FIELD OBSERVATIONS OF DIAMOND AND BENDIX GEYSERS, ORAKEI KORAKO, NEW ZEALAND

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Abstract Permission was obtained to attempt field measurements on two geysers in the Orakei Korako geothermal area of New Zealand. The data obtained include temperature profiles, eruption height measurements, and time intervals between and during eruptions. These data are to be used in MULKOM numerical modelling of geyser behavior and the predicted results will be matched against the observed patterns. Work on the computer simulation is in progess. The data collected on the geysers are presented in this paper.

INTRODUCTION

Geysers are one of the rarest geological features, and they are as unique as fingerprints. No two geysers exhibit the same behavior, due to virtually endless combinations of factors such as water supply, heat supply, and underground geometry. However, despite the variety seen in geyser behavior, theoretical models have been put forth to examine the basic principles which govern the geyser eruption process. (e.g., Allen and Day, 1935; Steinberg, et al., 1981; Weir, et al., 1992) Simple laboratory models have been used to test and modify geyser theories. (Anderson, et al. 1978; Steinberg, et al, 1981; Saptadji and Freeston, 1991) Numerical modelling is another way to test ideas. (Saptadji, et al, unpublished)

The next test of geyser models must be comparison with the behavior of actual geysers. This requires the collection of field data , but there are several obstacles to this goal. Equipment must be able to withstand a high temperature, high pressure geothermal environment and its associated corrosive gases. Care must be taken when instrumenting a geyser, to insure minimum interference with its normal operation. This is to avoid collection of misleading data, as well as to prevent damage to the geyser. Research is often limited in geyser tourist areas, due to fear of damage to the attractions, and non-tourist areas may be remote, with poor access and limited electrical supply.

Two geysers in Orakei Korako, New Zealand were selected for field monitoring. Temperature profiles with depth, eruption height, and time intervals between and during eruptions were recorded. These data are presented in this paper and will be used for numerical modelling of geyser behavior.

ORAKEI KORAKO

Orakei Korako is located nearly halfway between Rotorua and Taupo, in the heart of the Taupo Volcanic Zone. (Fig. 1) Lloyd (1972) gives a detailed description of Orakei Korako; Hedenquist (1986) summarizes information on this field.

Hydrothermal activity occurs over a 1.8 km^2 area. The heat flow from Orakei Korako is calculated to be 340 MW, and the measured fluid discharge is at least 400 liters/sec (Lloyd, 1972). The heat output of the geothermal field is associated with the multiple rhyolite domes of the Maroa Volcanic Center, located immediately west of Orakei Korako.

Orakei Korako is an excellent example of a fault controlled geothermal field, with hot spring and geyser activity distributed along numerous Holocene faults. (Fig. 2) It is bounded to the north by Whakaheke Fault, and to the south by Matangiwaikato Fault. The faults in Orakei Korako are branches of the Paeroa Fault, and all are normal, northeast-southwest trending, and downthrown to the northwest. (Lloyd, 1972)

