Temperature Microstructure in Crater Lake, Oregon[1]

ABSTRACT

Vertical temperature profiles made in Crater Lake with a modified XBT system show that layers of nearly isothermal water, separated by sheets of relatively high temperature gradient, exist in the upper 265 m of the lake. The microstructure was better developed and more persistent in late than in early summer. The relationship between temperature microstructure and rate of vertical heat transfer in lakes is still undetermined.

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Observations of temperature microstructure in the oceans have been reported (e.g., Stommel and Federov 1967; Tait and Howe 1968). We have measured temperature microstructure (Neal et al. 1969) and salinity (conductivity) microstructure in the Arctic, where the isothermal layers were also isohaline.

Different rates of diffusion for salt and heat may produce the layered structure found under certain oceanographic conditions (Turner 1967; Stern 1969). If diffusion of heat and salt are both required for the production of microstructure, then microstructure should not exist in fresh-

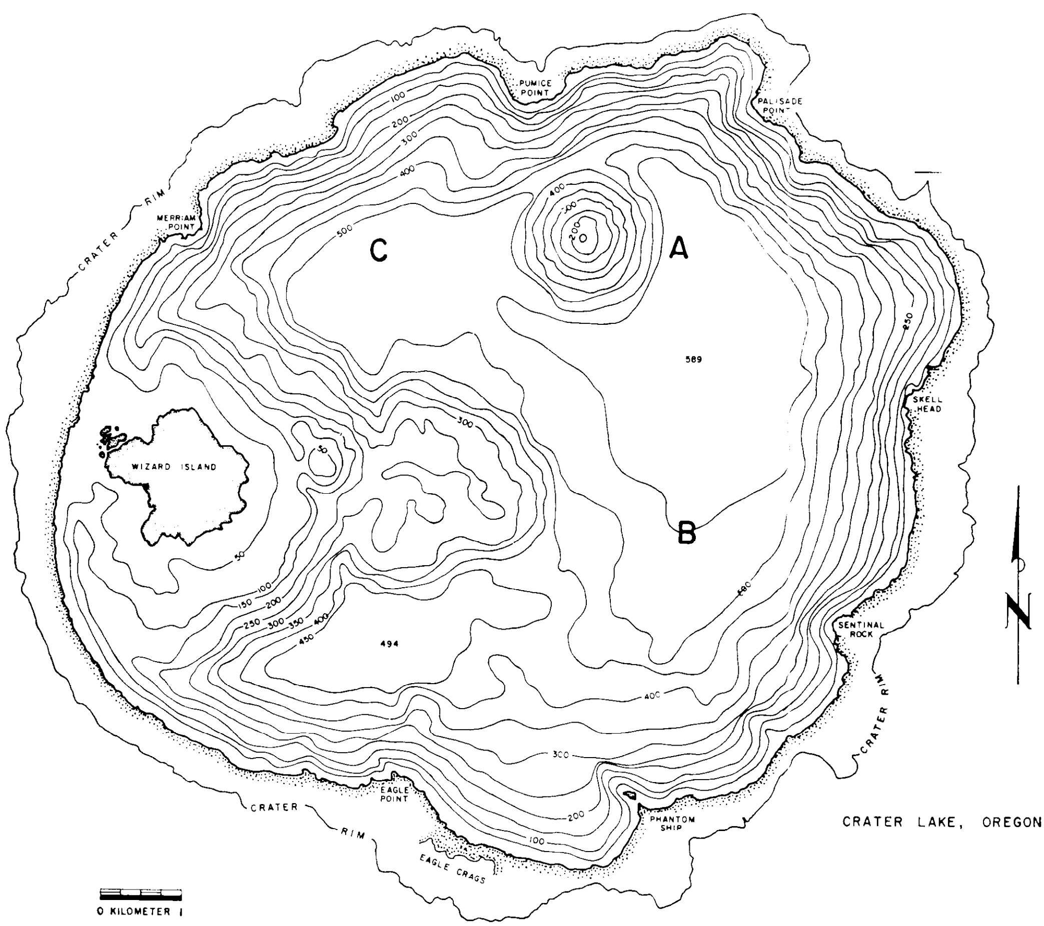

FIG. 1. Bathymetric chart of Crater Lake showing sampling stations A, B, and C (adapted from Byrne 1965).

