FLUID STATE AT WAIRAKEI

Malcolm A Grant
Applied Mathematics Division, DSIR
Box 1335 Wellington

Abstract

The initial fluid distribution at Wairakei is described, and its division into single- and two-phase tones. The effects to exploitation appear as a pressure drop in the deep, liquid-dominated part of the field, and the creation and enlargement of a vapour-dominated tone.

Introduction

A Considerable amount of modelling work has been done on Wairakei: Whiting and Ramey (1969), McNabb (1975), Mercer and Paust (1978), Marshall (1970), Pritchett et al (1976), Allis (1979).

The observed initial state of the field was described by Banwell (internal reports) and Elder (1966). Under exploitation the pressure has fallen more or less uniformly across the field (Bolton 1970). Nearly all the modelling and interpretation has used this pressure as principal or only datum for model verification. However, each model assumes, implicitly or explicitly, some distribution of pressure change and fluid state change with depth. Thus McNabb (1975), in a drainage model, assumes a vapour-dominated zone forms at the bottom of the two-phase region. Pritchett et al (1976) construct a model in which there are large saturation changer at production depths, and interpret much of the response in terms of where boiling occurs. Whiting and Ramey (1969) assumed that the reservoit vas entirely liquid.

It is easy to get a good fit to the history of the field pressute, and indeed the best fit is given by the zero-dimensional model:

$$l = ap + b\frac{dp}{dt}$$

As the various models cannot be discriminated by the pressure history, additional data is needed. Thus Whiting and Ramey (1969) fail becaure the imputed reservoir volume is far too large. Pritchett et al (1976) fail becaure their saturation changer imply large enthalpy changes, which have not occurred.

The object of the present work is to supply the deficit, with more detailed information about the initial state of the field, and changes in it. This work is only partly complete and this paper is a progress report, giving results to date and those expected later.

Analysis

The walls at Wairakei have never been analysed in the detail that is now usual at Broadlands or Ngawha. In part there is a deficiency of information, But the main defect is that present techniques of interpreting down hole measurements were not developed until after Wairakei's development.. The present project consists of a re-examination of all well measurements on all wells at Wairakei. This work is presently about 40 % complete. A complete set of interpretations will be published as a technical report, as will an explanation of the interpretation techniques..

Well data is analysed on the basis that each well has one or a few feed points, at which it contacts the reservoir fluid and pressure. Pressures elsewhere in the well merely reflect the fluid column in the well. With two feed points, there will be a flow in the well, or a two-phase column in the well, or a steam column overlying a water column.

For each well, its major feed point was identified. Pressures at that point in the wall were taken to give a history of reservoir pressure. Discharge was assumed to come from here, so that enthalpy history is also available ("enthalpy" means discharge enthalpy, or the flowing enthalpy in the reservoir (Grant Sorey 1979)). After the field is exploited, and the vertical pressure difference between two points is less than hydrostatic, a well will stand with a stem column over a water column, and field pressures are obtained at two points in the well.

When fluid flows up the standing well, it indicates that the vertical pressure gradient in the field exceeds hydrostatic. The fluid in this flow - boiling or non-boiling - also indicates whether two-phase or liquid conditions prevail. Nearly all early temperatures in Wairakei wells are measured in such a rtate, where the well contains an upflow of boiling water from near well bottom, and consequently do not reflect fluid temperatures except near well bottom.

With the development of interpretation techniques, steadily greater emphasis has been placed on fluid flow in the well' disguising true reservoir values. Particular care has been taken here to use all the check data that exists. Many of the very early wells were drilled and tested in stages, often quite small rtages. "here were also temperatures during drilling. Later, some wells were deepened, or plugged and perforated. These measurements provide undisguised depth profiles, for comparison.