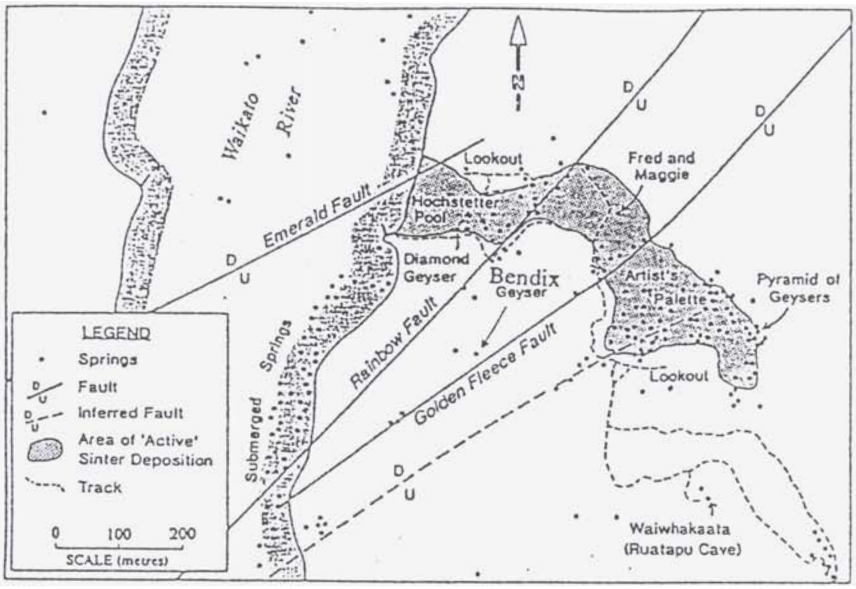
DIAMOND GEYSER

Diamond Geyser is a pool geyser associated with the Rainbow Fault. (Fig. 2) It is also less popularly known as Spring 95. It has an irregularly shaped basin, which is 1.6 m by 1.7 m at the surface and 3.7 m deep. (Lloyd, 1972) The basin is covered with silica sinter, an indication of a deep chloride water source.

Eruptions from Diamond Geyser may last minutes or hours. It plays up to 3-4 m in height, though occasionally water may be ejected up to 8-9 m. Most of the water returns to the vent after (and during) an eruption, but some runs down its mini-sinter terraces.

Fig 1. Location of Orakei Korako (Lloyd, 1972)

Fig. 2 Distribution of surface features in Orakei Korako (after Lloyd, 1972)



Field Measurements

Three K-type thermocouples were inserted into Diamond Geyser at depths of approximately 2, 2.5, and 3 meters below the surface of its pool. Fishing weights were used to prevent the thermocouples from being thrown out of the geyser. Temperatures at the three depths were measured and recorded every second for approximately 23 minutes, using a Campbell Scientific 21X Micrologger.

Data

During monitoring, Diamond Geyser erupted continuously to a height of about 0.5 m above its surface. Water was occasionally thrown to 1.5 m.

The temperature data obtained were smoothed using a five point moving average technique. Figure 3 shows the data obtained during three minutes of the eruption, representative of the data collected.

Statistical Analysis

As no clear patterns or cycles emerged from this data, the statistical correlations between temperatures at the different depths were calculated. A computer program for the analysis of time series was used to determine the cross-correlation coefficient between two series at various offsets (lags) in time.

The cross-correlation coefficient is defined as:

