DEVELOPMENT STRATEGY FOR NGAWHA

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ABSTRACT

Ngawha geothermal field in Northland differs from the explored fields of the Taupo Volcanic Zone in a number of ways. It has a capped reservoir, and it appears that there could be little or no recharge laterally from groundwater. The reservoir rock is fractured greywacke, and has low porosity. These factors mean that the large heat store in the reservoir might not be fully producible, for lack of water to carry the heat to surface.

Delineation by drilling will not of itself determine the extent to which the reservoir's electric power potential may be limited by its fluid reserves. A substantial discharge will. It is proposed that a back-pressure turbine be installed in the next year. Provided that over 100 t/h of steam is withdrawn from the reservoir for three or more years, reservoir properties should be fully defined when it is time to design a power station.

PART 1. THE RESERVOIR

INTRODUCTION

Scientific work from all disciplines has been published in a recent report. The following material is adapted from that report (DSIR 1981), and in particular from Grant (1981).

The geology of the field appears deceptively simple. A caprock of poor permeability overlies greywacke. (Skinner & Grindley, 1980) Within this greywacke, some wells encounter fracture zones of very high permeability. Figure 1 is a map of the field, showing the wells drilled to date, and isotherms at the base of the caprock.

The chemistry of the surface activity is predominantly steam- and gas-heated, with only small discharge of chloride water. Well NG1 was drilled in 1965 to 580m, just below the cap. It produced a small flow of high enthalpy and gas content. For these and similar reasons, there has been a persistent feeling that there could be a vapour-dominated reservoir at Ngawha.

LIQUID-DOMINATED RESERVOIR

The reservoir is however liquid-dominated. The wells stand full of water,

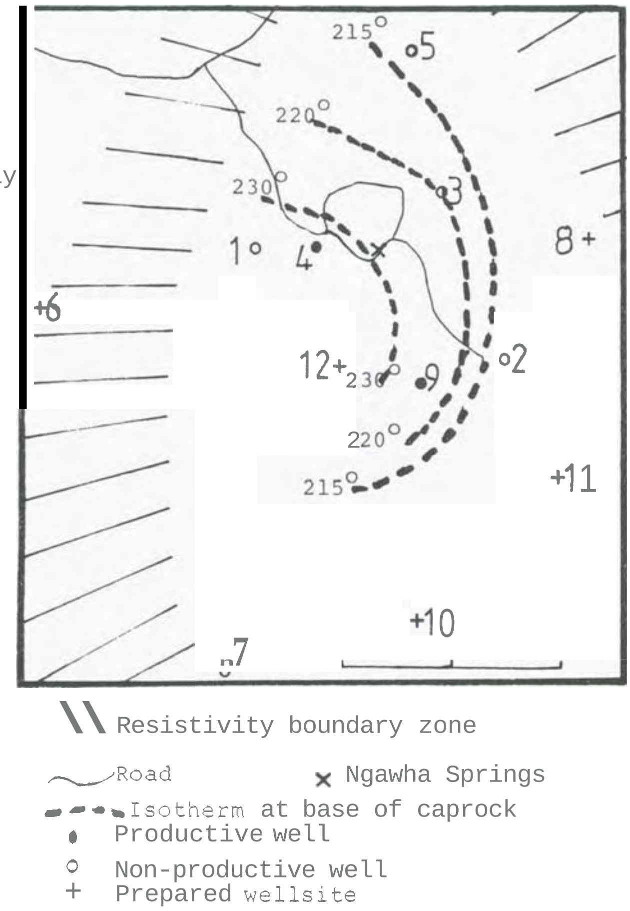

FIGURE 1 SKETCH MAP

and the productive wells discharge chloride water. Downhole profiles show water entering the wells, and measured enthalpies are close to downhole water. Figure 2 shows a plot of reservoir pressures, determined at the feedpoint(s) of each well, against depth. Within the reservoir there is a gradient of 8.0 kPa/m, or hydrostatic at 237°C. At the base of the caprock, RL-250m, pressure is 55bg, giving a gradient of 11 kPa/m over the 500m thickness of the caprock, confirming that it is a cap. This

