EVIDENCE FOR GEOTHERMAL AREAS BENEATH LAKE TAUPO FROM HEAT FLOW MEASUREMENTS

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ABSTRACT - Temperature and heat flow measurements made in the sediments at the bottom of Lake Taupo during May to July 1992 show high heat flows (up to 4300 mW/m^2) in several separate areas of the lake. Surrounding the areas of high heat flow were areas of below average heat flow. The heat flows are thought to be the signature of geothermal systems consisting of a central plume of hot water, with cold recharge water being drawn down in the surrounding area to recharge the base of the plume.

INTRODUCTION

Lake Taupo is situated in the centre of the North Island of New Zealand at the southern end of the Taupo Volcanic Zone. The lake lies in a complex caldera formed during eruptions over the last third of a million years. Most of the lake is deeper than 100 m (Fig 1), but not a great portion is deeper than 125 m. The maximum depth of the lake is 163 m. Three geothermal fields, Motuoapa (Bibby et al., 1991), Tauhara, and Tokaanu (Fig 1) lie near the lake and geothermal activity extends to the lake edge or into the lake. Within the lake in the vicinity of Horomatangi Reef gas bubbles have been reported (Northey, 1983), which may be associated with geothermal activity.

Among the first investigations of the thermal activity in the lake floor of Lake Taupo were those made by Calhaem (1973) who measured heat flow in the lake sediments. These measurements showed four areas of high heat flow, one centred on the Horomatangi reef, one in an area to the north of Horomatangi reef, one in the very northwest of the lake, and one in the southwest near Tokaanu. Lake-borne resistivity measurements (Caldwell & Bibby, 1992) show low resistivities which are indicative of geothermal conditions, covering a considerable area centred on the Horomatangi Reef. Areas of moderately low resistivity occur in the northwest and southwest. The cause of these moderately low resistivities is not clear but may be due either to the type of sediments or to thermal activity.

A series of heat flow measurements were made in the bottom sediments of Lake Taupo to delineate areas of high heat flow and to determine the magnitude of the heat flow in areas of low resistivity. These heat flow measurements were made using state-of-the-art techniques and give heat flow values that are considerably more accurate than those obtained by Calhaem (1973).

Calhaem's heat flow probe consisted of two temperature sensors 1.5 m apart, from which only a single temperature difference was obtained. Neither the angle of penetration, the shape of the sediment temperature profile, nor the bottom water temperatures were measured. Hence it was not possible to correct for skew penetrations and very difficult to estimate the depth of penetration of the probe into the sediments. Significant errors can be introduced if the depth and angle of penetration are not known accurately. Our heat flow probe could measure all these parameters and therefore enabled more accurate heat flow values to be obtained. prior to the heat flow measurements, the lake bottom water temperatures had been measured for almost 3 years, and these were used to correct for bottom water temperature changes. The use of measurements gives more accurate results than a theoretical model of the type used by Calhaem for bottom water temperature corrections.

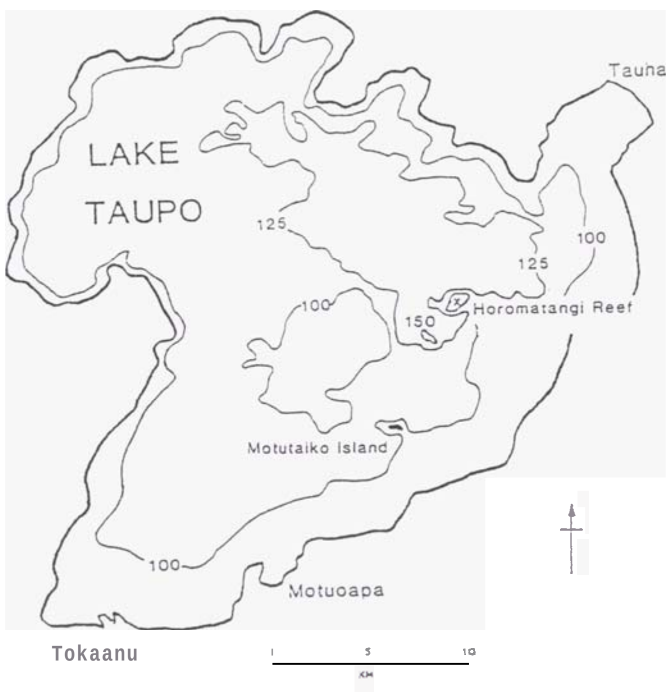

Fig 1. Map showing the bathymetry (m) of Lake Taupo, and the location of geothermal fields lying near the lake.

