NOTE ON THE OCCURRENCE AND COMPOSITIONS OF CALCITE FROM THE TE MIHI SECTOR OF THE WAIRAKEI GEOTHERMAL SYSTEM, NEW ZEALAND

Colin C. Harvey and P. R. L. Browne
Geothermal Institute and Geology Department, University of Auckland

SUMMARY - Four types of calcite occur in cores and cuttings recovered from 14 wells drilled into the Te Mihi section of the Wairakei geothermal field, i.e. (a) vein and open space calcite which *contains* up to 3 wt % MnO, (b) bladed calcite of stoichiometric composition, (c) calcite, with about 0.5 wt % MnO, pseudomorphing primary plagioclase, and (d) calcite present in grout. Calcite is much more abundant (5 - 15%) in samples from wells drilled between 1985 and 1987 than it is in cores from wells drilled before 1962 (0 - 3% calcite). This shows that calcite has formed in the shallow parts of the reservoir as a result of boiling from the pressure drop accompanying water drawdown. Drawdown has also allowed shallow ground waters, into which CO_2 derived from the deeper alkali chloride water has condensed, to infiltrate the reservoir. Calcite deposited in veins and vugs as this water was heated by its contact with hotter rocks. Calcite that replaces plagioclase deeper in the reservoir formed by slow reaction between primary feldspar and the alkali chloride reservoir fluid of the Wairakei system.

INTRODUCTION

The Wairakei geothermal system (Fig. 1) is contained within a sequence of Quaternary silicic volcanic rocks interbedded with lake sediments (Grindley, 1965). Fluids, at temperatures up to 270°C, ascend via a series of normal faults and hydraulic fractures and then flow laterally within permeable pyroclastic units.

Well measurements (Stacey and Thain, 1983; Bixley, 1986), gravity surveys (Allis and Hunt, 1986) and chemical monitoring (Brown, et al., 1988) at Te Mihi show that exploitation of the Wairakei system since 1958 has resulted in:

(i) a lowering of the piezometric surface in the reservoir by at least 300 m; this has caused -
(ii) a pressure drop from 35 bars (g) in 1960 to 25 bars (g) in the early 1980's, producing extensive boiling and increasing the enthalpy of the discharge fluids.
(iii) local dilution of the deep reservoir fluids by heated ground water, condensate, or a mixture of both.

Calcite is a common hydrothermal mineral over a wide range of depths at Wairakei (Steiner, 1953, 1977). There are at least four possible mechanisms that cause it to precipitate:

(i) calcite may precipitate in veins or vugs where deeply circulating ground water mixes with hotter fluid or comes into contact with hotter rock.

(ii) calcite will precipitate where deep reservoir fluids lose CO_2 by boiling or effervescence, according to:

$$Ca^{2+} + 2HCO_3^- \Rightarrow CaCO_3 + CO_2 + H_2O.$$

Calcite formed by boiling typically has a bladed morphology and this is analogous to calcite scale that deposits in wells and pipework (Tulloch, 1982).