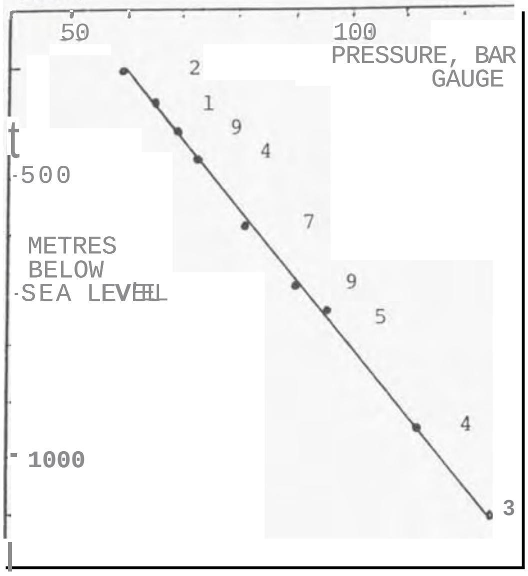

FIGURE 2 RESERVOIR PRESSURES

is in direct contrast with Wairakei and Kawerau, where the original reservoir pressure was linear to mean ground surface.

RESERVOIR TEMPERATURES AND FLUID

Downhole temperatures divide the wells drilled to date into two categories. NG2 & 5 have temperatures that increase steadily, if slowly, with depth. NG4 & 9, and to a slight extent NG3, have downflows of water between permeable zones. These downflows disguise the reservoir temperatures; but it appears that these temperatures do not increase with depth as they do in NG2 & 5. The highest temperature to date is 251° at the bottom of NG5. In the productive wells, temperatures are in the range 225-230° in their productive interval. (A shallow hot spot is present in NG4 just beneath the cap) NG7 is peripheral and finds temperatures increasing to a maximum of 190°. NG1 was drilled to just below the cap, and found 236°.

The reservoir fluid in the productive wells is liquid water, at 225-230°, and containing 1-1.2% of carbon dioxide. In NG2 & 5, and the shallow peak at NG4 and NG1, the reservoir fluid is two-phase. Boiling conditions are possible at the low temperature and high pressure because of a very high gas content.

CONCEPTUAL MODEL

Figure 3 shows a conceptual model of the natural state of the field. There is an upflow of boiling, gassy fluid in the east and north of the field. Thus the isotherms in figure 1 do not indicate the position of the upflow. As it strikes the caprock, this upflow spreads laterally. Temperatures at the base of the caprock at NG5 are low because of high gas content. Higher temperatures are encountered at this depth in NG1, as the fluid here is comparatively degassed. The natural upflow consists largely of vapour; hence the appearance, in the surface chemistry, of a vapour system. This vapour flow rises together with a slower flow of water. The natural flow resembles bubbles of steam and gas rising through almost static water.

In the west and south of the field is a region of liquid water. This has flowed downwards and outwards from the boiling upflow, and this region of the field contains fluid of very uniform temperature and chemistry. This is also the region of high permeability, to date.

The pressures support this model. The vertical gradient indicates that 225-230° water must be flowing downwards. There is also a slight lateral pressure trend, with NG5 being slightly higher in pressure and NG7 slightly lower.

PERMEABILITY

Permeability structure in the reservoir can be partly estimated from well tests and the natural discharge of the field. 30 MW of heat is discharged by conductive loss. This must be transported from the reservoir as vapour. Taking a separation condition at the base of the cap as 60 bar, 235°, the flow required is 20 kg/s of CO_2 and 10 kg/s of steam. This is the loss to surface. To this must be added an unknown amount of water that rises and recirculates - rising in the upflow area and descending in the downflow area. Assuming that the temperature maxima in NG5 and NG4 define a boiling trend, this amount of water is 10 kg/s.

Figure 4 shows a stylised field permeability model, with permeabilities estimated in the vertical and horizontal directions. The vertical permeabilities are estimated from the natural flows and the pressure gradient. Well tests show the existence of permeability that greatly exceeds the vertical, and so must be horizontally oriented. Permeability-thickness is determined for each well and averaged over the open interval to obtain a nominal permeability. As wells NG4 & 9 have permeability-thicknesses of more than 100 and 50 d-m repsectively, this results in a high permeability. There is also some permeability associated with the contact between the reservoir and its cap, encountered by NG1 & 2. The permeability model is thus divided into four zones: the cap, the contact zone, the upflow zone and the downflow zone. Of these only the downflow zone is of interest for production, so far.