HEAT FLOW MEASUREMENTS

Heat flow measurements were made in the lake-bottom sediments using the marine technique (Langseth, 1965), in which a temperature probe is dropped into the sediments and a (near) vertical temperature profile measured. The thermal conductivity of the sediments is measured either in-situ, or in the laboratory from a core sample obtained using a gravity corer. The heat flow is calculated from the sediment temperature gradient and thermal conductivity.

Heat Flow Instrument

The temperature probe consists of a stainless-steel strength member, 2 m in length, with thin stainless steel tubing containing the temperature sensors mounted parallel and alongside, surmounted by a larger diameter cylindrical steel case containing a water-tight recording instrument (Fig 2). Five sensors, positioned along the length and within the

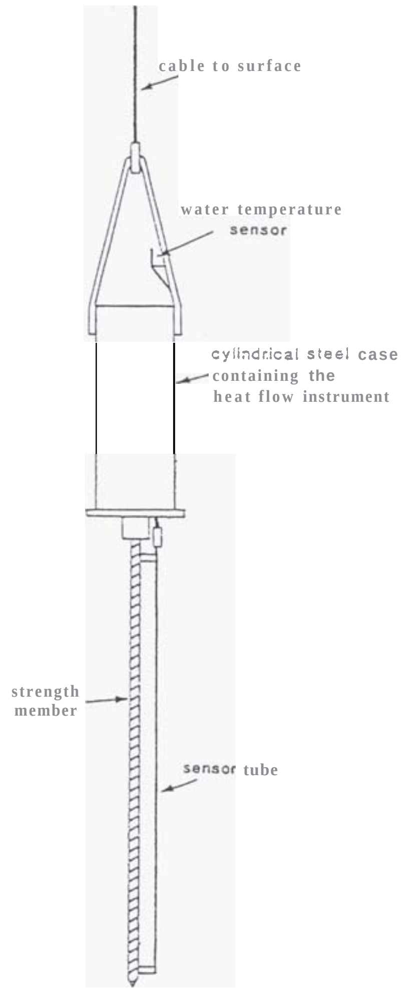

Fig 2. A schematic diagram of the temperature probe.

stainless steel tubing, measure sediment temperatures, and a sixth located above the cylindrical case, measures the bottom water temperature. The temperatures are measured to an absolute accuracy of a few hundredths of a degree (Celsius) but it is possible to resolve differences of a few thousandths of a degree. A heater lies along the length of the thin stainless steel tubing for making in-situ thermal conductivity measurements. Inside the case are two orthogonal tiltmeters which measure the angle of penetration of the probe into the sediments. Measurements are stored in digital form in solid state memory within the instrument until the probe is brought on board the boat where it can be interrogated by a computer.

MEASUREMENTS

Successful measurements were made with the temperature probe at 57 sites. The sites are more closely spaced over features of interest than elsewhere. The location of each site was determined by a Magellan GPS navigation system which was mounted in the boat. Positions are accurate to about 30 m.

RESULTS

Seasonal Water Temperature Corrections

The bottom water temperatures of Lake Taupo vary slightly with an annual cycle, as seen in the temperature measurements plotted in Fig 3 which were made by the Taupo Laboratory of DSIR Marine and Freshwater (T. Viner pers com) and DSIR Geology and Geophysics prior to the

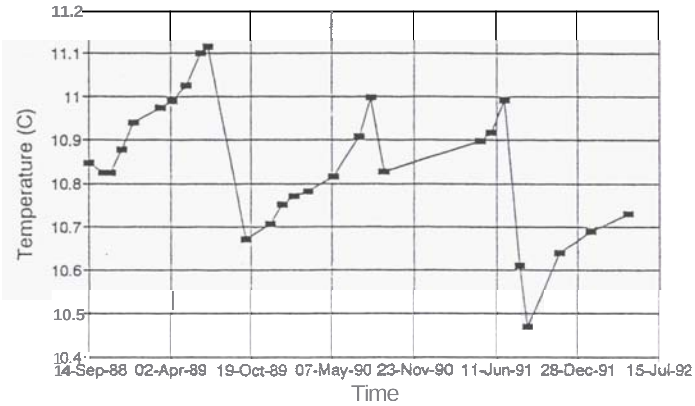

Fig 3. Plot of Lake Taupo bottom water temperatures from September 1988 to May 1992.

