74. Terrestrial Heat Flow in Lake Biwa, Central Japan

Preliminary Report

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During the past decade, the number of terrestrial heat flow measurements in and around the Japanese Island Arc has increased up to 500 (Uyeda and Vacquier, 1968; Watanabe et al., 1971; Yasui et al., 1971). As a result, the Japanese region has become one of the areas in the world that are most densely surveyed geothermally. The measurements have revealed that heat flow is low in the trench zone and uniformly subnormal in the Pacific Ocean basin in front of the trench zone, while it is high in the continent-ward zone of the arc and the marginal seas, such as Japan Sea, Okhotsk Sea and Okinawa Trough. Such a distribution of low and high heat flows is probably characteristic to certain active island arcs and provides a clue to understanding the tectonics associated with plate subduction (Hasebe et al., 1971; Matsuda and Uyeda, 1971). In order to investigate the thermal processes under island arcs more thoroughly, it is desirable to make more detailed heat flow surveys in the transitional zone between high heat flow and low heat flow zones, which lies along the axis of an island arc. Most heat flow measurements on the land area have been made utilizing suitable deep mines or boreholes which are not available easily. One possibility for obtaining more additional data for land heat flow is to utilize lakes of which the bottom has a relatively stable temperature. In fact, such an attempt has been made in some lakes recently, utilizing the techniques of oceanic measurements (Diment and Werre, 1965; Hart and Steinhart, 1965; Lubimova and Shelyagin, 1966; Sclater et al., 1970; Hanel, 1970, Herzen et al., 1972). When the lake or the sea is shallow, however, the bottom temperature varies with time considerably, so that the temperature in the bottom sediments is suspected to change with time also. In such a case conventional Bullard-type oceanic heat flow probes are not suitable for measuring the true geothermal gradient. We, like

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some of the above authors, have also been trying to develop a technique
of heat flow measurement at shallow waters by utilizing longer probes
so that the effects of time variations of bottom temperature may be
eliminated. So far in the Japanese area, however, we have had no
reliable heat flow value in shallow waters against which our modified
“oceanic” measurement could be checked.

Recently a group headed by one of the authors (SH) drilled a
borehole in the central part of Lake Biwa, Central Japan, to sample a
long core of bottom sediments. This borehole reached a depth of
197.2 m below the lake bottom or of 262.4 m below the lake surface,
and provided a good opportunity for determining the reliable heat
flow value in the lake. Present paper reports the heat flow measured
in this hole by the conventional land heat flow technique.

The temperature gradient was measured by a thermistor thermo-
meter with a 500 m insulated cable and the thermal conductivity of
the sediment cores by von Herzen-Maxwell type needle probe method.
The temperature measurement in the borehole was conducted six times
during the drilling period from November 1 through December 19,
1971 as shown in Table I, the results being summarized in Fig. 1,
with the results of thermal conductivity measurements of the
cores. The water temperature at the bottom varied within a range of
about 0.4°C during this period. This range of temperature variation
was much smaller than that at the surface. The temperature vari-
ation in the upper 50 meter layer of the sediment, however, was greater
than that at the lake bottom. During drilling, the lake water at a
depth of about 10 m was circulated inside the casing of the borehole.
Apparently the variation in the temperature of this circulating water
affected the temperature in the upper-most part of the borehole. The
temperature gradient in the upper 20 meter layer of the sediment is
larger than that in the deeper part (Fig. 1). This is partly due to the
thermal disturbance by the water circulated during drilling, and partly

to the smaller thermal conductivity of the upper layer. It is also pos-
able that the temperature of the lake bottom at the time of measure-
ment was lower than its annual mean. However, the temperature
gradient in the sediment layer deeper than 150 meter from the lake
surface was fairly stable. The mean value of the gradient in the layer
between 150 meters and 250 meters from the lake surface is $5.5 \times 10^{-4}$°C/cm.

Thermal conductivity measurement was made on Dec. 31, 1971
on the cores which had been stored in a freezer. The cores were
thawed before the measurements. Since the effect of freezing and
thawing of sediments on their thermal conductivity is not known, this
way of measurement was probably not satisfying. The thermal con-
ductivity of the sediments thus measured, however, appeared to have a systematic increase with depth (Fig. 1); especially in the uppermost layer, which may be less consolidated than the deeper layer. The mean thermal conductivity in the layer where the temperature gradient was established, i.e. the layer from 150 meter to 250 meter depths from the lake surface, is $2.20 \pm 0.09 \times 10^{-3}$ cal/cm sec °C. From these values, it was concluded that the magnitude of the heat flow value in Lake Biwa is $1.2 \times 10^{-6}$ cal/cm² sec.

Fig. 1. Vertical profile of temperature and thermal conductivity in Lake Biwa.
Thermal conductivity measurement on the more cores was made on Dec. 13, 1972, i.e. about a year after the first measurement. The results of the later measurement are plotted in Fig. 1 by encircled crosses. For heat flow assessment, we used only the values obtained by the first measurement and included the later values only for reference, since the core specimens stored in a freezer for a year, during which an unwanted thawing and re-freezing took place, appeared to have changed their properties considerably; loss of water, for example, was apparent.

The value of heat flow might be affected by the existence of the lake itself (Lachenbruch, 1957, Johnson and Likens, 1967; Hanel, 1970). In the case of a circular lake, the following formula was derived for the steady-state anomaly (dt/dz) at the center (Lachenbruch, 1957).

\[
\frac{dt}{dz} = - \frac{\Delta t}{R} \frac{1}{\left[1 + (z/R)^2\right]^{3/2}}
\]

where \( R \) is the radius of the lake, \( z \) is the depth below the lake bottom and \( \Delta t \) is the temperature difference between the lake and its surroundings at \( z=0 \). Though Lake Biwa can scarcely be considered to be circular in shape, the order of magnitude of the effect of temperature contrast between the lake bottom and its surroundings may be estimated by this formula as a first approximation. Putting \( R=10^6 \) cm, \( \Delta t=10^5 \)°C and \( z=10^4 \) cm, we obtain a magnitude of \( 10^{-5} \)°C/cm for the anomalous temperature gradient which is negligibly small compared with the measured temperature gradient.

The observed thermal gradient might be disturbed by the effect of drilling also. This problem is to be studied by comparing the gradient measured so far with what will be measured after the steady state is attained in future. For this purpose, a thermistor chain was put inside the borehole at the termination of the boring project.

Despite the possible disturbances caused by drilling and the uncertainty about the thermal conductivity as mentioned above, the

| Date       | Depth of the borehole bottom | Time of measurements after cessation of drilling operation |
|------------|-----------------------------|----------------------------------------------------------|
|            | From the lake bottom        | From the lake surface                                    |
| November   |                             |                                                          |
| 11         | 30 meters                   | 95 meters                                                | less than 1 hours |
| 12         | 83                          | 148                                                      |
| 14         | 83                          | 148                                                      | 2 days           |
| December   |                             |                                                          |
| 5          | 143                         | 208                                                      | 1 day            |
| 13         | 174                         | 239                                                      | 20 hour          |
| 19         | 197.2                       | 262.4                                                    |
magnitude of $1.2 \times 10^{-6}$ cal/cm² sec is consistent with the heat flow distribution of the Japanese region obtained so far. Fig. 2 is the most up-date heat flow distribution taken from the Japanese UMP-Monograph (1972). Although final conclusion must await the steady-state data from the buried thermistor chain, it seems that the heat flow contour needs only a slight modification as indicated by the dotted curve in Fig. 2.

Fig. 2. Smoothed heat flow distribution in and around Japan derived from values averaged in one degree grid in the latitude and longitude.
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