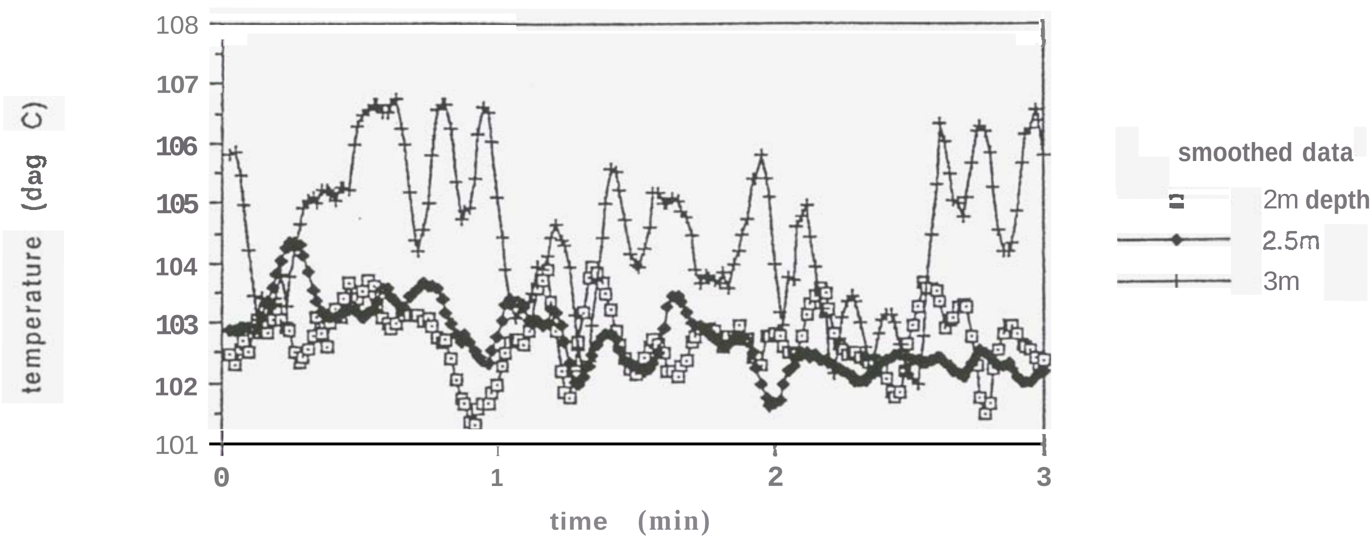
$$r_k = \frac{cov_{1,2}(k)}{s_1 s_2}$$

$Cov_{1,2}$ is the sample covariance between two series where series 2 has been shifted behind k time units relative to series 1. S represents the sample standard deviation of a series. A perfect positive correlation yields r = 1; for a perfect negative correlation r = -1. If there is no correlation r = 0. A significant correlation exists if the value of r falls outside the limits of $\pm 2/\sqrt{n}$, where n is the the number of overlapping points in the two series. The results of these calculations, for offsets (k) ranging from -30 to +30, are shown in Figure 4.

The dotted lines in Figure 4 mark the limits of significance. It is seen that little statistical correlation exists between the temperature series at a depth of 3 m and either temperature series at 2 or 2.5 m. (Figs 4b, 4c)

One possible physical explanation for this lack of correlation is the presence of some sort of convection that separates the deeper water from the shallower water.

Fig. 3 Temperature profile -- Diamond Geyser during eruption



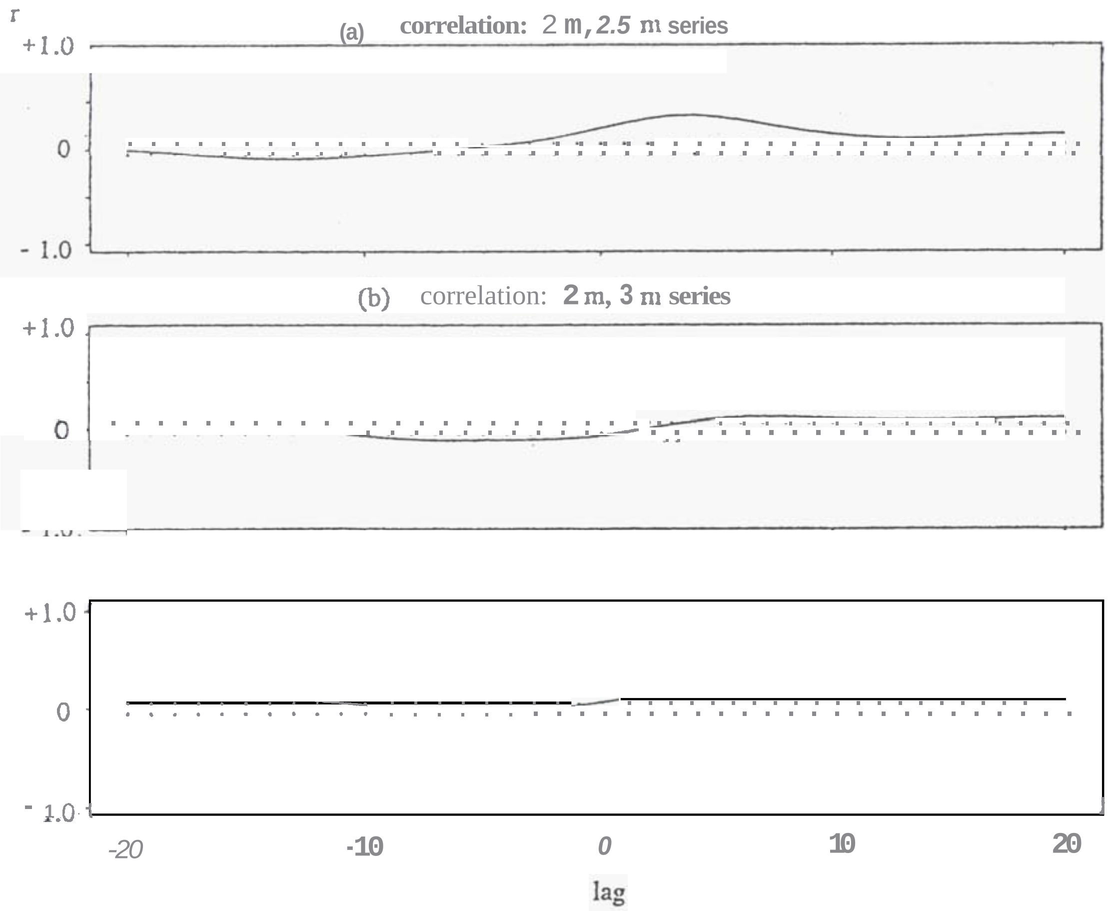


Fig. 4 Crosscorrelation coefficient of temperature series vs. offset
Diamond Geyser

