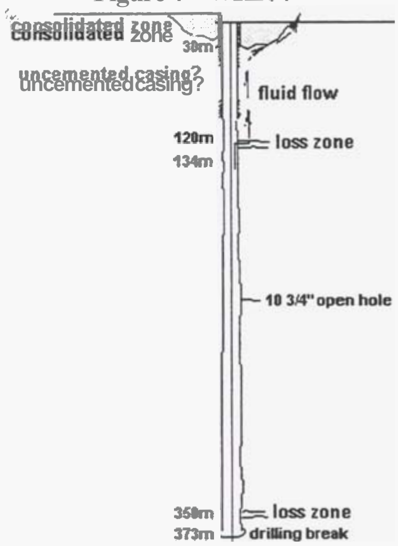
The equipment acquired for WK26A enabled accurate logging of all future wells.

3.2. WK204

The drilling programme called for 16" casing to 30m, 11 ¾" casing to 120m and 8 $^5/_8$" casing to 300m. The 11 ¾" was run as planned but required 6 times the casing annulus volume to cement. It was suspected that the annulus was not correctly cemented. Drilling proceeded to 300m with major losses at 134m. The low temperature of the mud returns resulted in drilling continuing without running the 8 $^5/_8$" casing. Circulation was lost at 350m. Attempts (over several days) were made to regain circulation, each time deepening the well until, at 373m, the bit dropped 1.5m. Further attempts were made to regain circulation. Failure of the pumps allowed the well to heat up and come under pressure while tripping out. Some 7 ½ hours later, steam appeared 30m fkom the drillrig (Bolton, 1961). Bolton suggests that the well pressure was sufficient to break down the formation at the 134m loss zone. Fluid then flowed to the surface by means of the uncemented length of 11 ¾" casing. On reaching the consolidated area the flow was diverted to the edge of the zone. There was sufficient time for the drilling equipment to be removed and then a large crater formed, larger than the entire drillsite.

Graphically this is shown in Figure 4.

Figure 4 – WK204



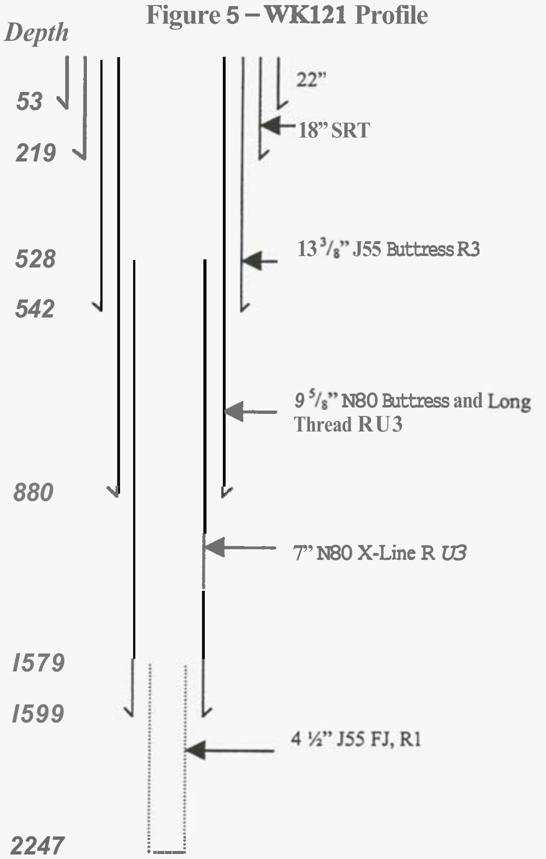
4. THE DEEP WELL WK121

In order to investigate the Wairakei field and other fields at depth a larger drillrig, the Continental Emsco GC350, was purchased and the drilling of WK121 commenced in June 1968. The well was drilled as shown in Figure 5.

Features of the GC350 were:

- The much larger D550 downhole pumps.
- Rotary Table 27-1/2" instead of the 17-1/2" on the T12's
- Drillstring was 4 ½" O.D. x 16.6 lb/ft
- A 20" BOP stack was introduced
- Improved instrumentation
- Koomey accumulator system

Figure 5 – WK121 Profile



5. DRILLING MUD AND CEMENTING

The drilling muds in the initial investigations consisted of a bentonite water mixture. Clay (from a source near Wairoa) was then added to the base mud to increase the density and supposedly to reduce the viscosity.

In the early days, while there was a general understanding of desirable properties in a drilling mud, lack of experience, of equipment and, most importantly lack of access to high quality mud materials made the production of a really satisfactory drilling fluid difficult. Because so called "suitable" local materials were available, the MOW was prohibited from importing Wyoming bentonite.