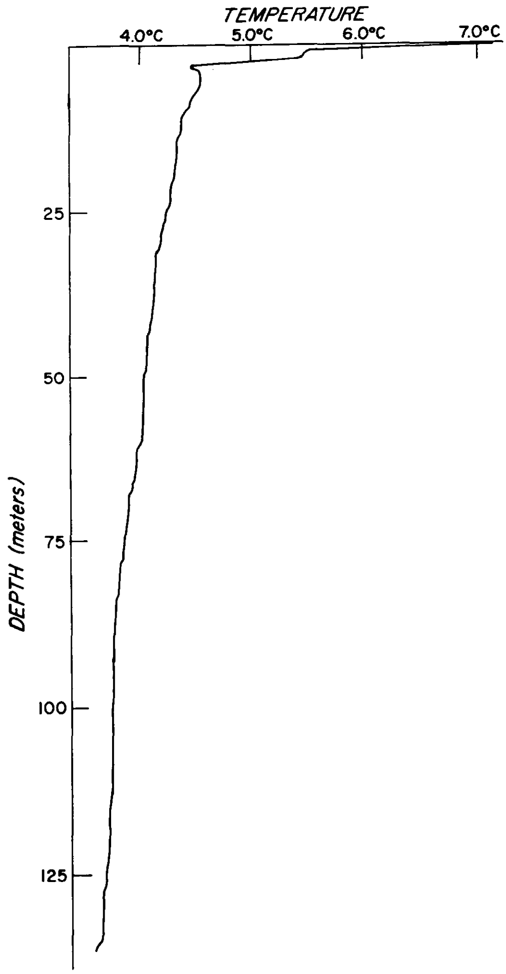

FIG. 2. A portion of a temperature profile taken with an XBT probe with drag chute at station A (June 1969).

water. We decided to test this hypothesis by making measurements in Crater Lake, Oregon, during summer 1969. Simpson and Woods (1970) have since reported temperature microstructure in Loch Ness, a freshwater lake.

Certain features of Crater Lake make it more comparable to an ocean than are other lakes in this area. Although its surface area is only about 55 km^2, it is very deep, averaging 325 m with a maximum of 589 m, the second deepest lake in North America (Byrne 1965). Since it occupies a caldera, the ratio of its land drainage area to the lake surface area is small (about 1 : 4). The lake has no surface outlet and no permanent stream flowing into it. The most important source of water is direct precipitation (Phillips 1968). There is little precipitation in summer, so conditions in the lake during summer are generally not influenced much by land runoff.

METHODS AND EQUIPMENT

We used the modified expendable bathythermograph (XBT) system that we have been using for temperature microstructure studies in the Arctic. These XBT probes were designed to free fall through seawater at about 6 m/sec. We reduced the fall rate to about 2 m/sec by attaching a drag chute. We also lowered some of the probes by winch. Circuitry modifications (for details *see* Denner et al. 1971) increased the resolution to better than 0.002 C. The time constant of the thermistors mounted in the probes is about 100 msec.

RESULTS

We began our work in Crater Lake in late June 1969. At that time the epilimnion was practically nonexistent. The temperature dropped sharply from 7.2C at the surface to less than 5C at 6 m. Weather conditions were unstable then, with frequent periods of rain, snow, or both.

We measured vertical temperature profiles at stations A, B, and C (*see* Fig. 1). We used one probe as a regular free fall unit at station A. Temperature microstructure was evident in the profile obtained. When we used the XBT probes with drag chutes at all three stations, the temperature microstructure was more clearly shown. Figure 2 shows the upper portion of a profile taken at station A by a probe with drag chute attached. The apparent inversion below the first step is due to recorder overshoot. Profiles obtained with probes that were allowed to fall to the

