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MICROSEISMIC ACTIVITY AT WAIRAKEI AND OHAAKI GEOTHERMAL FIELDS

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ABSTRACT

A 23 month study of microseismicity at Wairakei, and a 35 month study at Ohaaki show the natural activity within the two fields to be completely different. Wairakei displays continuous, low to moderate activity, while at Ohaaki, only two microearthquakes have been recorded within the field. A 13 month reinjection test in the eastern borefield at Wairakei gave no detectable change in the occurrence of microearthquakes within the geothemal field. This contrasts with the seismicity induced by the injection test at Wairakei in 1984. The difference appears to be directly related to the wellhead pressure used on each occasion. During 1984 this ranged from 20 to 30 bars, while during the 1988-89 test, the well accepted fluid under gravity and no pumping was required. At Ohaaki the continual fluid withdrawal and reinjection that followed the commissioning of the power station gave no increase in seismicity, even though the wellhead pressures used for reinjection were similar (if not greater) than the 1984 Wairakei test. One explanation could be that the deep water table at Wairakei (240 m below the ground surface) due to the effect of 30 years of drawdown. This meant that the formation overpressures were 24 bars above the wellhead pressure during the injection. If this is the critical factor detexmining the seismicity, then this implies the local stress regime must have adjusted to the effects of the drawdown. An alternative explanation is that the low natural seismicity at Ohaaki is due to a relatively weak layer which cannot accumulate strain, and slips aseismically. Such behaviour could be caused by the presence of partial melt in the lower crust, or rocks with a high clay content.

INTRODUCTION

In the 1970's a number of authors suggested that geothermal fields had a level of natural microseismic activity higher than the surrounding area, and that this characteristic could be used as an exploration tool (Ward and Bjornsson, 1971; Ward, 1972; Coombs and Hadley, 1977). Subsequently a number of papers have shown this is generally not the case (Evison et al., 1976; Robinson 1981). During the 1980's there were many papers published on induced or triggered seismicity as a result of fluid withdrawal or injection in geothermal fields (Batini et al., 1980, 1985; Allis, 1982; Eberhart-Phillips and Oppenheimer, 1984; Sherburn, 1984; Allis et al., 1985; Bromley et al., 1987; Stark, 1990). The consensus from these studies was that fluid injection could cause induced seismicity as a result of the Hubbert-Ruby (1959) mechanism of increased pore pressure. In this mechanism the effective normal stress on a fault, which tends to prevent slip, is negated by an increase in fluid pressure in the fault zone, and the fault slips at a level of applied shear stress previously insufficient to cause slip.

This study describes the results of microseismicity monitoring at Wairakei and Ohaaki geothermal fields during periods of major reinjection at both fields. The fields are just 25 km apart, but as we will show, the natural seismicity is remarkably different.

GEOLOGICAL SETTING

The central part of the Taupo Volcanic Zone (TVZ) is dominated by two main structural features (Grindley, 1960; Figure 1). The Taupo Fault Belt, an area of recent, dominantly normal faulting runs northeast from the northern shore of Lake Taupo until it is covered by recent volcanics at the southern boundary of the Okataina Volcanic Centre. East of the Taupo Fault Belt, and bounded to the east by the Kaingaroa Fault scarp is the Taupo-Reporoa Basin, a 10-15 km wide tectonic depression filled by recent volcanic sediments. The Wairakei Geothermal Field is located 10 km north of Lake Taupo, across the boundary between the Taupo Fault Belt and the Taupo-Reporoa Basin, and the Ohaaki Geothermal Field, 25 km north east of Wairakei, sits in the middle of the Taupo-Reporoa Basin.

