A STUDY OF CYCLING IN GEOTHERMAL WELLS

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ABSTRACT

Instability in discharging and shut in geothermal wells, is in general caused by multiple feeds, permeability and enthalpy contrasts between the feeds being the major controlling factors. The form of cycle exhibited depends on the balance between these factors and the well head pressure at which the well is discharged.

Data on some Olkaria and NZ wells is analysed for evidence of multiple feeds and degree of permeability. The forms of discharge and shut in instability are described by output and/or downhole temperature and pressure profiles. Interpretation of these measurements allows fluid source during instability to be determined and permeability of lower feed to be estimated.

Any efforts to improve well performance are limited by economics and the technology of carrying out the operation.

INTRODUCTION

Instability in well discharge in geothermal wells is undesirable, but not an unexpected phenomenon since thermal manifestations associated with geothermal systems like geysers and fumaroles exhibit unstable behaviour on both micro and macro time scales.

In geothermal wells, within a certain range of pressures and occasionally at all pressures, the output fluctuates, at times with such large amplitudes as to make the wells unexploitable. This has been the case in Olkaria field in Kenya and the same behaviour has been observed in some wells in Wairakei, Broadlands and Rotokaua fields in New Zealand and Okoy and Tongonan fields in the Philippines.

The nature and degree of fluctuations will depend on a number of factors of which the following can be identified:

a - presence of two or more feeds;
b - restricted well permeability in one or both feeds;
c - wellhead pressure (WHP) at which the well discharges;
d - pressure and enthalpy difference between the feeds;
e - presence of cold inflows, from above (e.g. in poor cementing of insufficient depth of production casing) or from lateral flows;
f - gas content in fluid which will influence boiling point;
g - operating flow regime in well bore (Annular/Slug;
h - time and history of operations on the well which influence transient behaviour, and state of exploitation of the field which may result in formation of vapour dominated zones above liquid dominated ones.

Interaction of these factors results in output fluctuations of varying nature. Some fluctuations have regular periods lasting a few minutes to a number of hours while others are irregular with no specific period of magnitude. This study outlines the general field characteristics of Olkaria, the individual characteristics and the forms of instability observed in some Olkaria and New Zealand wells. Suggestion is made on possible methods of controlling well output. The temperature and pressure profiles in wells during heating and WHP recorder charts during fluctuations are appendixed.

IDENTIFICATION OF MULTIPLE FEED ZONES

Feed points in geothermal wells are identified by Loss Zones during drilling, cold water loss zones during completion tests, temperature peaks and inversions and pressure 'hinge' points during heating. Some wells develop internal circulation which originates at one feed point and terminates at the other during heating.

Permeable zones can also be inferred from cuttings and cores, by studying the nature and type of rock, presence of fractures, and degree and nature of mineral deposition and alteration. Caliper logs and electrical resistivity methods in quenced wells can also be used for fracture detection.

At Olkaria the steam-water interface is defined as the deepest depth at which 35 barsa (242°C) steam is obtained. All the wells intersect at least one steam and one liquid feed zone. The static pressure profiles', show that Olkaria has a liquid dominated zone below 1175 m.a.s.l., steam zone 1175-1275 m.a.s.l. (major production zone) and upper cool liquid zone 1275-1675 m.a.s.l. and a shallow low pressure steam zone above, which supplied surface features. Of significance is the apparent temperature inversion of 220°C obtained at 1075 m.a.s.l., probably deriving from lateral flows within the field.

In Olkaria, the deep liquid dominated zone has fairly low permeability, which results in strong transient effects during drilling, well completion and discharge.

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THE CYCLING MECHANISM

According to Grant[2,3], cycling indicates the presence of multiple feeds, but multiple feeds to not guarantee instability. Fig. la shows one type of cycling mechanism, which is now common at Wairakei, a liquid dominated field in which exploitation has caused formation of a vapour dominated zone above. If the deep feed is not very permeable it soon becomes so drawn down that, aided by the collapsing two phase column above, it stops discharging and begins recovering, re-establishing the cycle. If both feeds discharge at a higher WHP than the upper feed alone, then the upper feed will partially choke so that most of flow comes from the upper feed, hence very wet flows are observed in some wells at high WHP.