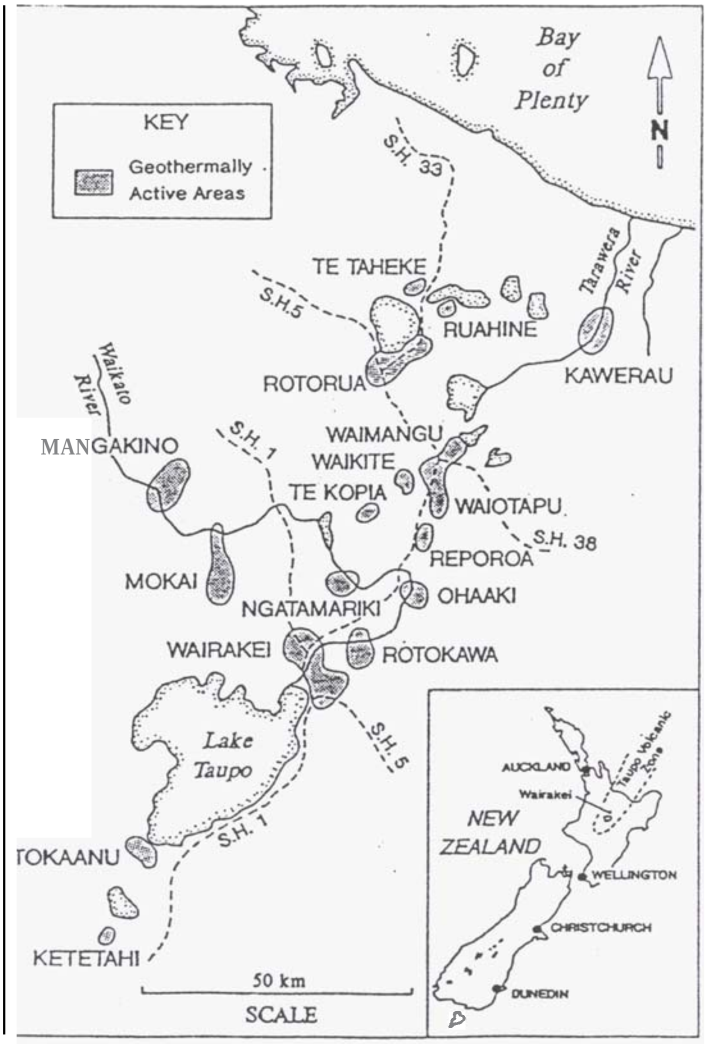

Figure 1. Map showing the location of Wairakei.

(iii) interaction between the deep fluids and primary plagioclase or pyroxene results in their replacement by a suite of alteration minerals which commonly includes calcite and calc-silicate phases, as represented by a reaction such as:

$$\text{Plagioclase} + CO_2 + H_2O \Rightarrow \text{Calcite} + \text{Clay} + \text{Ca alumino silicate} + Na^+$$

(iv) from the carbonation of grouts used to cement well casing (Verbeck 1958).

$$CaO + CO_2 \Rightarrow CaCO_3$$

The purpose of this paper is to describe the Occurrence of calcite in the Te Mihi section of the Wairakei field since the distribution of different types of calcite present in samples recovered from both the early (1950's) and later wells (1980's) record evidence of physical changes that have occurred in the reservoir due to its exploitation.

PREVIOUS WORK

Ellis (1970) showed that the deep reservoir fluids at Wairakei were close to saturation with respect to calcite. Steiner (1953, 1977), working on cores from the pre-exploitation drillholes, reported minor amounts of calcite present at both shallow and deep levels of this system. He recognised three favoured sites for calcite to deposit:

1. away from productive fissures - that is, in zones of low permeability, where primary plagioclase is replaced by calcite accompanied by wairakite and/or albite;
2. in the hanging walls of productive fissures;
3. at shallow levels in drillholes which did not intersect productive fissures.

Clayton and Steiner (1975) concluded, on the basis of isotopic measurements, that calcite at shallow depth formed from steam-heated, CO_2-rich waters. Based on a study of changes in fluid chemistry with time, Mahon and Finlayson (1983) and Brown et al. (1988) demonstrated that there has been appreciable dilution of the deep reservoir fluids by heated ground waters as a consequence of exploitation. Their findings have been supported by a series of isotopic studies made by Henley and Stewart (1983) and Stewart (1984).

Kinnearly (1960) identified calcite and portland cement in grouts from several of the early drillholes at Wairakei.

METHODOLOGY

Samples and Sampling

Samples of core material were taken at intervals of approximately 40 metres from six of the pre-exploitation drillholes (drilled between 1951 and 1962) in the Te Mihi sector. The wells were WK7, WK202, WK206, WK212, WK215 and WK219 (Fig. 2).

Figure 2. Location of drillholes sampled in the Te Mihi sector of the Wairakei geothermal system.

Samples were also obtained from later drillholes (1985-1987). Only two cores per well were recovered from drillholes WK228, WK232, and WK234. Three short cores were obtained from drillholes WK229, WK231, WK233, four from WK230 and seven from WK235. The cores are mostly 1 to 2 metres long, with core recovery varying from 50% to 100%. Because fewer cores were taken during the 1985-7 drilling, cuttings were also sampled, where needed, at intervals of about 40 m.