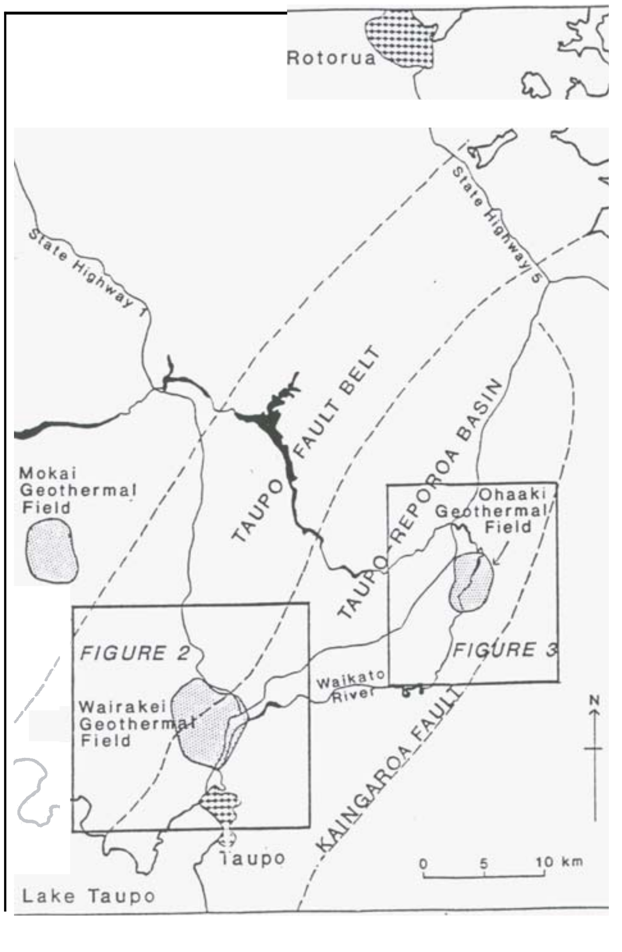


Figure 1 A part of the Taupo Volcanic Zone showing places mentioned in the text, and the locations of Figures 2 and 3.

PREVIOUS MICROSEISMIC STUDIES IN THE GEOTHERMAL AREAS OF THE TVZ

Smith and Webb (1986) summarised the seismicity of the TVZ since 1940 and noted that between 1964 and 1983 relatively few earthquakes larger than M_L4.0 occurred in the region between Lake Taupo and Lake Rotorua. This region contains most of the geothermal areas in the TVZ. The predominant focal mechanism solution for crustal earthquakes is consistent with shear faulting, implying that the maximum and minimum principal stresses are horizontal.

Evison et al. (1976) investigated the occurrence of microearthquakes in the central part of the Taupo Volcanic Zone. They noted microearthquakes were common in the Taupo Fault Belt, but very uncommon in the Taupo-Reporoa Basin and Kaingaroa Plateau further to the east. The distribution of microearthquakes did not coincide with known geothexmal areas. They accounted for the distribution of seismicity in terms of a reduction in the shear strength of the crust under the Taupo-Repoma Basin, due to the presence of molten or semi-molten material within a few kilometres of the ground surface. Beneath the seismically active Taupo Fault Belt they believed the molten material was at least 6 km below the ground surface, which allowed brittle shear failure in the upper part of the crust.

A 3 week microearthquake survey of the Mokai Geothermal Field (Figure 1) in 1985 (Sherburn, 1986) was made to measure the background level of seismicity. The overall level of activity recorded in the survey was similar to that recorded by Evison et al. (1976) for the Taupo-Reporoa Basin, and as a result Sherburn suggested the Taupo Fault Belt was bordered on either side by an area of substantially lower seismic activity.

A five week microearthquake survey of the Wairakei Geothermal Field was made in 1978 (Hunt and Latter, 1982). This indicated a level of seismicity similar to that in the nearby Taupo Fault Belt. The distribution of microearthquakes did not correspond with known areas of surface geothexmal activity, the main area of production, or an area of major subsidence within the Wairakei Field.

Sherbum (1984) and Allis et al. (1985) described the results of a study of microseismic activity at Wairakei during the WK301 injection test in June and July 1984. Clear induced seismicity was observed with over 70 events being recorded within 3 km of the injection well during a total of 9 days of injection. Wellhead pressures during injection were typically 20-30 bars, about 50 bars above the static pressure in the well, The focal mechanism of the induced earthquakes was very similar to the northeast trending dextral shear obtained by Hunt and Latter (1982) for regional seismicity in the Taupo Fault Belt.

SEISMIC NETWORKS AND REINJECTION AT WAIRAKEI AND OHAAKI

In October 1987 a microearthquake network of four stations was installed in the Wairakei Geothermal Field to monitor microseismic activity during a reinjection test into the Eastern Borefield (Figure 2). This network supplemented the existing Huka seismograph operated by DSIR Geology and Geophysics. Recording started in October 1987 and continued until July 1989 when the network was removed. The reinjection test at Wairakei occurred between April 1988 and April 1989. During the test a total of 5.2 Mt of separated water at 130°C were injected at about 450 m depth in one well, WK62 (Hunt et al., 1990). No pumping was required, with the well accepting the fluid under gravity. At the end of the injection test an elliptical cone of impression of the deep liquid zone had built up which was over 1 km wide on its long axis, and over 50 m in amplitude at its centre near the injection well.