When the well is partially opened from shut in position (Fig. 1b), dry steam will be discharged from upper feed (profile DEC). Profile FGC shows lower feed about to be entrained into the flow, HJ hoth feeds discharging (low enthalpy lower feed) and KL both feeds discharging (high enthalpy, low flow lower feed).

When the well is throttled from low WHP, because the lower feed is already discharging, it will continue discharging at higher WHP. Occasionally (Olkaria Well 11), the upper feed may stop discharging and will partially recover, while the upper feed continues discharging probably partially into the upper feed. Thus wells behave differently when tested from high to low WHP and vice versa. This hysteresis effect is characteristic of multiple feeds.

Instability in well performance is driven by a varying pressure difference between the two feeds which oscillates between a light two phase column and a column of liquid water. Instability is most pronounced at WHP where one of the feeds is just entrained into the flow. At low WHP (high flow rate), the tendency will be to maintain a fairly steady pressure difference between the feeds and hence steady flowrates, while at higher WHP only upper feed will flow. Fig.1c shows ideal enthalpy variation with WHP under various field conditions.

OLKARIA WELLS

Feneral field characteristics

The Olkaria field is underlain by a 250-300°C hot water reservoir in which temperatures follow boiling point for depth profiles from 240°C at 750 m depth to at least 300°C at 1600 m. The water reservoir is capped by 50-250 m thick steam zone in which up to 75% is vapour. In most wells, the steam-water interface is found at 35 barsa (242°C) and is defined by impermeable tuffs, but in others by several aquicludes with permeable interbeds.[4]

Trachyte lavas and tuffs with generally low permeability constitute the reservoir rocks. Most of the steam is produced from fractures (probably joints) in the basalt lava and pyroclastic horizons extending 1150-1500 m.a.s.l. in Olkaria 4 and reducing to 1250-1450 m.a.s.l. in Olkaria 15. The liquid producing zones are spread in fractures in the lower-lying tuff sediments, rhyolite and trachyte horizons.

Pumping tests yield specific capacities in the range 30-60 litres/minute/bar (lpm/bar) in Olkaria 8, to 540 lpm/bar in Olkaria 12, while shut in tests yield values of kh = 0.2 - 2.0 darcy-metre. Generally wells with low permeability in steam zone do not develop a high shut in WHP.

Producing wells reduce reservoir pressure in their vicinity and cause intense boiling in the rocks. The resulting relative permeability effects reduce the overall output of the wells to an average of 28 t/hour mass, enthalpy 2200 kJ/kg at 6 barsa.

Some wells require up to five months to attain stable discharge while others have remained unstable throughout discharge periods lasting several months.

All output measurements were measured using the lip pressure method except for Olkaria 2 which was measured by the separator method for part of the discharge.

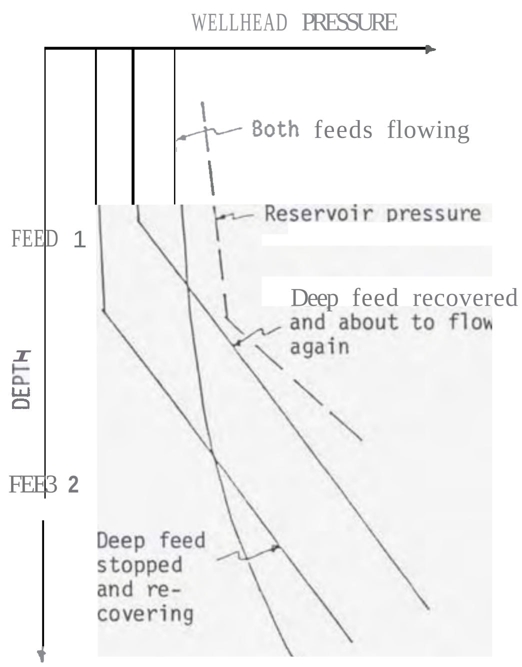
Olkaria Well 4

This well is drilled to 1660 m, but results of completion tests are not available. However, temperature and pressure measurements during recovery suggest steam feed is located around 750 m and water feeds at 825-850, 1200, 1400 and 1660 m (Fig. 3). The major feeds are probably steam at 750 m and water at 1400 m.