Textural studies were made by petrographic microscope, with subsequent analysis by X-ray diffraction and electron microprobe. Semi-quantitative estimates of calcite abundance were made using dissolution by sodium acetate at pH 5 (Jackson 1969). A series of electron microprobe analyses were made of the different forms of calcite identified.

DISTRIBUTION OF CALCITE

Calcite was present in fewer than 25% of the samples recovered (Table 1) from the early drillholes and, in most cases, comprised less than 5% of the rocks. Two samples, however, from drillholes WK202 (280 m R.L.) and WK215 (325 m R.L.) contain 10 and 19% calcite respectively.

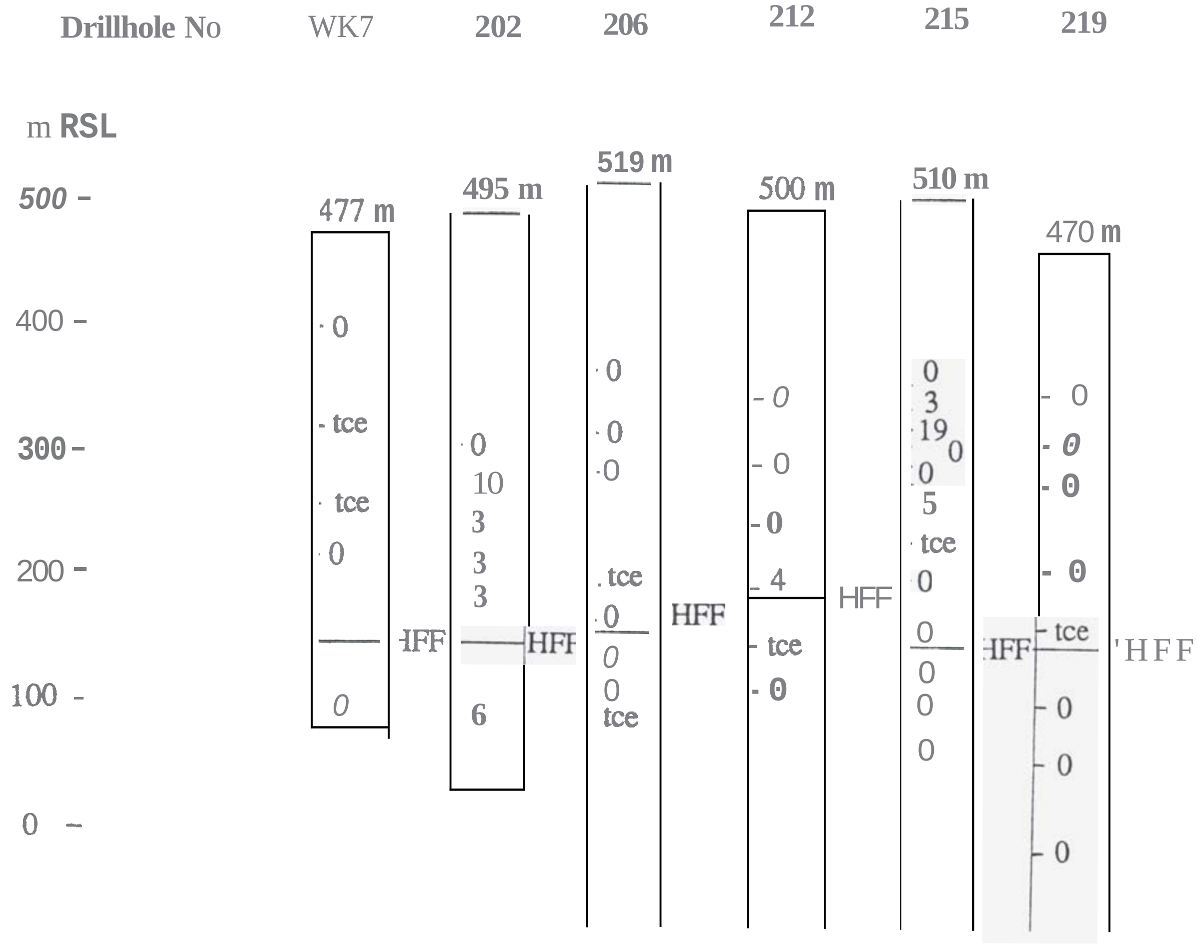

Table 1. **Distribution and abundance** (%) **of calcite present in cores from wells WK7** (drilled 1951), **WK202** (1957), **WK206** (1960), **WK212** (1961), **WK215 (1961) and WK219 (1962). HFF = Huka Falls Formation sediments.** Tce = trace