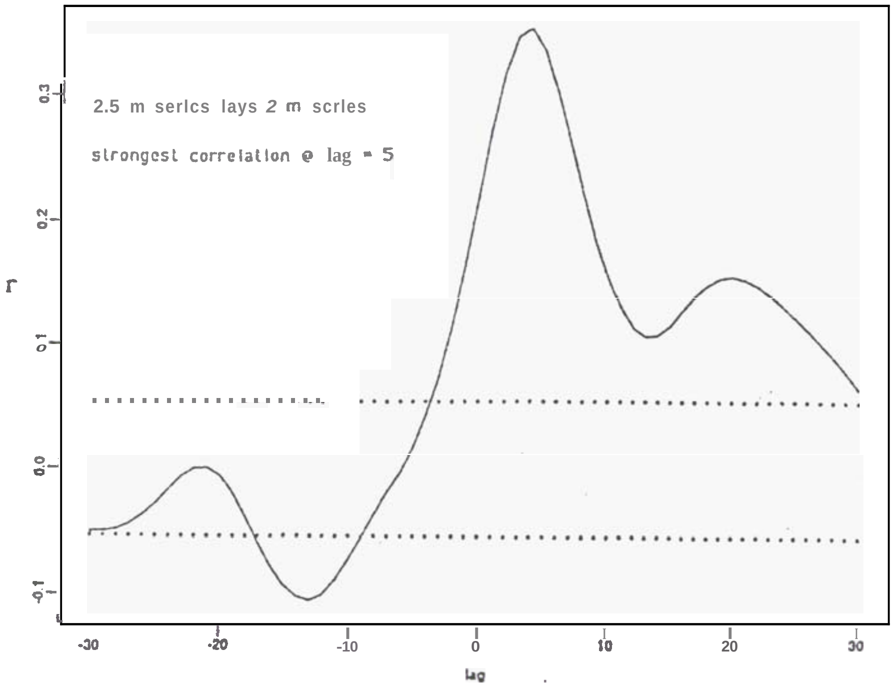


Fig.5 Correlation coefficient vs offset

2 m, 2.5 m temperature series
Diamond Geyser

(from Fig. 4a)

There is a stronger correlation for the 2 and 2.5 m series, with the correlation highest (r = .35) at a lag of +5. (Figs. 4a, 5) This means that when the temperatures in the 2.5 m series are shifted to lag behind the 2 m series by an offset of 5 seconds, the series have the strongest mathematical relation. This result was not expected, as it was thought that if a relation existed, any pattern in a deeper temperature series would be repeated at a later point in time by a shallower series. This may indicate some counterflow is occurring, but no physical explanation for this is put forth at this time.

BENDIX GEYSER

Bendix Geyser, also known as Kurapai and Spring 708, is located along the Golden Fleece Fault. (Fig. 2) Bendix is an excellent example of a columnar or pipe geyser because it is literally a pipe. The geyser was created in 1961 by Ted Lloyd, by the insertion and concreting of a pipe into the basin of a hot spring. The pipe allows a column of water to boil and erupt water and steam as a geyser.

The pipe visible in the basin is 2.34 m long, with a diameter of 11 cm. The basin is 6.4 by 3.5 m, and 2.5 m deep, elongated in the NE-SW direction, with a fissure running along this axis (the same trend as the faults in the rest of the geothermal field). It is located about 180 m southwest of the Golden Fleece Terrace, and the warm ground in between is known as the Dead Area. Lloyd (1972) describes geological conditions beneath this tract of ground where impervious sinters are intersected by SSW trending faults and fractures, slope gently west, and are overlain by 1-4 feet of Taupo Pumice. He states that rainfall can "soak into the pumice, percolate westward on the sinter/pumice contact, enter the first fracture crossing its flow path and, because the water table is beneath the surface, mix with hot water in the fractures. A high percentage of the precipitation thus enters the hydrothermal system at shallow depths."