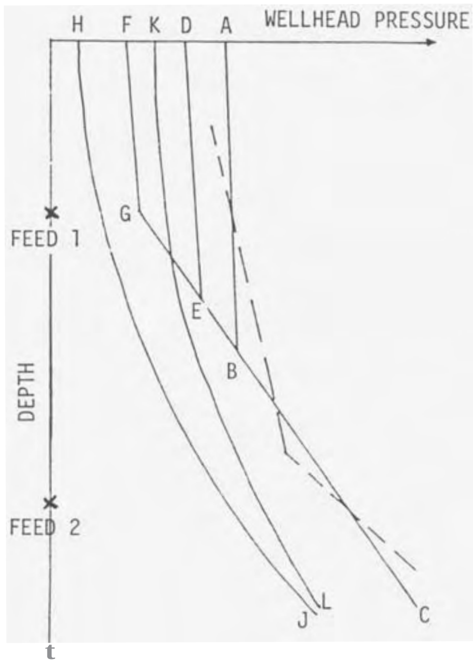
Strongest WHP fluctuations with amplitudes of up to 6 barsa are observed during discharge on 4" lip pressure pipe (3.6 barsa) in 1978. Fluctuations still persisted in 1979, though with slightly reduced intensity. The fluctuations varied in period from 40-60 minutes and lasted 3-4½ hours followed by recovery of up to 11 hours before the fluctuations re-established.

An attempt was made to establish flowing pressure profiles and pressure record in deep feed during fluctuations. It should be appreciated that flow especially under cyclic conditions is dynamic and it is impossible to establish flowing pressure profiles in the well at a particular phase of the cycle, since traversing the well with a pressure gauge will take a finite time. Therefore, actual pressure profiles can only be roughly determined and then, only for cycles with relatively long periods.

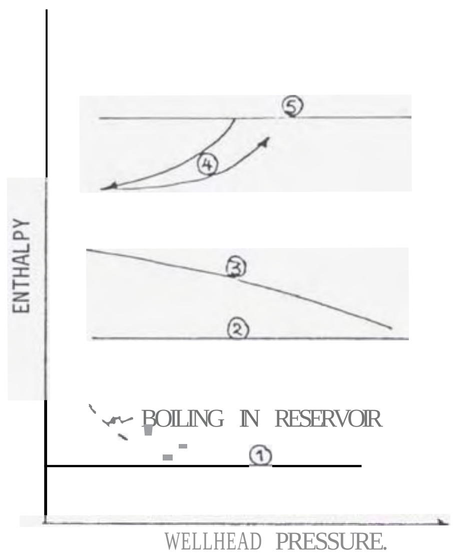
Figs. 2 shows the downhole pressure record at 1400 m and the corresponding WHP record during fluctuations. The periods when flowing pressure profiles were taken are shown. The pressure record shows that when WHP is declining, the downhole pressure is recovering. Fig. 3 shows the flowing pressure profiles in the well during various phases of the cycles. It is indicated that the fluctuation mechanism depicted in Fig.2a is operating. Repeated dipping of WHP before sudden rise when the lower feed flows, marks the



1a. Flowing pressure profiles in a two feed well during cycling



1b.



1c. Wellhead pressure/discharge enthalpy.

(1) Water fed well.

(2) Two phase high permeability well.

(3) Two phase low permeability well.

(4) Steam over water well.

(5) Vapour fed well.