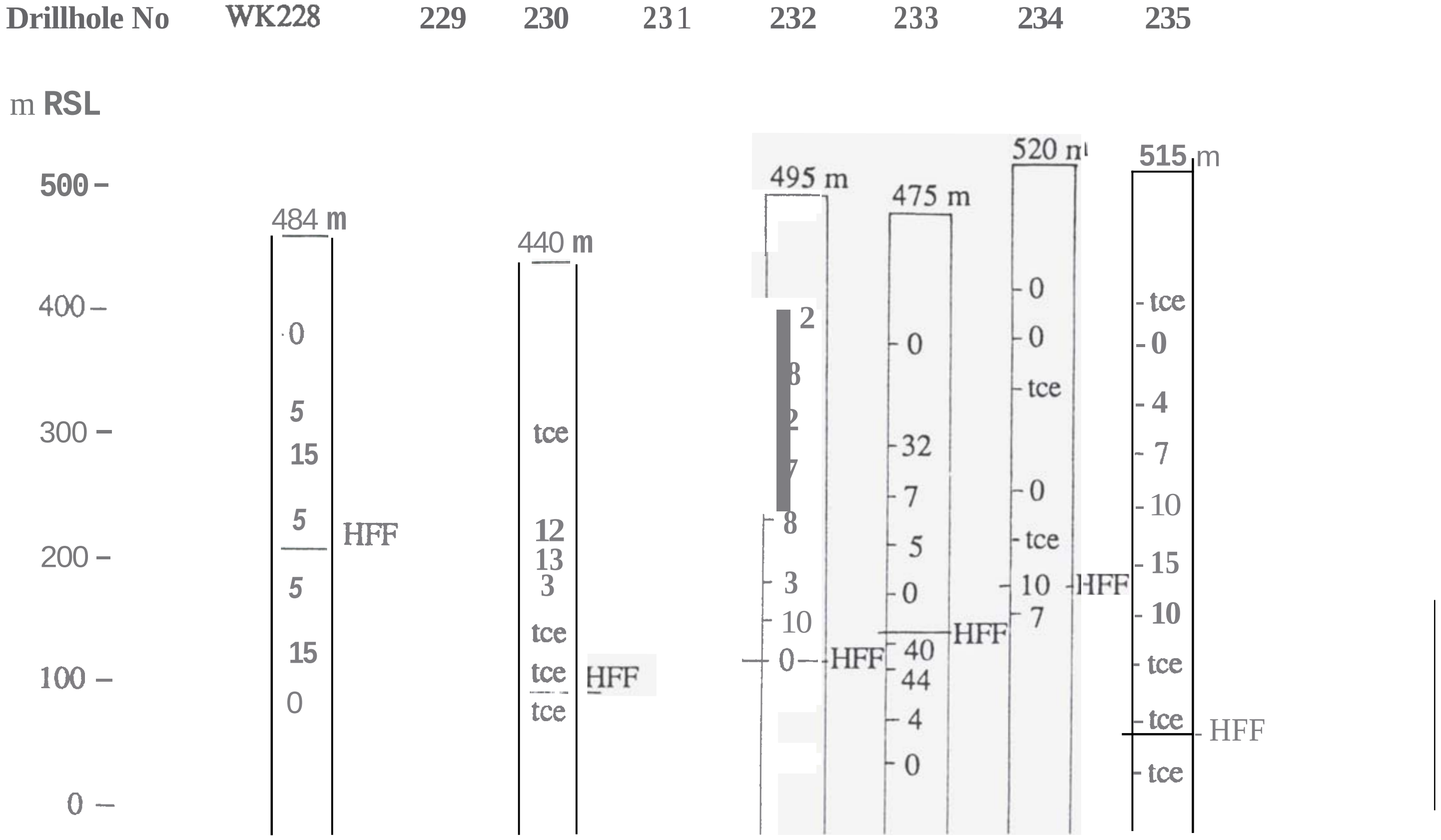

Table 2. Distribution and abundance (%) **of calcite present in cores and cuttings from wells** WK228 **(drilled 1985),** WK230(1987), WK232 (1987), WK233 (1988), WK234 **(1987)** and WK235 **(1987).** HFF = **Huka** Falls Formation **sediments,** Tce = trace