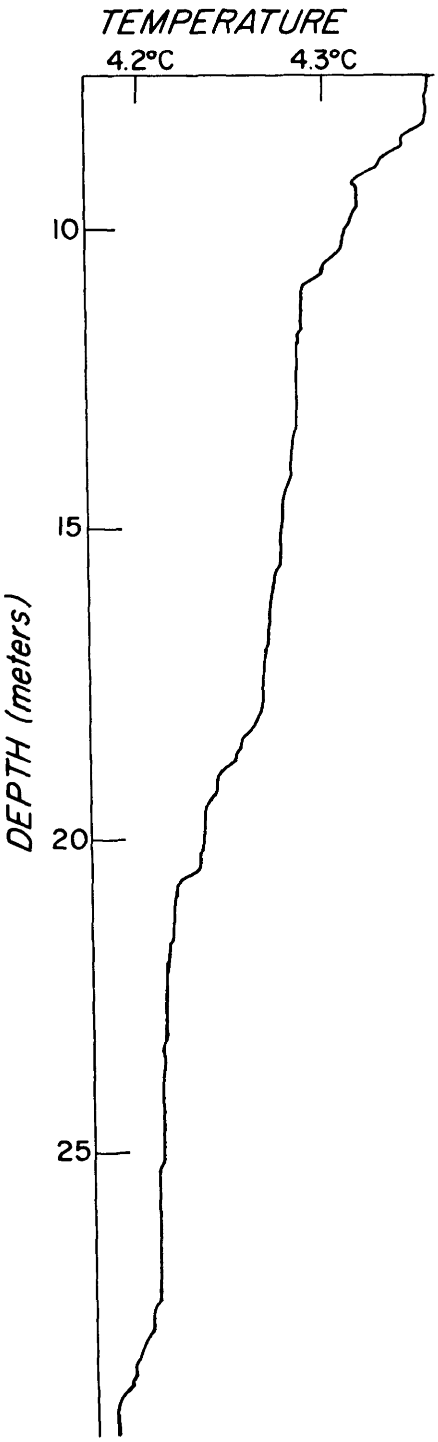

FIG. 3. A temperature profile produced by an XBT probe when lowered by winch at 40 cm/sec (June 1969).

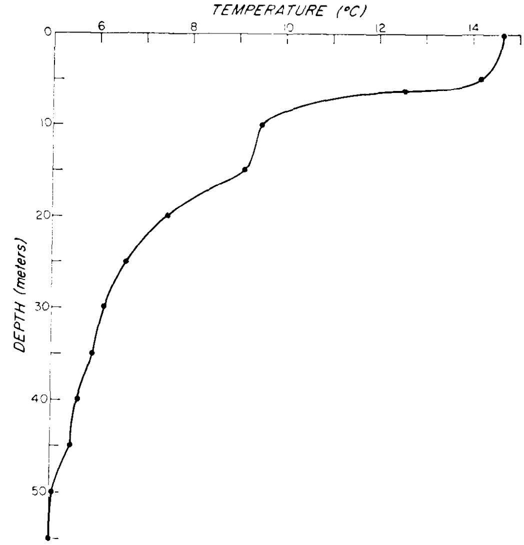

FIG. 4. A typical temperature profile drawn from measurements made at discrete intervals (August 1969).

bottom showed layers down to 265 m. The deepest temperature step (at about 265 m) was observed at all stations, as was the temperature step just beneath the surface. Other layers, however, could not be traced from one station to another.

When the probes were allowed to free fall, either with or without a drag chute, the range of temperatures covered in the fall was too great to use high sensitivity. Therefore we lowered probes by hand winch through smaller temperature ranges (Fig. 3). Although some of the steps shown in Fig. 3 were identifiable in profiles taken several hours later, most were not. The structure seemed to be in a nonsteady state as the number and thickness of layers changed within the shortest sampling interval (20 min).

Our work in June was terminated when inclement weather (rain, wind, and snow) set in. However, we were able to continue it later in the summer under calm and clear weather conditions.

A typical August temperature profile (surface to 55 m) taken with a conventional thermistor probe is shown in Fig. 4.