Results

Figure 1 shows a cross-section of the field in its initial state. The cross-section tuns from neat the powerhouse, up to well 3 and 219. Data used is from 1950 to about 1955-56. Several different contours are plotted. At tha bottom is a 250° contour. This is in liquid water. Some distance above this two-phase conditions are encountered. The next contour is the 1100 J/g isenthalp in two-phase. With in this is a 1200 J/g isenthalp. Both isenthalps refer to tho enthalpy of the (horizontally) flowing fluid in the reservoir. Marked wlth a double line is the top of the two-phase zone. Above this is again liquid vater. Temperature, higher than 250° are encountered above the 250° isotherm. There is a horizontal component in the aatural flow, and this fluid dervies from off thir section.

The near-surface conditions are quite interesting, Over most of the field cool or cold water occurs in the top 100-200 m. This is presumably maintained by contact with groundwater. Near natural discharge vents, hot or two-phase conditions reach surface. However even here there is a contrast with the deeper consists of a re-examination of all well measurements on all wells at Wairakei. This work is presently about 40 % complete, A complete set of interpretations will be published as a technical report, as will an explanation of the interpretation techniques..

Well data is analysed on the basis that each well has one or a few feed points, at which it contacts the reservoir fluid and pressure. Pressures elsewhere in the well merely reflect the fluid column in the well. With two feed points, there will be a flow in the well, or a two-phase column in the well, or a steam column overlying a water column.

For each well, its major feed point was identified. Pressures at that point in the wall were taken to give a history of reservoir pressure. Discharge was assumed to come from here, so that enthalpy history is also available ("enthalpy" means discharge enthalpy, or the flowing enthalpy in the reservoir (Grant Sorey 1979)). After the field is exploited, and the vertical pressure difference between two points is less than hydrostatic, a well will stand with a stem column over a water column, and field pressures are obtained at two points in the well.

When fluid flows up the standing well, it indicates that the vertical pressure gradient in the field exceeds hydrostatic. The fluid in this flow - boiling or non-boiling - also indicates whether two-phase or liquid conditions prevail. Nearly all early temperatures in Wairakei wells are measured in such a rtate, where the well contains an upflow of boiling water from near well bottom, and consequently do not reflect fluid temperatures except near well bottom.

With the development of interpretation techniques, steadily greater emphasis has been placed on fluid flow in the well' disguising true reservoir values. Particular care has been taken here to use all the check data that exists. Many of the very early wells were drilled and tested in stages, often quite small rtages. "here were also temperatures during drilling. Later, some wells were deepened, or plugged and perforated. These measurements provide undisguised depth profiles, for comparison.

Results

Figure 1 shows a cross-section of the field in its initial state. The cross-section tuns from neat the powerhouse, up to well 3 and 219. Data used is from 1950 to about 1955-56, Several different contours are plotted. At tha bottom is a 250° contour. This is in liquid water. Some distance above this two-phase conditions are encountered. The next contour is the 1100 J/g isenthalp in two-phase. With in this is a 1200 J/g isenthalp. Both isenthalps refer to tho enthalpy of the (horizontally) flowing fluid in the reservoir. Marked wlth a double line is the top of the two-phase zone, Above this is again liquid vater. Temperature, higher than 250° are encountered above the 250° isotherm. There is a horizontal component in the aatural flow, and this fluid dervies from off thir section.

The near-surface conditions are quite interesting, Over most of the field .cool or cold water occurs in the top 100-200 m. This is presumably maintained by contact with groundwater. Near natural discharge vents, hot or two-phase conditions reach surface, However even here there is a contrast with the deeper reservoir, At depth, both at Wairakei and other fields, fairly homogeneous two-phase fluid is found. The steam and water are quite well mixed. Near surface the phases are much more prone to separate, with distinct flows of steam and water. There is a very patchy, criss-cross flow of steam, hot water and colder waters.

Figure 2 shows a vertical section, initially and in 1972. The initial pressure distribution corresponds to a gradient about 1.1 x hydrostatic, as has been found before by McNabb.