FIGURE 1

arrival at the steam feed, of the fluid column from below, the top of which is probably cool and quenches the steam zone. This causes the sudden WHP dip, which triggers the flashing of the rising water column. Due to limited permeability in the lower feed, drawdown causes collapse of the two phase column above and cycling is re-established until all the liquid column is unloaded. After complete unloading, a fairly steady flow is maintained for a few hours, but drawdown forces the lower feed to stop flowing and the cycle is re-established.

No output measurements were taken during this monitoring period; however, from a series of hourly readings (see Haukwa, 1981) ouput during phases of the cycle can be obtained from which output over one cycle is constructed. From these measurements the average flow over the unloading part of the cycle if 27 t/hour at enthalpy 1650 kJ/kg.

By assuming that the lower feed recovery is not affected by other feeds, a conventional Miller, Dyes, Hutchinson analysis of the recovery cycles can be carried out from which an average slope of 17.8 bar/cycle is obtained. Using a reservoir temperature of 280°C and the above output values, yields a kh = 0.25 darcy-metre for the lower feed. The above assumption is perhaps not completely valid since the water column flashes when it approaches the upper steam feed but the analysis suggests that the permeability of the liquid zone is at least five times less than is obtained in good steam zones at Olkaria. A similar analysis of the behaviour of wells Olkaria 11, 14, Broadlands 14, Rotokaua 3, and Wairakei 61, has been carried out (see Haukwa, 1981 for details).

METHODS OF CONTROLLING WELL INSTABILITY

Methods of controlling well instability can be divided into two groups:

a - controlling the output inside the bore;

b - controlling the output at the surface.

Controlling output inside the bore

(a) Sealing less permeable zones - By cementing off less permeable zones, the well will be controlled by one feed only. In case of Rotokaua 3 casing deep enough to eliminate cool upper zone and in case of Olkaria 4 and 14, cementing lower liquid feeds would eliminate fluctuations in output.

(b) Double completion - By isolating the major feed zones, the output from the wells will be independent. However, the size of the inner tubing has to be optimised due to extra restriction to flow imposed by tubing. The output of Ngawha Well 2 (NZ) was reduced from 500 t/hour to almost half by double completion. Alternatively, partial double completion will introduce restriction to lower feed only and preventing its drawdown (hence less tendency to instability) without restriction to the flow of upper feed.

The use of a small diameter casing which would increase flow velocity and decrease tendency for fluid to segregate has also been suggested.[5]

(c) Well Stimulation - Any method which will improve overall permeability or increase the dominance of one feed in the flow will decrease tendency to instability. By pumping at large flowrates during completion, to overpressure the formation, some less permeable zones may be opened up. In Broadlands 14, although there was no measurable increase in injectivity by pumping up to 1000 t/hour, the instability had ceased on subsequent discharge probably as a result of stimulation. Other stimulation methods with still limited application include use of explosives and chemical treatment.

Controlling output at the surface

(a) Use of surge tanks - surge tanks designed and built to date are mainly for cold fluid transmission and are of two forms:

(i) Surge chamber; designed to absorb large pressure transients such as are caused by sudden valve closing or high head turbo machinery stoppage.

(ii) Pulsation damper; designed to smooth out fluctuations in output such as are caused by reciprocating pumps.

Though the magnitude of pressure surges in transients may be large, two features distinctive here are that the periods involved are small typically a fraction of a second, and there is no heat storage involved. Air is used to absorb shock either directly or via an isolating diaphragm and surge tanks are only a few litres in volume. The variation in delivery of the pump is essentially sinusoidal making analysis by electrical analogies easy.