survey. Temperature variations propagate down into the sediments as an attenuating wave and alter the sediment temperature profile. The effect on the sediment temperature profile is barely discernible in profiles exhibiting average or above average heatflow, as the bottom water temperature variations are quite small. The effect is noticeable in the sediment temperature profdes which have a low gradient. To reconstruct the sediment temperature profile which would exist in the absence of bottom water temperature variations it is necessary to remove these effects using the bottom water temperatures measured prior to the heat flow measurements. This was done using Fourier analysis (Whiteford, 1992). The corrected sediment temperature profde can then be used to calculate the sediment temperature gradient. A typical sediment temperature profile is shown in Fig 4. At the time of writing, the in-situ thermal conductivities had not been analysed, but instead the values of sediment thermal conductivities obtained by Calhaem (1973) were used. The thermal conductivity does not vary much throughout the lake, and the variation is insignificant when compared with the variation in sediment temperature gradients. Most of the thermal conductivities measured by Calhaem were within about ±5% of 0.85 w/m/°C, and a value of 0.85 w/m/°C was chosen to calculate the heat flows fiom the temperature gradients.

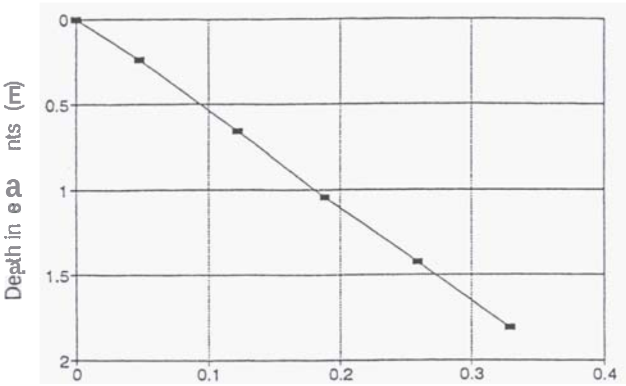

Fig. 4. A typical sediment temperature profile measured by the temperature probe in Lake Taupo. The depth is the depth into the sediments.

The heat flow patterns for high heat flow, average heat flow, and below average heat flow are shown in different shadings in Fig 5. The unshaded areas are where measurements have not been made. Areas of high heat flow are apparent in seven separate localities. The largest area is centred on the Horomatangi Reef which is to the east of the centre of the lake. Two large areas of high heat flow are in the north west. The remaining four areas of high heat flow are small. Two lie adjacent to the southeastern coast, and of the other two, one is north west of the Horomatangi Reef, and the other is to the south west.

Below average heat flows are measured over a larger area than either the high heat flow, or the average heat flow. The below average heat flows generally surrounds the areas of high heat flow. Sometimes the transition from high heat flow to below average heat flow is rapid, and sometimes gradual with a region of average heat flow being measured between high heat flow and below average heat flow. Average heat flow also occurs in areas independent of the high heat flow-below average heat flow regimes, such as the one in the southwest.

DISCUSSION

The most striking feature of the heat flow pattern is the large area of below average heat flow (<50 mW/m^2), which generally occurs around the areas of high heat flow. Only a relatively small proportion of the lake bottom has heat flow in the range 50-100 mW/m^2 which, for the purpose of discussion has been termed average heat flow. The world wide mean heatflow is 80 mW/m^2 (Chapman & Ryback, 1985).

The measurement of high heat flow in the Horomatangi Reef area complements Calhaem's (1973) results and is consistent with the proposal that geothermal activity occurs in this area. In this area several values of heat flow are over 1000 mW/m^2, and the highest is 4300 mW/m^2. The latter corresponds to a temperature of 4.5°C above ambient at a depth in the sediments of 1 m. The high heat flows correspond to the low resistivity area centred on the Horomatangi Reef (Caldwell & Bibby, 1992).

All of the other areas of high heat flow coincide with areas of low resistivity and suggest that the low resistivities are of geothermal origin, except for the high heat flow area the northeast where the resistivity is not low.

The below average heat flows and the high heat flows are thought to characterise the features of a geothermal-hydrothermal system in which hot saline waters convect upwards in the centre of the area as a plume, and cold ground water migrates downwards in the area outside the plume to supply recharge to the plume at its base. The area above the plume is characterised by high heat flows and low resistivities and outside the plume the cold water migrating downwards gives rise to below average heat flows. The shape of the plume and hydrological flows would be controlled by the permeability of subsurface structures.

The high and average heat flow values observed in this work are similar to the range measured in Lake Rotorua (Whiteford, 1992), where values up to 3000 mW/m^2 were observed, and where below average values were also measured. A similar range of average and high heat flow values were measured in Lake Taupo and Lake Rotoiti by Calhaem (1973), but Calhaem did not report below average heat flows. Geothermal fields, on land, also have similar conductive heat flows of up between 1000 and 5000 mW/m^2, with hot spots of over 100,000 mW/m^2. In lakes, the sediments act like a blanket and smooth out rapid lateral changes occurring at hot spots; heat flows of over 100,000 mW/m^2 are generally not observed. Away from the geothermal fields on land below average heat flows have been measured and explained by the downward movement of ground water (Studt & Thomson, 1969).