The Ohaaki seismic network consisting of four stations (Figure 3) was installed in July 1987 to monitor microseismicity in the region after the commissioning of the Ohaaki Power Station in late 1988, and continues to operate. Reinjection is part of the overall field management strategy at Ohaaki, with separated water and condensate being pumped into a number of wells around the southern and western boundary of the field. The average injection flow rate during 1989 was 990 t/h with wellhead injection pressures typically in the range 20-35 bars. The total mass of injected fluid during 1989 was 8.8 Mt.

It is estimated the Wairakei network recorded all microearthquakes of at least magnitude 1.0 within about 5 km of the centre of the geothermal field. At Ohaaki, based on the recordings of a number of small earthquakes outside the network, it is believed that all earthquakes of magnitude 1.2 and above, within 5 km of the centre of the network were recorded. For the sake of comparison the detection capabilities of the two networks were similar.

All stations of both the Wairakei and Ohaaki networks used single, vertical component seismometers which were placed down a borehole to reduce the level of unwanted ground noise. The seismic signals were telemetered to the DSIR Geology and Geophysics office at Wairakei using either UHF radio or a telephone line, and were recorded on a SNARE digital earthquake detection system (Gledhill and Randall, 1986). The seismic outstations were powered by batteries and solar panels.

MICROSEISMIC ACTIVITY AT WAIRAKEI

The number of earthquakes recorded on the Huka seismograph between August 1987 and July 1989 varied between one and five per month (Figure 4; provided the anomalous activity associated with a nearby earthquake swarm in November 1987 is not included). Earthquakes contributing to this total had a trace amplitude (zero-peak) of at least 1.0 mm on the paper record, equivalent to about magnitude 1.5, and an S-P interval up to 1.5 s, equivalent to a distance of about 5 km from the seismograph. This is an average rate of 2.15 per month during reinjection, almost the same as the 2.17 per month recorded at other times. The reinjection is considered to have had no effect on the long term seismicity, and the earthquakes observed are therefore inferred to be representative of the natural or background activity.

Over 100 microearthquakes were 'actually located by the network in and around the Wairakei Geothermal Field during the 23 months the network operated (Figure 2; this is quite different from the earthquakes recorded on the Huka seismograph). The apparent concentration of events within the field is believed to be due to the detection capability inside the network being much better than outside the network.

MICROSEISMIC ACTIVITY AT OHAAKI

In the 35 months between the installation of the Ohaaki seismic network and June 1990 many large regional, and small earthquakes in the TVZ have been recorded. However, only two earthquakes were located within the field. This includes the 22 month period when the power station was operating and large scale fluid extraction and reinjection was taking place.

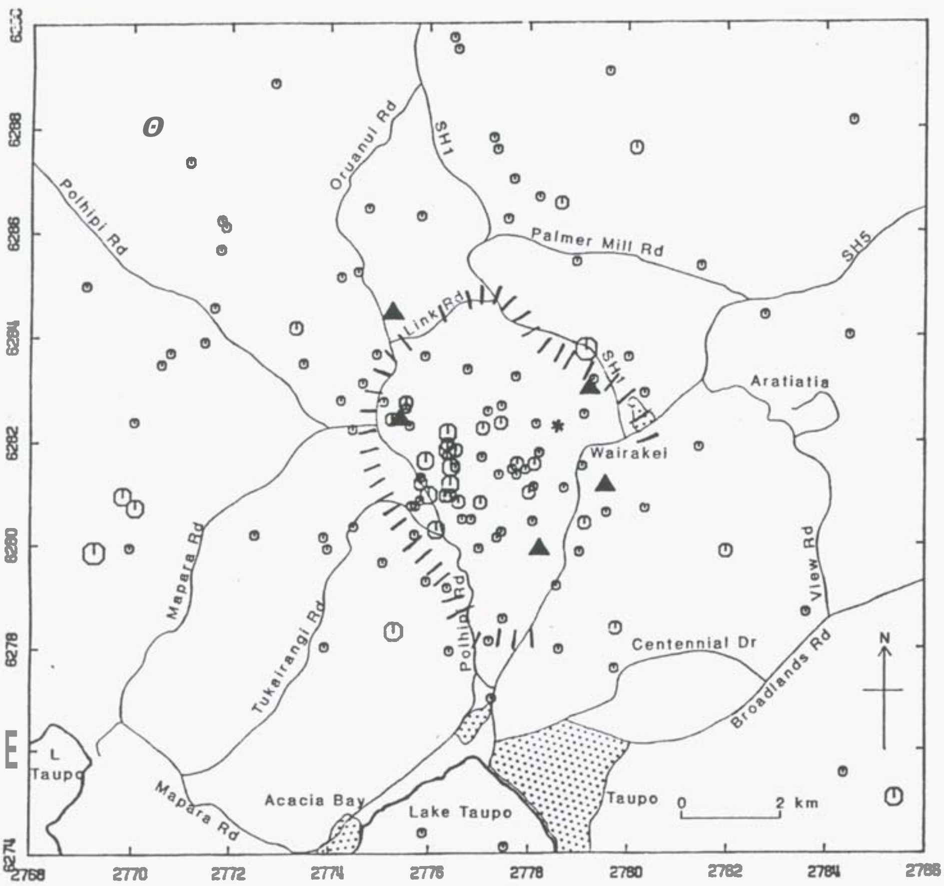
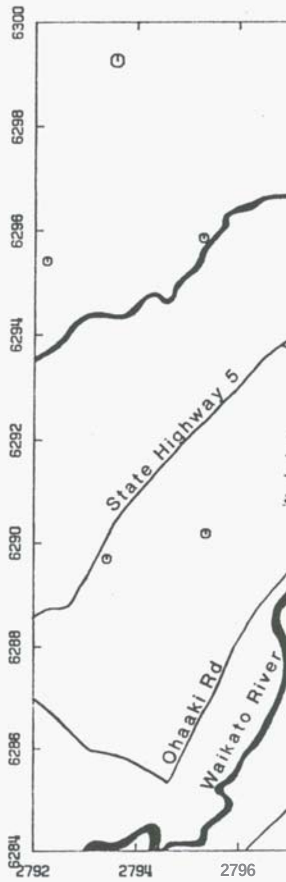