In geothermal wells, however, no such simple function can be attributed to variables as shown by outputs from Olkaria Well 2, 4 and 14. For Olkaria Well 4 for an average flow of 23 t/hour 2 tonne fluid have to be stored in the surge tank during 30 mins, which at 5 barsa, average enthalpy 1650 kJ/kg means surge tank volume 360 m^3. For no reverse flow into well when WHP falls below 5 barsa, non return valve has to be installed and the well will flow only 60% of the cycle, decreasing average flow to 14 t/hour and increasing stored fluid to 3.5 tonne, surge tank 630 m^3. Variation in output enthalpy makes this simple approach only an approximation. Nevertheless, this is a comparatively large vessel and overall dynamic performance especially when thermal inertia is taken into account is difficult to assess. Surge tanks are therefore not a practicable method for controlling output where fluctuations are large and flow two phase. Where fluctuations are small with period less than one minute, a large enough cyclone separator effectively acts as a surge tank.

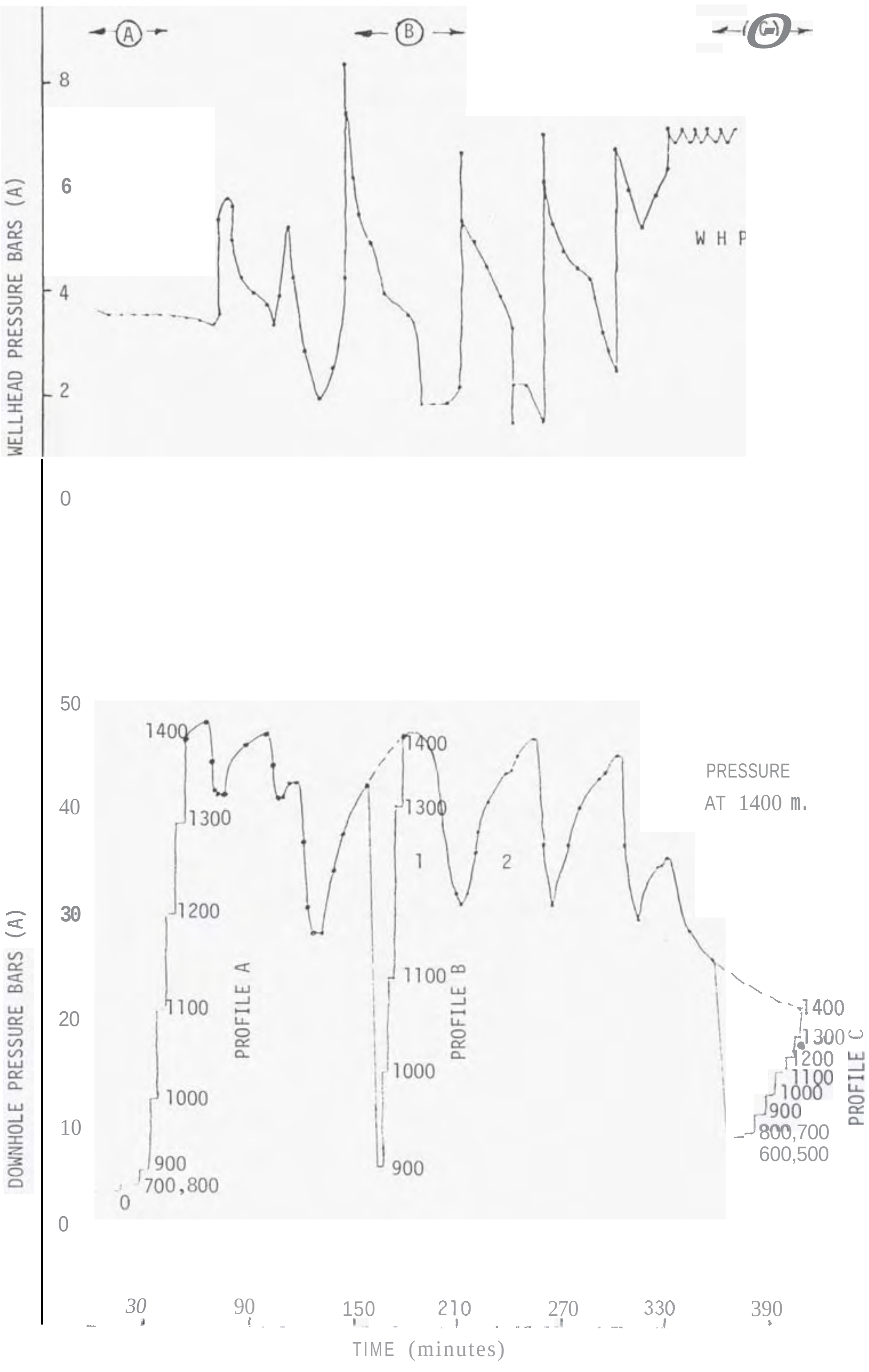


FIGURE 2: OLKARIA WELL 4 - WHP and pressure at 1400 m depth during cycling.

(b) Coupling of wells - By coupling wells with similar cycles before feeding into the separator, it is expected the cycles will lock onto one another and modulate the flow. Some loss in output of the wells will be expected as the wells will partially inject into one another during modulation. Actual practical operation of this method has not been attempted. It is unlikely that there will be two wells, close enough in the same field and having similar cycles at required operating WHP.

(c) Control of discharging WHP - This is by far the cheapest and most commonly used method. By operating the well at as low WHP as possible, the tendency will be for steady output from both feeds. Throttling back the flow will normally allow flow from only upper feeds.

(d) Venting flow during fluctuation - For wells which fluctuate only a small percentage of the flow time, it may be necessary to install a mechanism which vents flow to atmosphere until the fluctuations have ceased (e.g. Olkaria Well 14). In the same way, wells which show rapid drawdown will have to be closed to allow them to recover. This operation will demand the availability of spare wells to maintain load.

DISCUSSION AND CONCLUSIONS

Instability in well performance is caused by multiple feeds. The form of instability will depend on mainly the pressure and enthalpy difference between the feeds; the degree of permeability encountered in the well and the number of active feed points controlling the output. The period of the cycle will depend on the permeability of the less permeable feed which will influence rate of recovery and drawdown. The period will also depend on the distance between the feeds which will influence the quantity of fluid to be unloaded from the bore and the pressure to which the lower feed recovers before it is unloaded.