The activity of Bendix Geyser is very dependent on precipitation. (T. Spitz, pers. comm., 1992) It erupts at highly irregular intervals; the duration of eruptions usually is 2-3 hours or 2-3 days. It once played for 80 days straight, in 1983 or 1984, and then was quiet for about a year and a half. (T. Spitz, pers. comm., 1992) Average eruption height is 6 meters above the top of the pipe, with occasional jets up to 8-9 m high. The basin is normally dry, but during an eruption it fills with water to within 0.5 -1 m of the rim. On the northeast side of the basin, the water is relatively quiet and reaches temperatures of 97 °C. However, in the southwest portion of the basin, there are large splashes of water that sometimes are ejected 1-1.5 m high and reach above the rim of the basin. Temperatures there reach 102°C.

Field Measurements

The same pipe has been in place since 1961, and is now quite corroded. Several holes have been rusted in the pipe, which allow water and steam to escape. However, they also offered the opportunity to place K-type thermocouples along the length of the pipe to obtain a temperature profile in the conduit. Thermocouples were clamped in place at the open end of the pipe ,taken as 0 meters, and at depths of 1.18 m and 2.26 m. A fourth thermocouple was wrapped with wire and tied to fishing weights (to prevent ejection), inserted at the top of the pipe, and lowered to a depth of 5.7 m. Constrictions in the channel prevented lowering it any farther. One additional thermocouple was dropped into the fissure in the southwest portion of the basin, and left at a depth of approximately 3.5 m from the top of the pipe.

A Pitot static tube was clamped in place through a hole in the pipe at a depth of 1.39 m. PVC tubing connected the Pitot tube to a wet/wet 0 - 30 psi RadioSpares differential pressure transducer, which allowed the differential pressure to be recorded, along with temperature measurements, on the Campbell Scientific logger.

Temperatures and differential pressure were measured every ten seconds. The data were recorded if the temperature reading at the bottom of the pipe was equal to or exceeded 95°C, an indication of imminent activity. Measurements were also recorded once an hour in an attempt to establish a baseline for comparison.

Data

The proprietors of the Orakei Korako Geyserland Resort have recorded the activity of the geyser since July, 1992 for the purpose of this study. The eruptions are recorded below.

			approx. start
July	13	2-3 hours	10:00am
	20	2-3 hours	3:45pm
	22	2-3 hours	4:00pm
	23	2-3 hours	4:20pm
	24	2-3 hours	11:50am
	25	2-3 hours	8:20am
Aug	2	2-3 hours	3:20pm
	10-13	continuous	
	20-25	continuous	
	27-30	continuous	