Figure 2 The location of microearthquakes recorded by the Wairakei network between October 1987 and July 1989. The seismograph stations are indicated by triangles (A), and the earthquakes by circles (●), with the size of the circle being proportional to the magnitude of the earthquake. The reinjection well is indicated by a star (*), and the field boundary (Risk, 1984) is hatched.



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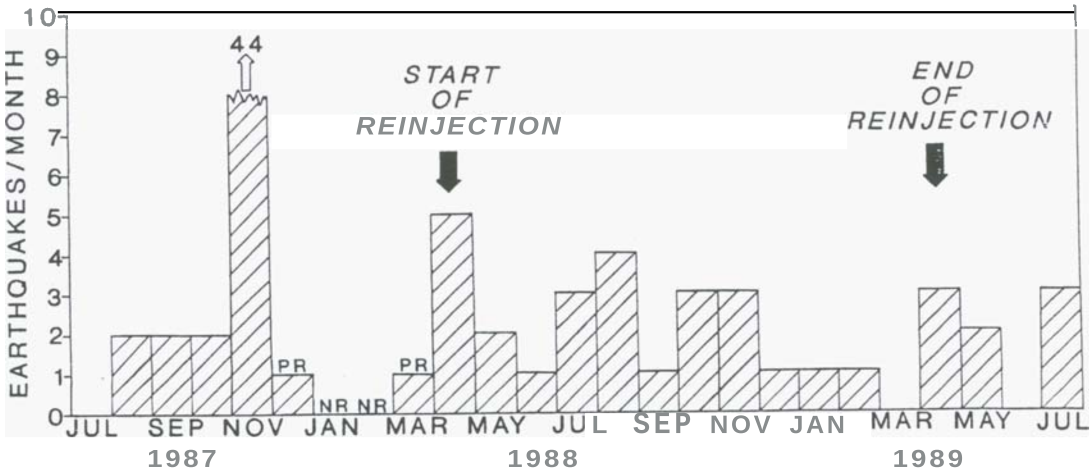

Figure 4 A 23 month record of the microearthquakes recorded on the Huka seismograph at Wairakei. All events were within 5 km of the seismograph (S-P interval ≤ 1.5 s), and had an amplitude of at least 1.0 mm on the paper record. The year long reinjection period is marked. NR indicates no seismic records due to an instrument fault for the whole month, and PR indicates that only part of a months record were obtained.