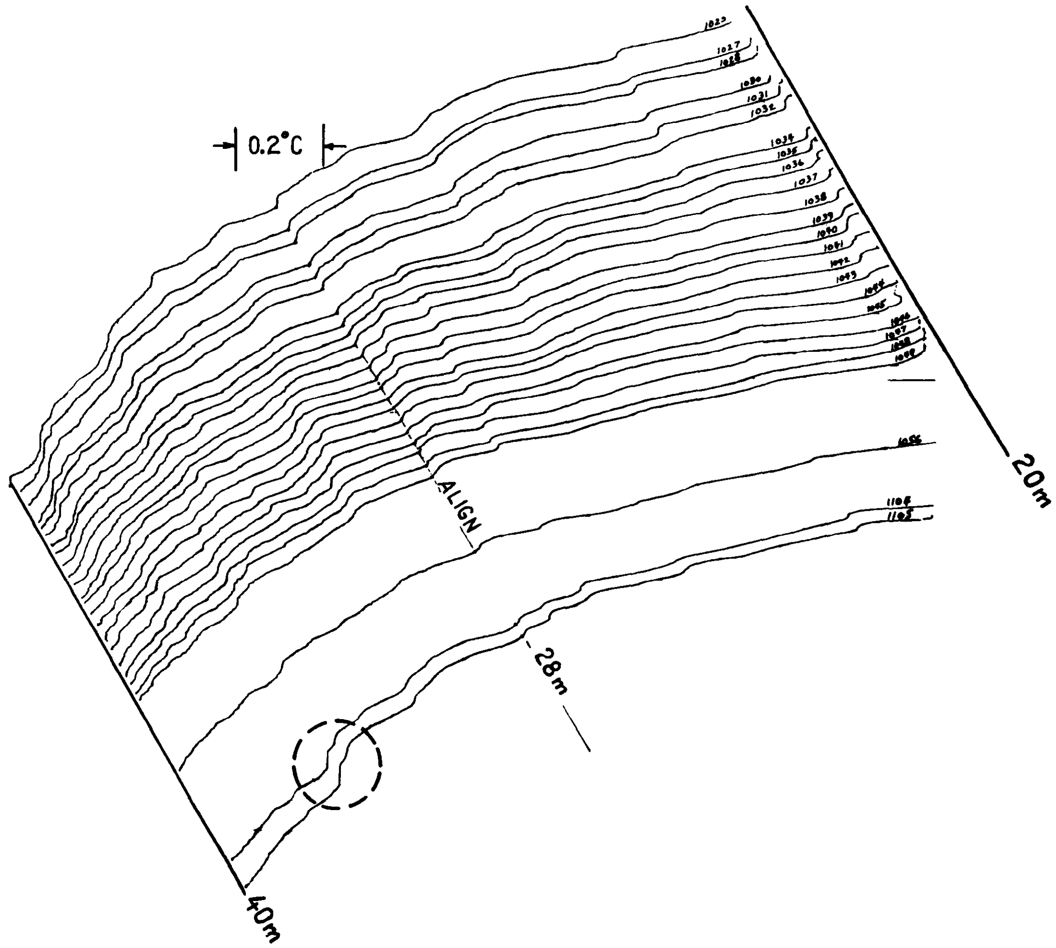

Fig. 5. Repeated profiles obtained by lowering the XBT probe by winch at station C (August 1969). That portion of the profile within the circle was measured at still higher sensitivity (*see* Fig. 8).

The epilimnion was shallow—the greatest temperature gradient was above 10 m.

To avoid any surface-related changes we confined our microstructure measurements to depths greater than 20 m. High resolution measurements made by lowering the probe at 40 cm/sec between 20 and 120 m are shown in Figs. 5, 6, and 7. Repeated profiles taken over several of those steps showed that most of them persisted for several minutes. An example of a series taken at approximately 1-min intervals over the region from 20–40 m is shown in Fig. 5; all but two of the steps in that interval persisted for the entire series of measurements. The step just above the alignment mark at 28 m appears to have merged with the step at 28 m while the step just below 20 m seems to have vanished during the first part of the measurement period but reappeared in the last two profiles.