Instability is most pronounced at the WHP at which one of the feeds is just entrained into the flow. Below and above this WHP, the output will normally be stable. It is therefore important that when selecting operating WHP for bores, zones of greatest instability be avoided. Use of double pressure turbines will allow some wells to be operated at WHP as low as 2 barsa with less tendency to instability. Where instability is not achieved within operating WHP range, consideration should be given to sealing off some of the less productive zones, double completion or stimulation.

The uncertainty in practical operation, low probability of finding wells with similar cycles and noting that instability cycles change in both period and magnitude with time, makes coupling of wells as a solution of remote proposition. Similarly, the size of surge tank required to store a moderate quantity of two phase fluid and uncertainty in dynamic performance make surge chambers uneconomic. If spare wells are available or loss in generation can be tolerated, then venting flow to atmosphere or closing wells to allow recovery may be a cheap solution.

Flowing temperature and pressure files during various phases of the cycle, help locate active feeds, Downhole pressure records in deep liquid during cycling can be used to estimate reservoir permeability of the lower feed. Recognition of instability due to multiple feeds in shut in wells can help in interpreting downhole temperature and pressure measurements. Output measuremeants during various phases of the cycle can be used to determine fluid source.

It has been hypothesised that for purposes of interpretation, the present Olkaria drill field is so small that it can be regarded as one well very thoroughly measured. The wells at Olkaria however show considerable heterogeneity in permeability structure associated with the number of permeable zones they intersect.

Recent geophysical re-interpretation of resistivity soundings[1] suggest that the present Olkaria drill field is some 6.5 km to the south east of the centre of primary upflow of the major Olkaria geothermal prospect. At the centre of this inferred upflow, the low resistivity strong alteration zone (<10 Ω.m) comes to within 500 m of the surface, with deeper coherent low resistivity layer (<5 Ω.m). This layer is almost two km below the presemt drill field and has not yet been penetrated. Drilling deep wells in present field, or nearer inferred centre of upflow may result in more favourable permeability structure and less tendency to instability.