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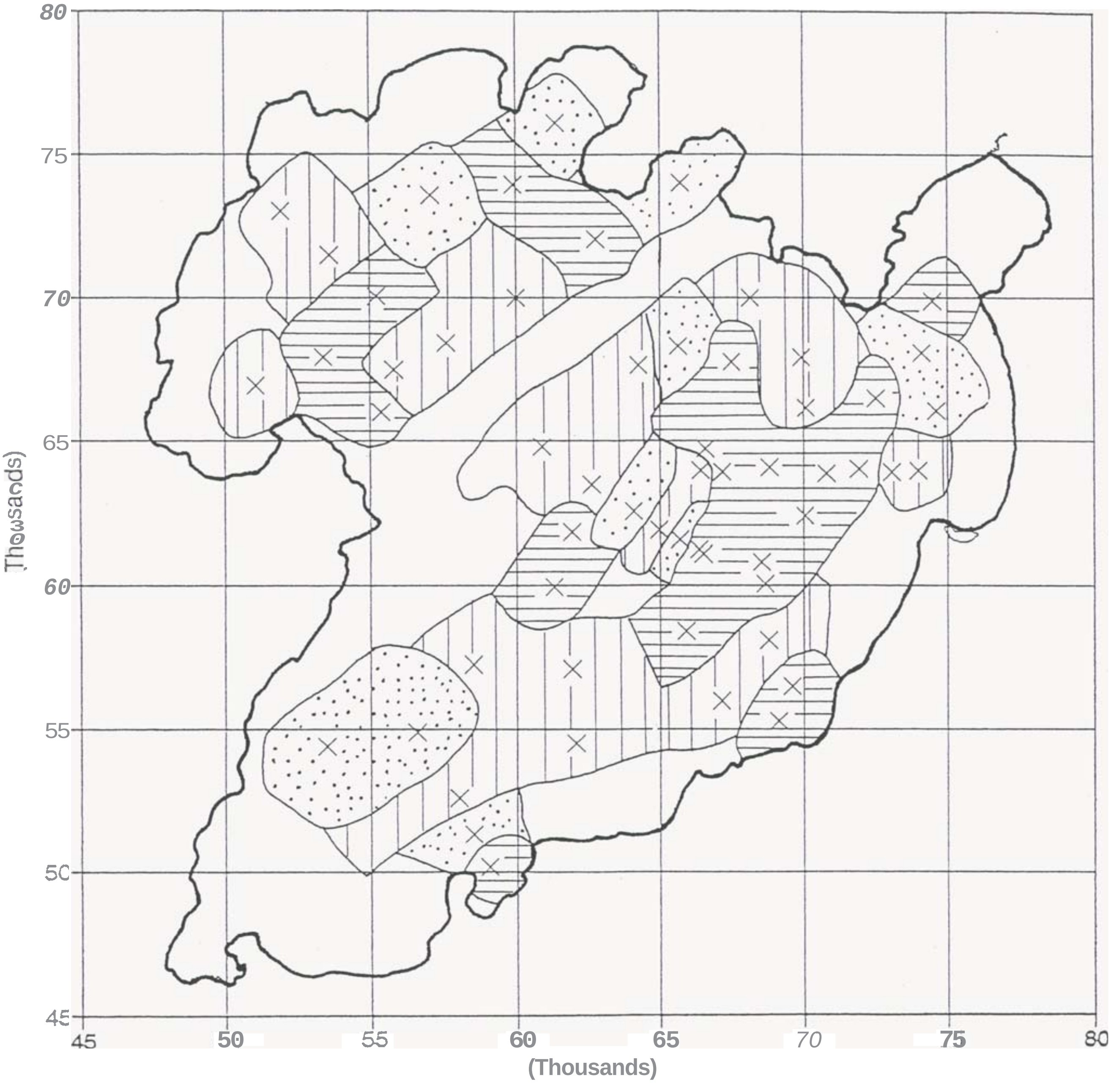

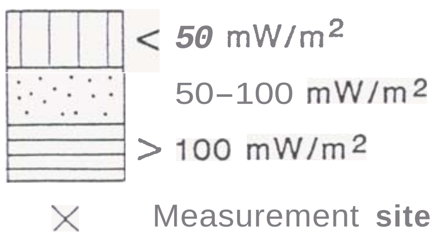

Fig. 5. The Lake Taupo heat flow pattern for high heat flow (>100 mW/m^2), average heat flow 50-100 mW/m^2), and below average heat flow (<50 mW/m^2). The location of measurement sites is also shown.