Calcite was present in more than 80% of the cuttings recovered from the holes drilled from 1985-87 (Table 2). Many samples contain more than 10% calcite with three from drillhole WK233 containing over 30%. There is appreciable grout contamination of samples from drillhole WK233, however, and indeed it is likely that a high proportion of grout was present in the cuttings recovered from the later drillholes. The chemical method (sodium acetate) used to determine the abundance of calcite does not distinguish between the different types present, however, it is clear that the samples recovered from the holes drilled more recently contain very much more hydrothermal calcite than is present in samples from the wells drilled earlier.

COMPOSITION OF CALCITES

Electron microprobe analyses were performed on the veins of calcite, bladed calcite, replacement calcite and grout particles from different depths in the selected drillholes. The number of analyses performed was insufficient to justify any statistical treatment of the data. However, there are significant differences in composition between the different forms of calcite; these are -

(i) higher manganese levels present in vein calcite
(ii) higher magnesium and silica levels present in grout calcite
(iii) lower manganese and magnesium levels prresent in bladed calcite

A selection of analytical data are plotted on a triangular diagram (Figure 3).

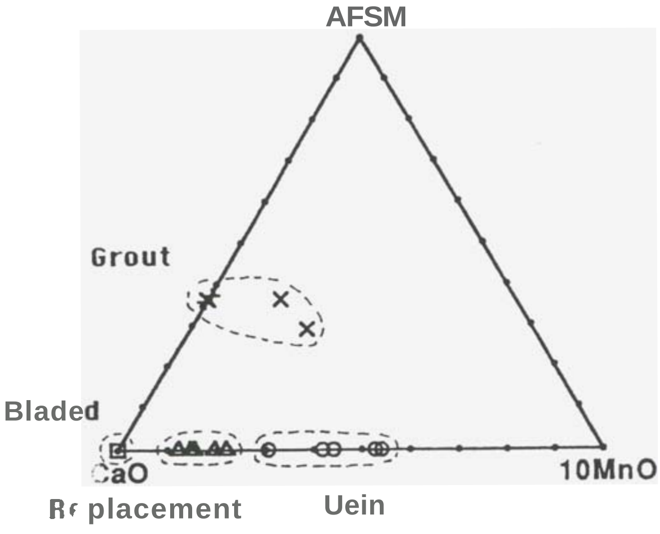

Figure 3. Triangular plot showing compositions of calcites from the wells drilled at Te Mihi. AFSM combines Al_2O_3, total iron oxide, SiO_2 and MgO.

CLASSIFICATION OF CALCITES

Four types of calcite are distinguished, based on their morphology, texture, associated alteration mineralogy, and compositions. These are :-

(i) open space filling and vein calcite;
(ii) bladed calcite;
(iii) replacement calcite associated with albite, wairakite and/or epidote;
(iv) grout calcite.

Open Space Filling and Vein Calcite

Calcite occurs in cores taken from both the pre-exploitation and later drillholes (Tables 1 and 2). This calcite occupies veins and cavities and some is optically continuous over several centimeters. None is bladed or associated with other alteration minerals. Vein calcite (Fig. 3) is low in iron and magnesium but high in manganese (up to 3% MnO).

Vein calcite from 183 m drilled depth (+325 m R.L.) in drillhole WK215 (drilled 1961) forms about 20% of the rock but there is no vein calcite present below this depth. Calcite occurs at 306 m depth (+214 m R.L.) in drillhole WK234 (drilled 1987) where it fills cavities and totally replaces plagioclase phenocrysts, but there are no hydrothermal aluminosilicate minerals present with it. No vein calcite occurs in cores from deeper than 360 m drilled depth (+163 m R.L.) in drillhole WK234. Note that vein calcite is present in drillhole WK234 (drilled 1987), 113 m deeper than it is in WK215 (drilled in 1961).