Any efforts to bring wells to stable production must be balanced by economic benefits that will be derived. Only when the anticipated output is large enough can it be justified.

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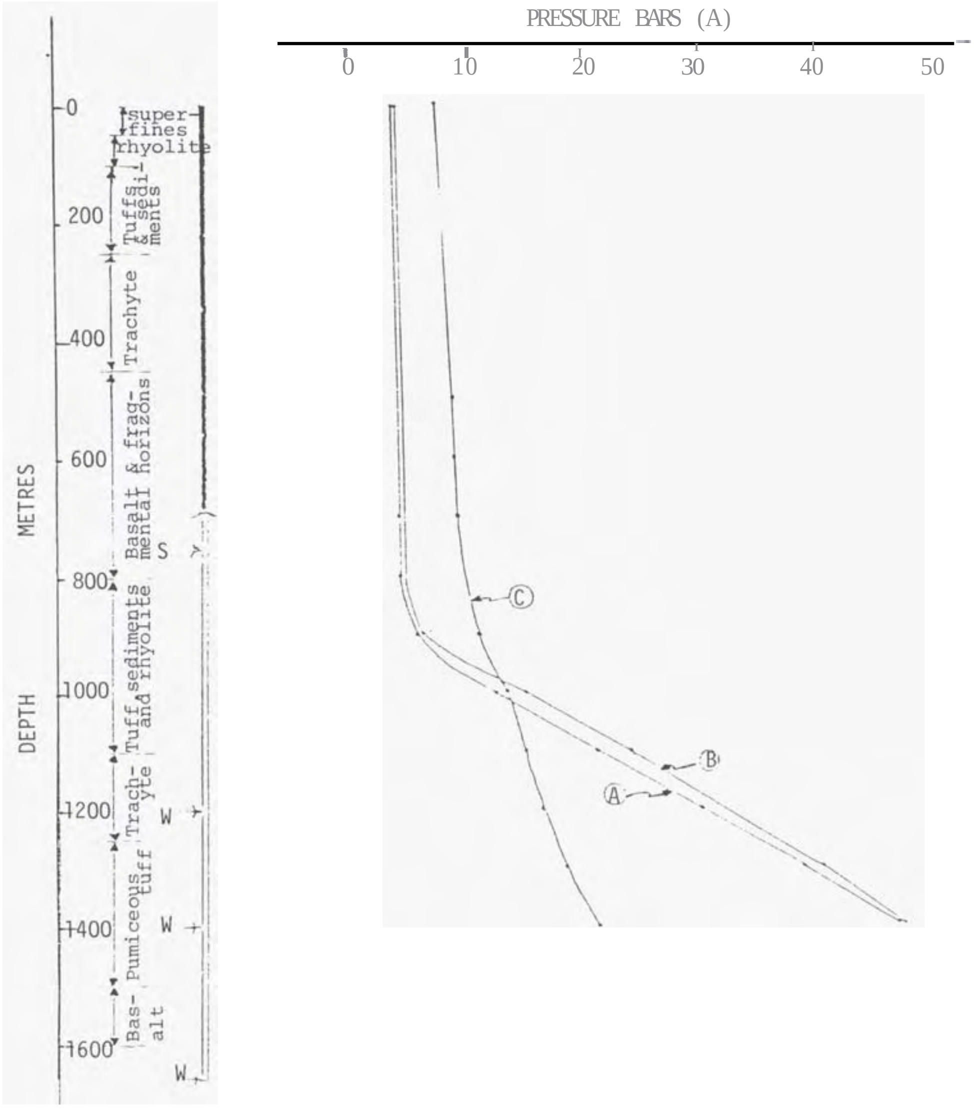

FIGURE 3: OLKARIA WELL 4 - Flowing pressure profiles during cycling

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