Porangahau bentonite from Hawkes Bay was initially favoured because it had low gel strengths, produced a higher density mud and had marginally better thermal stability. Unfortunately this bentonite had a very low yield, a large quantity was required to provide a mud of sufficient viscosity. In the early 1960's the higher yielding bentonite from Colgate, Canterbury, called Hororata bentonite (later to be known as Rheogel Bentonite) was experimented with. This bentonite was believed to produce high progressive gel strengths and considerable effort was put in to reduce these by blending increasing concentrations of Porangahau bentonite with it. It was finally concluded that neat Porangahau was the best option and a drilling mud using this bentonite, as the base material was used to drill all the initial wells. Extensive testing in the early 1980's using equipment which was more suited to downhole conditions was undertaken to disprove those early theories. Porangahau bentonite was replaced with the higher yielding Rheogel bentonite, chrome modified lignosulphonates and lignites. This formulation was used with great success up until the mid 90's. The chrome modified products provided increased temperature stability enabling excellent rheogical control. More recently the use of chromium products has lost favour for environmental reasons. Now more expensive but higher quality imported Wyoming bentonites are used, which have higher temperature stability and do not require chromium modified additives to control rheology.

The cement slurries used today are basically the same as those used in 1950, despite some major reviews. However major changes have occurred in mixing and placement technology. In 1950 the bags of cement were fed along a chain gang (24 men) and cut into a jet hopper. The mixing of the cement was done by one of the rig pumps while the other rig pump was used to pump it down hole. Vertical silos', allowing the use of bulk cement, were acquired after the initial drilling. However the major quality improvement did not come until the arrival of a Halliburton SKD-5 cementing unit and 8 pressurised "P" tanks. The cementing unit consists of two triplex pumps, two 1500 litres water tanks and a recirculating cement mixer (RCM). This enabled preblended cement from the "P" tanks to be mixed and pumped down hole at controlled densities and flow rates. Slurry volumes, flow rates, density and pump pressures are monitored continuously from the operator's console. Specialist additives are dry blended with the cement to control setting times, fluid loss and viscosity.

6. EQUIPMENT UPGRADES

A major upgrade was undertaken on the GC350 in 1980 after it had drilled only two geothermal wells (WK121 and BR15) and a number of oil wells. This work included:

- Provision of a Mack field truck
- Halliburton cementing unit including HT400 pumps, recirculating mixer, pressure cement tanks, compressors and handling equipment.
- The provision of the Iron Roughneck
- Major upgrade of the desanders, desilters and mud mixing unit.
- The provision of the "parallelogram" substructure so that the drawworks was elevated.

Additions and modifications of significance since then have been:

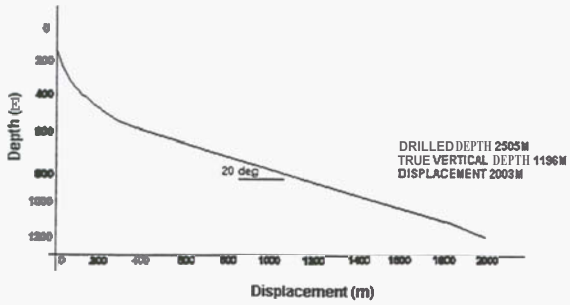
- Upgrade of the Koomey BOP accumulator, increasing the capacity by 50%
- Modifications to the C150B mud pumps.
- Electrification of the transfer pumps.
- Installation of the GC350 27 ½" rotary table onto the T12
- Provision of linear motion shale shakers

By 1997, the mud handling equipment, the D550 mud pumps and the generator system from the GC350 drilling setup was commonly used with the T12, and markedly improving performance.

7. THE LATER YEARS

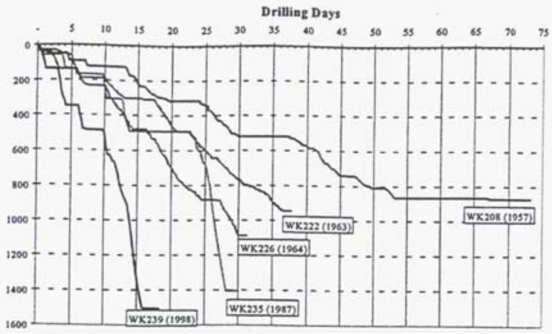
After the poor results at WK121 no further production drilling was undertaken until the mid 80's (not that the two are necessarily related) when it became necessary to drill make up wells, with WK228 (1985) and WK229 (1985) being completed. The first reinjection well WK301 was drilled in 1984. A total of 10 reinjection wells has now been drilled, a significant feature for some wells being the profile. A typical profile is given in Figure 6 for WK306.

Figure 6 – WK306 Profile



Production wells, both steam and liquid, continue to be drilled mostly with the National T12, which has been significantly modified since 1952. Drilling performance has improved. Timelines for random 200 series wells are provided in Figure 7.

Figure 7 - Well Comparisons



All the wells drilled for the Wairakei Power Project have been completed by the Ministry of Works and Development and its successors except WK305, WK306, WK307, WK308, WK309 and WK310. These long reach reinjection wells were drilled by the Parker Rig #228 which was significantly larger again than the Continental Emsco GC350.

8. CONCLUSIONS

The glanded BOP equipment built under Mr McMillian's supervision prior to the initial investigations is still used today. It is also remarkable that the two Failing rigs and one National T12 rig are still being used. Many parts have been replaced more than once, eg. the Failings have now had their third carrier. Use of the 27 ½" rotary table and the D550 pumps and modem mud handling equipment has made a significant difference to the drilling performance of the National T12. It is even more remarkable that drillcrews still enjoy their experience working on the "T12".

9. ACKNOWLEDGEMENTS

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