The geochemical data of Brown et al(1988) indicates that, with time, there has been an increasing proportion of ground water present in the discharge waters, suggesting that the ground waters, into which ascending CO_2 has condensed, are infiltrating to progressively deeper levels as reservoir pressures drop. The presence of vein calcite at deeper levels in the more recent wells is consistent with this interpretation. The significance of the high concentrations (1-3% MnO) of manganese (Fig. 3) present in the vein calcites has yet to be recognised but it may derive either from the dissolution of primary ferromagnesian minerals (e.g. pyroxene) or from manganese-bearing organic material present in sediments within the Huka Falls Formation or the Rautehuia Breccia.

Bladed Calcite

Bladed calcite occurs in veins and cavities and is near stoichiometric in composition (Fig. 3). This morphology has been recognised by Browne (1978) and Simmons and Browne (1990) to be a signature of boiling with calcite precipitating due to loss of CO_2 with the steam phase. Calcite scales deposited in pipes at Kawerau and Ohaaki-Broadlands (Tulloch, 1982) are also commonly platey, although some contain other constituents that together total 0.6%.

Vapour pressures in the Te Mihi sector decreased by 10 bars(g) during the 1980s (Bixley 1986) and there has been a trend of increasing well discharge enthalpy with time which is consistent with boiling in the aquifer, due to this pressure drawdown. Bladed calcite from one of the later drillholes (WK233) at 340 m drilled depth is low in iron, magnesium and manganese (all less than 0.3%). This occurs at an horizon of previous boiling, since the piezometric surface is now much deeper than this.

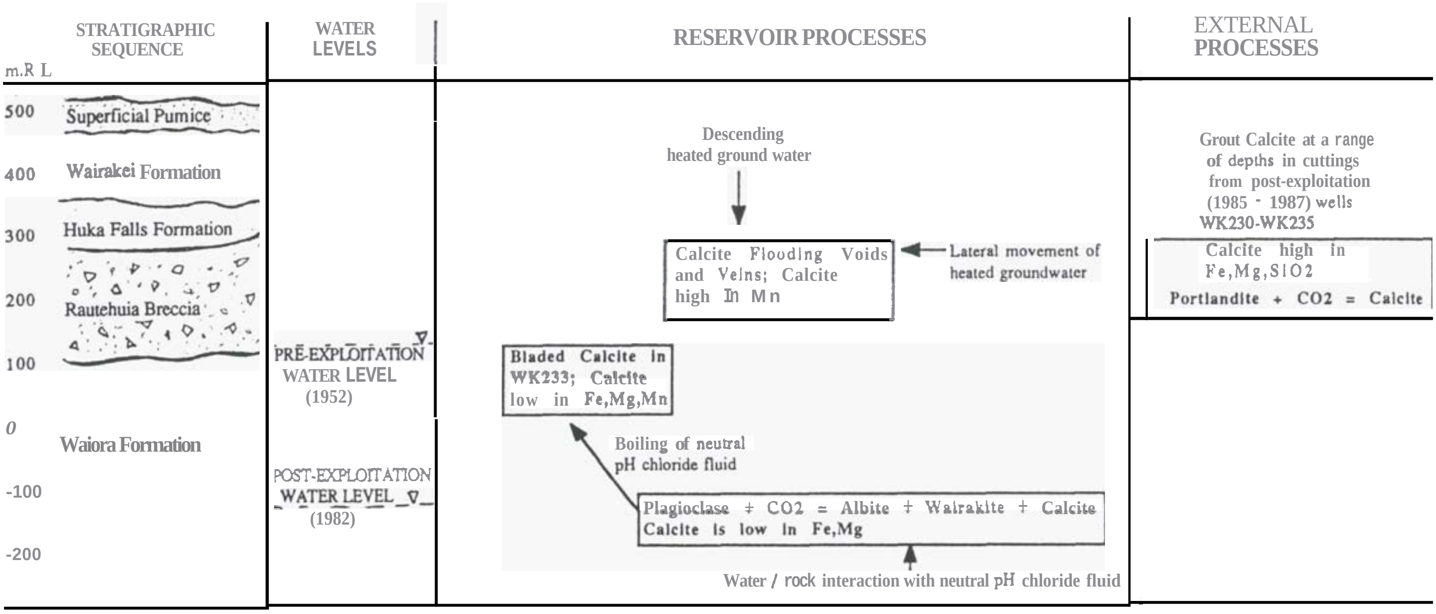

Figure 4. Summary of processes that cause calcite to deposit in the Te Mihi sector of the Wairakei geothermal system.