PART 2. POSSIBLE CHANGES UNDER EXPLOITATION

POOR RECHARGE AND LOW POROSITY

The cap rock indicates that little inflow of groundwater from above can be expected under exploitation. As the field is underpressured with respect to cold hydrostatic from ground surface, and lies on a ridge, there does not appear to be good

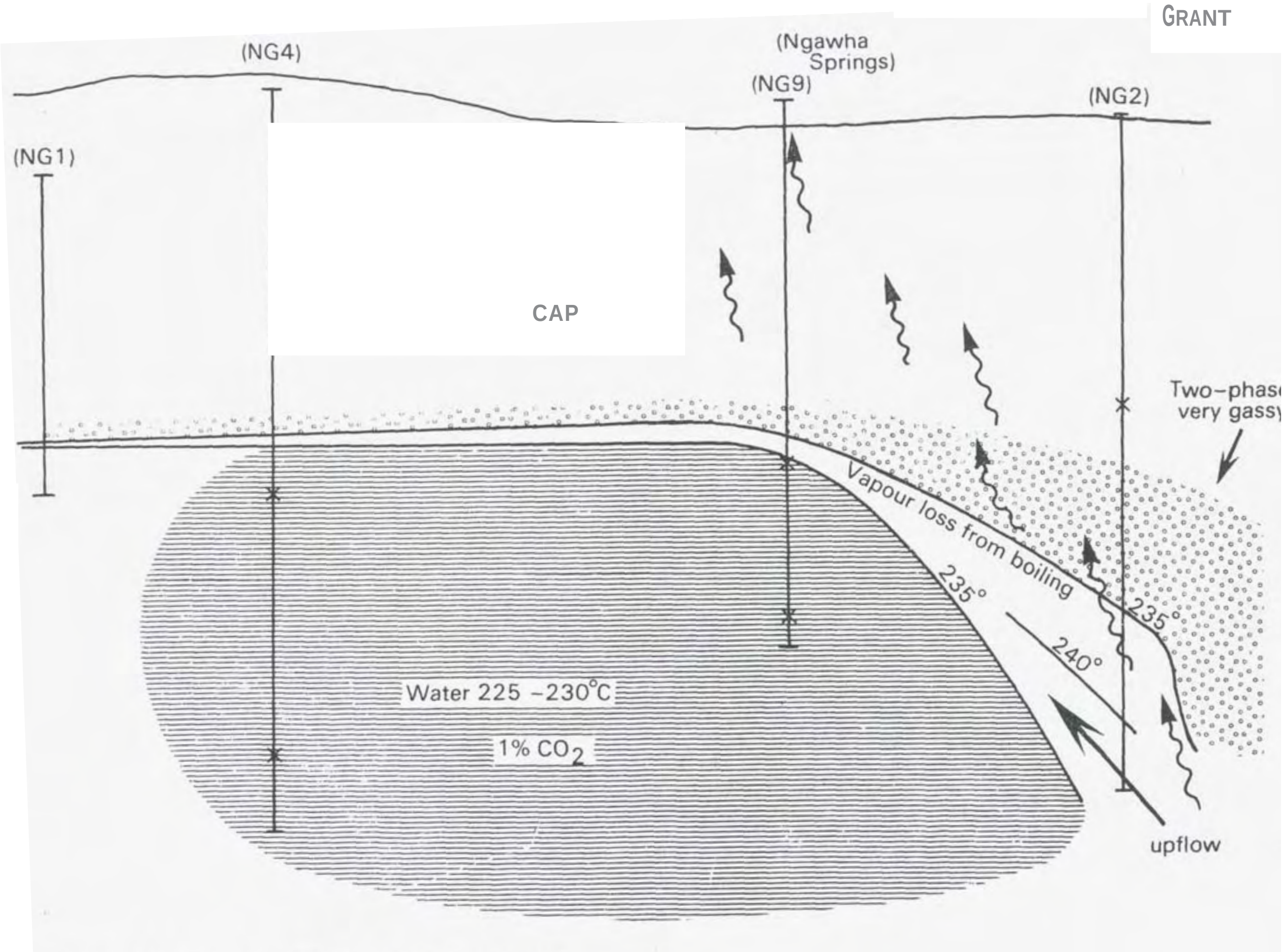

FIGURE 3 CONCEPTUAL MODEL

lateral contact with any groundwater aquifers. The poor vertical permeability argues against recharge from depth, which in any case has not been large at the more favourable fields of the Taupo Volcanic Zone. Thus there does not appear to be a likely source of substantial recharge, hot or cold, under exploitation.