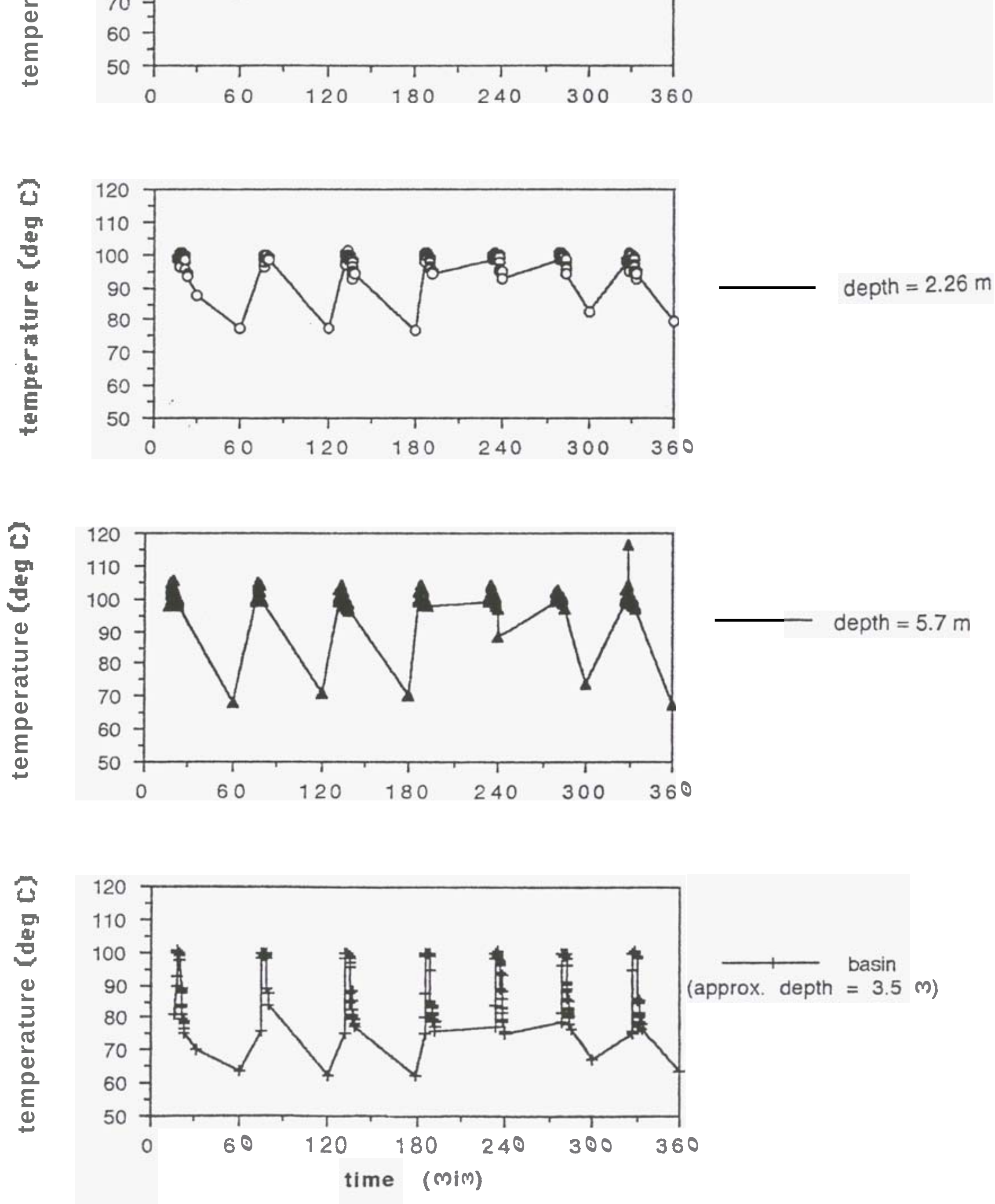


Fig. 6 Temperature profile -- Bendix Geyser

September 8, 1992

The geyser has not had a full eruption from the end of August until the time of writing. However, it has exhibited periodic steam emission, accompanied by minor splashing of water through fissures into the bottom of the basin The water then immediately seeps back into the ground. These steam emissions last two to three minutes and typically occur about once an hour.

Temperature profiles during the steam phase eruptions were recorded over a 45 hour period. An example of the data collected over a six hour period is shown in Figure 6. During these eruptions, the differential pressure was essentially zero.

The figures indicate the regularity of steam emission, and the fairly constant maximum and minimum temperatures at various depths. The top temperature readings show the greatest variation, due to exposure of the thermocouple to wind and local climate.

It should be noted that while the geyser was quiet, the deepest thermocouple, located at a depth of 5.7 m from the top of the pipe, consistently recorded temperatures ten degrees lower than the temperatures at 2.26 m depth. This may indicate a zone of cold water inflow or mixing. During a steam eruption, the temperatures at 5.7 m depth typically increased more quickly than those at 2.26 m depth, attained a slightly higher value, and cooled more quickly.

Modelling

The MULKOM-C02 code for calculating mass and heat flow in geothermal reservoirs (Pruess, 1988) is being used for numerical modelling of Bendix Geyser. A conceptual model has been produced, with estimates made for parameters such as chamber geometry, water supply and heat supply, using the methods described by Weir (1992). The MULKOM model produces temperature profiles of the geyser over a given period of time, which are compared with the field data collected. This work is on-going.

Meteorological records of rainfall and atmospheric pressure in the Orakei Korako region have been obtained. These data will be incorporated into future geyser models.

CONCLUSION

Geysers may exhibit very different patterns, both over time and from one geyser to another. During the period of observation, Diamond Geyser performed continuously. The activity of Bendix Geyser is highly dependent on rainfall.

A brief discussion of the behavior of two geysers was given here. This serves as a starting point for numerical modelling and perhaps a better understanding of the geyser eruption process.

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