Calcite Associated with Albite, Wairakite and/or Epidote

Steiner (1977) reports minor calcite present in samples from many of the pre-1963 drillholes where it occurs in close association with a range of alteration minerals including wairakite, albite, epidote and/or illite. Typically two or three different alteration minerals partially or totally replace plagioclase phenocrysts. This association is confirmed by our study. Electron microprobe analyses of calcites from drillhole WK215 at drilled depths of 687 m (-177 m R.L.) and 825 m (-315 m R.L.) show them to be low in iron and magnesium with less than 1% MnO (Fig. 3).

Grout Calcite

C. P. Wood (pers comm., 1987) noted appreciable quantities of cement or grout contamination in the cuttings at a drilled depth of 340 m (+135 m R.L.) in WK 233. This was indicated by the presence of portlandite, a calcium hydroxide cement product that converts naturally to calcium carbonate (carbonation) under atmospheric conditions (Verbeck 1958). Milestone et al (1986), working on grouts from wells in the Ohaaki (Broadlands) geothermal field, showed that carbonation can be rapid in environments where CO_2 concentrations are high.

Light grey particles of what appeared to be cement grout were hand selected from cuttings of well WK233. These cuttings had been stored in open core boxes for about 3 years. Cuttings from 340 m depth in well WK233 which had been sealed in a plastic bag, were kindly made available by C. P. Wood. X-ray diffraction analyses showed that cuttings stored in the open boxes are dominantly calcite with no detectable portlandite. However, the sealed sample was predominantly portlandite with only a trace of calcite present. Electron microprobe analyses of several grout particles, together with several chemical analyses by Kinnearly (1960), are also shown in Fig. 3. It is likely that at least some of the calcite present in the cuttings from the 1985-87 drillholes at Te Mihi is derived from the carbonation of grout material. Clearly grout comprises calcite mixed with discrete, fine-grained silicate phases (probably including quartz and clay).

Conclusions

Calcite is much more abundant in cores and cuttings recovered from wells drilled in 1985-1987 than it is in cores recovered fom wells drilled before 1962. This demonstrates that much calcite has deposited since exploitation of the Wairakei system began in 1958.

Figure 4 summarises the four main processes that cause calcite to deposit in the Te Mihi area, i.e:

(i) boiling, which produces bladed calcite,
(ii) infiltration of ground water into which ascending CO_2 condenses. This becomes heated as it descends causing calcite to precipitate in veins and vugs,
(iii) interaction between primary plagioclase and the alkali chloride water that constitutes the reservoir fluid at Wairakei,
(iv) by reaction of Portland cement.

Calcite deposited from boiling or ground water infiltration (cases i and ii) obviously does so as a result of exploitation at Wairakei which has reduced pressures by about 10 bars and lowered the boiling surface by 300 m or so.

The four different types of calcite can be distinguished from one another by their morphology, occurrence and compositions. For an unknown reason, calcites deposited from heated ground water contain higher manganese contents (MnO ≈2-3%) than either bladed or replacement calcites.

IMPLICATIONS FOR RESERVOIR MANAGEMENT

Deposition of vein calcite from descending or laterally moving ground water will decrease permeability. The development of a lower permeability region above the production zone will have a beneficial effect on reservoir performance by reducing further ground water inflow into the reservoir. Similarly, any ground water moving laterally will also form a calcite barrier that restricts further lateral flow. However, a deposition front of vein calcite that descends into the reservoir will reduce its permeability.

It is unlikely that calcite deposited due to boiling will appreciably reduce permeability within the productive formations at Te Mihi because the amount of CO_2 dissolved in the Wairakei water is very low.

Deposition of calcite by replacement of plagioclase is occurring within the liquid-only part of the reservoir. This is not extensive, however, and any reductions in reservoir permeability in this way are likely to be so slow as to have negligible effect on the reservoir.

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