The porosity of the greywacke is low: 3% is given from cores, and also by a mass, heat and CO_2 balance on the discharge of NG1. The maximum amount of heat would be extracted from the reservoir, given the constraint on water supply, if all the water were boiled to steam. Then 1 km^3 of reservoir contains 25Mt of water, and this would supply net consumption of 800 t/h of steam (a 100 MW station) for less than 4 years. In so doing, the reservoir would be cooled by about 20°C. It is unlikely that it would be possible to extract all the water, so that the reservoir's fluid supply is not

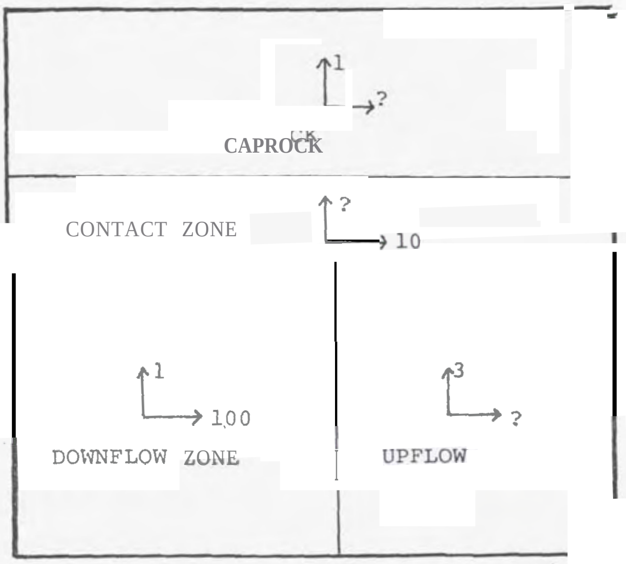

FIGURE 4 PERMEABILITY

(Approximate values in millidarcy)

sufficient to extract the bulk of the heat stored in the reservoir.

It has been the practice in New Zealand to estimate reservoir capacity on the basis of the stored heat content. At Ngawha, consideration of the fluid supply appears more important.

A SCENARIO OF CHANGES UNDER EXPLOITATION

Considering the reservoir at Ngawha as a permeable box containing water and dissolved carbon dioxide, figure 5 shows changes that could occur in the pressure profile under exploitation. It is assumed that once boiling occurs ("boiling" means the formation of a vapour phase of any composition) the reservoir drains to form a clear vapour-dominated/liquid-dominated interface ("water level"). This assumption is appropriate at Ngawha, where the temperature and boiling pressure of the reservoir fluid does not increase with depth. At a field like Broadlands, where boiling conditions are initially present over a large depth interval, drainage takes more time.

A is the initial reservoir pressure profile. The box is full of water, which is at boiling point at the top. This boiling point is 60 bar - 28 bar partial pressure of steam and 32 bar partial pressure of CO_2. B is the next profile, produced by the withdrawal of water by the wells. A free surface has formed, and a vapour zone at 60 bar is present above it. Once the water level has fallen below the feed point of one well, production of vapour from the vapour zone starts. This rapidly reduces the vapour zone pressure, by degassing effects. Profile C occurs partway through this porcess. Continued production of vapour may dry out the vapour zone, so that eventually a superheated zone, at very low pressure, forms. Profile D is the reservoir at abandonment. A low-pressure vapour zone is present, and water beneath it at too low a pressure and temperature for production.

Great changes can be expected in the fluid produced from the wells, especially the shallow-fedding wells. The present large discharges of 225-230^{o} water are not typical of the fluid discharge over the field hsitory. The flow of separated steam from a well could fall greatly, and its gas content could also change greatly, including a temporary period of gas content up to 70%, the amount in the vapour zone when it first forms.