The first well drilled in 1950-51, were shallow and there is no discernable effect of their discharge, except upon each well itself. Deeper drilling and discharge, began in 1953. The first observable field response was the reduction of the natural discharge, in 1953-54. Natural features are very sensitive to deep production (Grant in Prep). A general drawdown is perciptible in 1955-56, after the natural discharge was severely affected. This drawdown, located principally within the two-phase zone, grew. In 1958 a vapour zone first appeared it grew and spread across the field, and was full established by 1962. Since then the vertical pressure profile has been of stable shape. The top segment AB is little disturbed. BC is the vapour zone, contains steam and water of low mobility (i.e. two-phase vapour-dominated). Beneath this is a two-phase liquid-dominated segment CD, and then liquid DE. The vertical pressure gradient in the liquid-dominated section CE still exceeds hydrostatic. Within the two-phase zone there is an enthalpy profile from liquid rising to about 1300-1400 J/g at the inerface with the vapour. It is hoped to define this profile accurately. The"corners" B and C are not defined accurately by the data, so it cannot be said how sharp are these interfaces. There is in places a two-phase zone above the vapour.

There has been production of saturated steam from the vapour zone. Because of this, there is a pressure gradient in it, towards the production area; and its pressure has steadily fallen. In fact the vapour zone pressures are probably now controlled by the pressures on the HP steam line, As the vapour zone pressure has fallen, this zone has risen, so that it is in places less than 150 m from the surface. Note this is above the mudstone. The mudstone does not appear to have any influence on field behaviour.

There is much evidence of the advance of cold water into the field. Peripheral wells, such as 23 and 35, show shallow cooling water moves inwards. Wells such as 31,101,107 have been killed by cold intrusions. There are also high-enthalpy wells whose enthalpy has fallen, and wells producing from the vapour zone show the presence of mobile water; this water must be moving downwards. It appears that there is some entry of cold water, through the vapour zone, and into the deeper reservoir. It is hoped, by studies of enthalpies and hence mobilities of the two phases, to estimate the downflux of water.

The enthalpies of up to 1400 J/g in the 'liquid-dominated two-phase zone similarly demonstrate an upflux of steam, and consequent heat loss from the deep liquid. It is hoped similarly to estimate this flux, and finally to construct a heat and mass balance between the four zones (AB,BC,CD,DE of figure 2) of thd field.

Comparisons with other fields

A vapour zone at about 55 bar developed briefly at Broadlands, and BR19 discharged dry steam. The zone first formed in 1970, and persisted for a year after the field shutdown in 1971. It decayed with the stem pressure falling, which indicates upward loss of steam. Both at Broadlands and Wairakei the steam zone formed within the two-phase zone, and was not confined or controlled by any stratum. It is conjectured that its formation is controlled by exploitation - and it appears above the level of greatest drawdown.

The natural discharge, and changes in it, are being simultaneously examined for useful guides to modelling Rotorua field. At present the only obvious conclusion is that deep exploitation appears to affect the natural discharge mora inmediately than shallow withdrawal.

References

ALLIS, R.G. (1979) "Thermal History of the Karapiti Area, Wairakei", Report 137, Geophysics Division DSIR

BOLTON, R.S. (1970) "The Behaviour of the Wairakei Geothermal Field During Exploitation", U.N. Conf., Geothemics Special Issure 1426-1449.

MARSHALL, D.C. (1970) "Development of a Theory of the Wairakei Geothermal Field by the "Simplest Cases First" Technique,", UN Conf, Geothemics Special Issue 669-676

MERCER & FAUST (1978) "Geothermal Reservoir Simulation III: Application of Liquid - and Vapour dominated modelling techniques to Wairakei, New Zealand" Unpublished.

McNABB, A. (1975) "A model of the Wairakei Geothermal Field". Unpublished paper.