DISCUSSION

The most fundamental reason for the difference between the occurrence of induced seismicity at the two fields is indicated by the difference in the natural seismicity. The Ohaaki Field is in a region of remarkably low seismicity, in contrast to the Wairakei Field just 25 km away. Areas of very low seismicity in the TVZ may not be uncommon. Sherbum (1989) has shown that an aseismic area exists in the Western Bay of Lake Taupo, the site of the 10000 year BP Lake Taupo eruption. It is possible that major accumulations of magma are still present in this mgion. Evison et al. (1976) suggested that difference between the Taupo Fault Belt where the Wairakei Field is sited, and the Taupo-Reporoa Basin where the Ohaaki Field is sited, is due to the relatively shallow depth of a weak layer which cannot support earthquake shear slip. This raises the interesting possibility that the low seismicity in the Ohaaki area could be the result of partial melt accumulated in the crust. Alternatively, hydrothermal alteration of rocks to low strength clay minerals may play a part in low level of earthquake activity. Detailed long term seismic recording and seismic tomography studies in this part of the TVZ may provide more insight into the causes of the lateral seismicity variations.

A somewhat surprising result has been that during reinjection at Ohaaki Field this extremely low rate of microearthquake activity has not changed. This is despite the fact that Ohaaki reinjection wells were operating at wellhead pressures similar to, or even in excess of the wellhead pressures which were associated with induced seismicity during the brief injection test at Wairakei during 1984. However, the lack of seismicity during the 13 month injection test in the eastern borefield at Wairakei during 1988 and 1989 is not unexpected given the very low wellhead pressures (< 3 bars).

The absolute value of the wellhead pressure during injection may not be the critical factor determining the likelihood of induced seismicity. The injection wells at Ohaaki tend to have a slight artesian pressure, so the formation overpressure is almost equal to the wellhead pressure of 20-35 bars. WK301 has a static pressure equivalent to -24 bars (i.e. water level at 240 m depth; Figure 5). Prior to production the water levels at Wairakei would have been near the surface, but during the they decreased due to fluid withdrawal. The overpressure on the formation due injection in WK301 amounted to 44-54 bars, made up of 24 bars from filling the well, and 20-30 bars of wellhead pressure.

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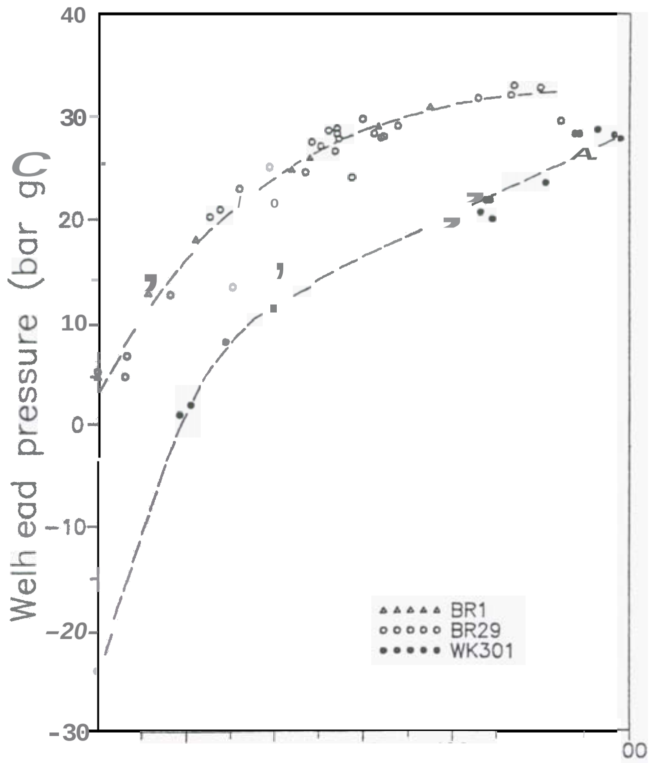

Figure 5 Injectivity curves for Wairakei and Ohaaki wells. WK301 (●) was used during the 1984 injection test at Wairakei. Ohaaki data from BR1 is indicated by open triangles (A), and BR29 by open circles (O). Note the increase in injectivity (decreased slope of the graph) with increasing wellhead pressure.

An interesting characteristic at both WK301 and Ohaaki wells is the non linearity of the injectivity curves, with injectivity increasing significantly as the wellhead pressure increases (Figure 5). This behaviour is most likely due to the progressive opening of existing fractures as well as the formation of new fractures. There are insufficient data at present to accurately determine whether there is a critical threshold pressure above which a significantly increased injectivity occurs. The scant injectivity data from Wairakei and Ohaaki Fields suggest a major change between about 10 and 35 bars above absolute pressure. This pressure may be indicative of the value of the minimum principal stress in the vicinity of the wells.

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