PART 3. TESTING THE RESERVOIR

INTERFERENCE TEST

One possible means of refining the reservoir's properties is by interference test. For wells connected by a layer of confined liquid, an interference test will determine the permeability-thickness and porosity-thickness. The latter is just the total water content, per unit area, of the aquifer. Such interference would be

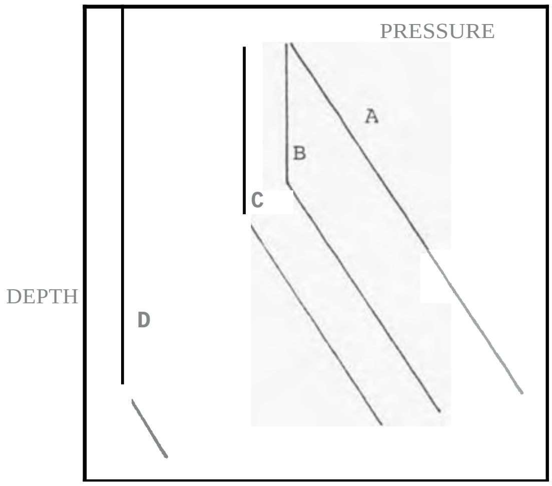

FIGURE 5 PRESSURE UNDER EXPLOITATION

possible at Ngawha with sensitive gauges, and would also provide some information about the lateral extent of the permeable zone. It should be a high priority to obtain appropriate instruments and execute such a test.

However this is not the full answer. Substantial changes in fluid distribution in the reservoir are expected, and these cannot in the present state of knowledge be predicted from theory and interference data. More conclusive observations would be obtained from discharge sufficient to form the hypothesized vapour zone in the reservoir, and from observations after its formation.

PROPOSAL

It is proposed that the most important next step in the investigation of Ngawha is the installation of a turbine exhausting to atmosphere, whereby discharge can be sustained over a period of years, sufficient to disturb the reservoir.

HOW LARGE A TURBINE?

Taking what at the moment appears a reasonable view, the productive area of Ngawha is guessed as 10 km^2. This would be sufficient to support a 100 MW station for over 30 years. The turbine should be large enough to disturb a reservoir this size. With a porosity of 3%, and complete drainage, net discharge (production minus injection) of 100 t/h would cause a fall in water level of 10m/year, or a pressure change of 1 bar/year. This is enough to be sure of detecting with repeat Kuster measurements; and 30m drop in 3 years should be enough to be sure that such a zone has formed.

100 t/h of steam is about the upper limit of a "small" turbine. At 5 bar 5 MW

would be generated. Alternatively the two Wairakei HP sets could be adapted to accept 75 t/h (each) at 7 bar, generating 4.9 MW each. The two sets together would take 150 t/h, which provides a margin above 100 t/h.

From the point of view of the reservoir test, the choice of turbine is irrelevant, provided that the net discharge is 100 t/h or more. Convenience and cost will decide the appropriate turbine.

WHERE?

NG9, with the dual completion removed, will supply 75 t/h at 7 bar. For convenience of pipelines and construction, generation could be based on NG9, and additional wells drilled nearby as neccessary. Injection could similarly be based on NG4.

As a consequence of this proposal, it also follows that the next target of drilling should be to supply the needed additional producers and injectors. After these wells delineation drilling across the field should continue as previously planned. Delineation wells in the possible productive area south and west cf NG4 & 9 should provide observation points for the effects of exploitation, and also test the extent of the productive area.

INJECTION

It has been implicitly assumed that waste water will be reinjected; and, more importantly, assumed that this water will be recycled by returning to the productive wells reheated to reservoir temperature. If this is not so the reservoir's fluid reserve is further reduced.

Because of the need to avoid thermal degradation of producing wells, all the arguments against close reinjection apply at Ngawha. One advantage of NG4 as injector and NG9 as producer is that these wells are respectively deep and shallow producers.

The hopefully large size of the Ngawha productive area means that, as at Wairakei, it should be possible to separate producers and injectors by a large distance of hot and permeable ground. The lack of such distance at Broadlands has meant considerable cost and effort to find places to inject waste.

If a superheated zone should develop after full-scale exploitation, there would then (but not before) be a need for shallow injection to recover heat from the dry rock. Injectors in the contact zone, like NGl, would be suitable.

SUMMARY

Because of its difference from known fields like Wairakei and Broadlands, Ngawha needs a different exploration strategy. A trial discharge is needed early in the exploration to define reservoir properties.

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