We increased the sensitivity of our instrument still more and took another time series. The results are shown in Fig. 8 and cover the interval shown within the circle in Fig. 5. The probe was lowered through the interval at 30 cm/sec once every minute. The step at 34 m persisted throughout the series even though it ap-

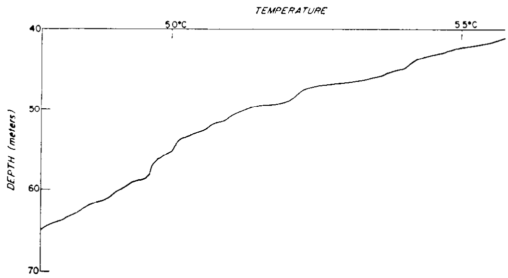

FIG. 6. Profile showing microstructure between 40 and 65 m (August 1969).

parently underwent some changes in form. Since the lowering was done by hand winch, some of the change in profile shape could be due to variations in lowering rate. Internal waves could also have caused these variations.

DISCUSSION

Crater Lake contains dissolved solids at about 80 ppm in the upper layers (Phillips 1968), but the TDS is less than the mean salinity difference between adjacent

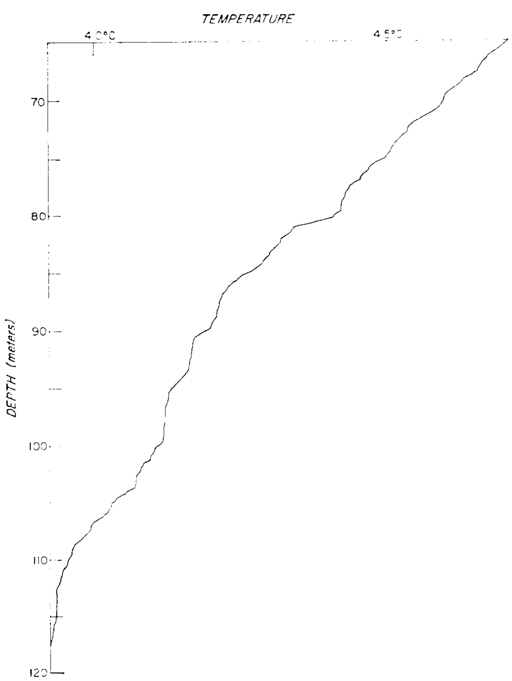

FIG. 7. Profile showing microstructure between 65 and 120 m (August 1969).

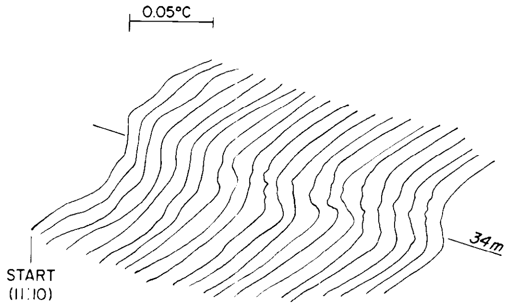

FIG. 8. Repeated profiles taken through the section enclosed in the circle of Fig. 5 (August 1969). The profiles were taken at 1-min intervals.

layers in the Arctic Ocean. Therefore we do not think they play a role in the formation and maintenance of microstructure in the lake.

The downward mixing of heat by wind and surface wave action, although important in transferring heat through the epilimnion, is unlikely to have any affect on the distribution of temperature below the thermocline during late summer. The temperature microstructure must therefore arise from other causes. Possibly diffusion associated with turbulence produces a stepwise transfer of heat downward. The exact nature of this process is unknown.

Extensive fieldwork will be required to provide a complete picture of the microstructure in Crater Lake. However, the data we have obtained so far indicate the layers are more persistent in late summer than in spring; year round studies may provide information regarding the onset of temperature layering. The relative inaccessibility of the lake during much of the year makes synoptic measurements extremely difficult until continuously recording temperature measuring systems (now being planned) are installed.

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VICTOR T. NEAL
STEPHEN J. NESHYBA

Department of Oceanography,
Oregon State University,
Corvallis 97331.

WARREN W. DENNER

Department of Oceanography,
U.S. Naval Postgraduate School,
Monterey, California 93940.

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