WHITING R.L. & RAMEY, H.J.Jn, (1969) "Application of Material and Energy Balances to Geothermal Steam Production, Journal Petroleum Technology, 898-900

PRITCHETT, J.W., GARG, S.K., BROWNELL, D.H.J. (1976) "Numerical Simulation of Production and Subsidence at Wairakei New Zealand". Geothermal Reservoir:- Engineering Standford University 310-323

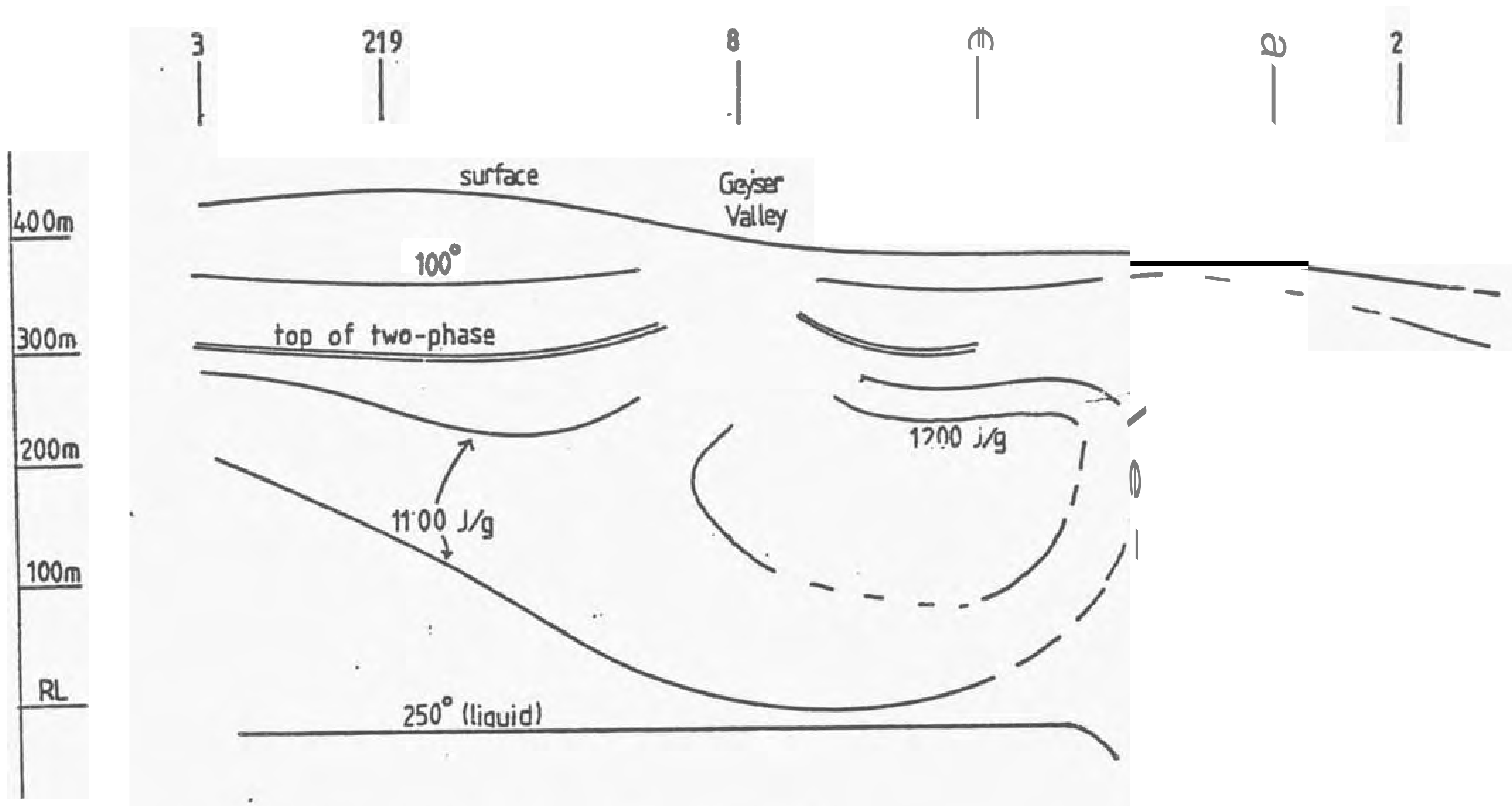

FIG.1 CROSS-SECTION, INITIAL STATE

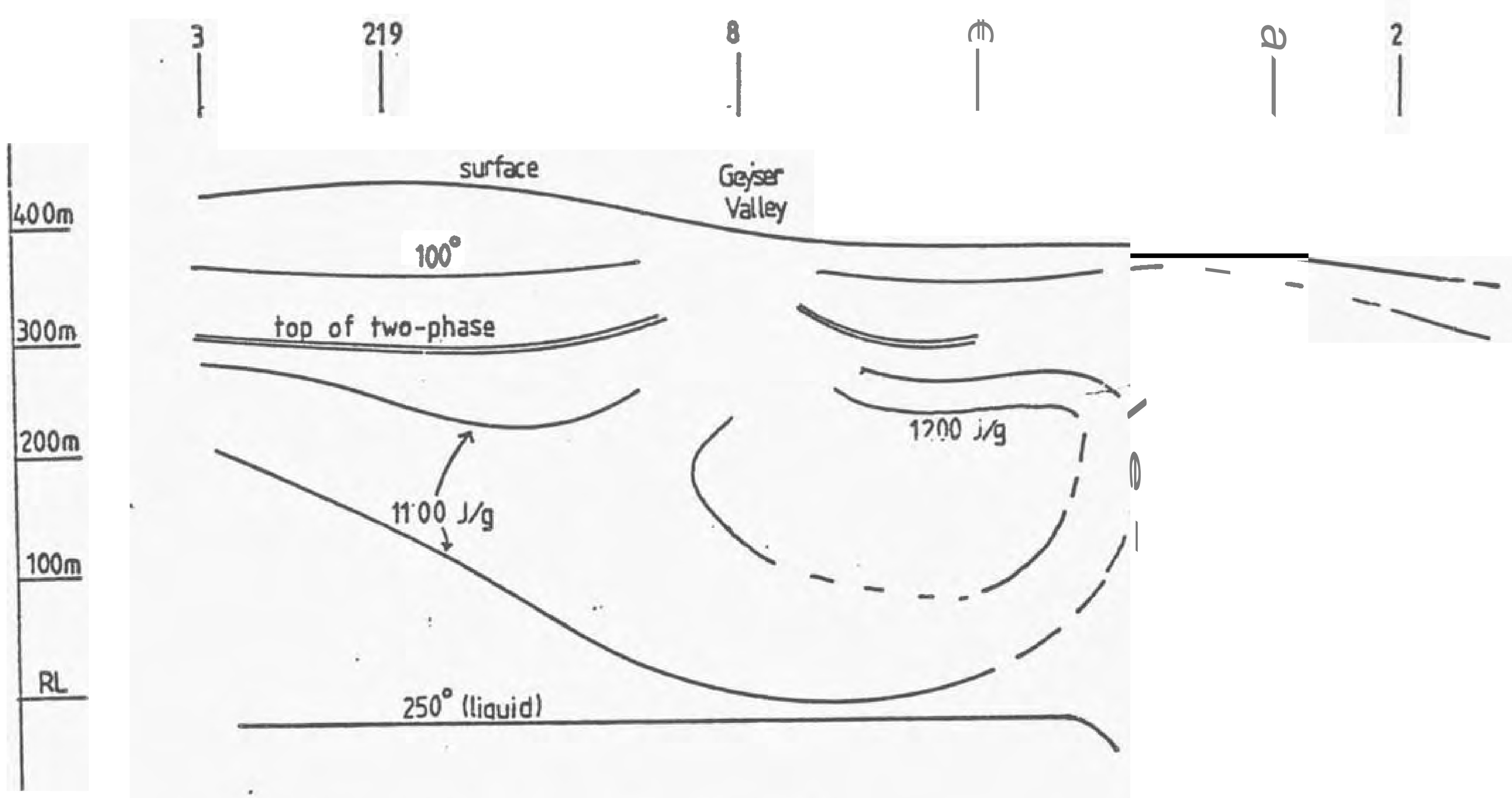

FIG.1 CROSS-SECTION, INITIAL STATE

FIG. 2 PROFILE NEAR WK9