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Thermal microstructure on a lake slope[1]

Abstract—As shallow water is approached via a steep lake-bottom slope, increased mixing of heat is indicated by the presence of a highly "stepped" temperature profile. This mixing activity operates over a wide range of vertical scales.

Observations near Bermuda by Wunsch (1972) of vertical temperature profiles show that temperature microstructure increases in amount as the island is approached, and indeed one can see on the traces shown that the profiles are more steplike near the island, smoother in deeper water. The asymmetry of the microstructure in azimuth about the island led Wunsch to conclude that the mixing is associated with the mean flow past the island, rather than being caused by incoming internal wave energy (Cacchione and Wunsch 1974). The mechanism of mixing on slopes is likely an important element in determining the vertical structure of oceans and lakes, but no other observations of this effect have been reported, and the effect has not been seen in freshwater.

In a study of the thermal structure of freshwater Lake Tahoe (California-Nevada), we observed a quite similar effect in the seasonal thermocline as the slope was approached on a number of occasions. On one day a line of stations (Fig. 1) was run across a very steep slope with a temperature-microstructure instrument (Caldwell et al. 1975). The resulting profiles (Fig. 2) show the increased "steppiness" in shallower water to an even greater degree than Wunsch's traces. Profile E was taken last, so the increase was not progressive in time, but in space. The steps have vertical scales up to 10 m, and die out horizontally in 500 m. The similarity of the two most shallow profiles is especially striking. Evidently these structures are coherent over a cross-slope distance of a few meters, but since profile E is different in detail they are not coherent over 200 m.

The mechanism demonstrated by Cac-

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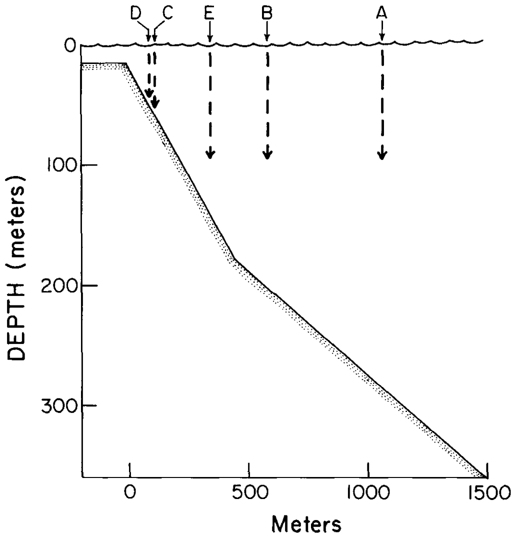


Fig. 1. Locations of temperature microstructure profiles. Stations are in northwest part of lake, on a bearing of 110° magnetic from Lake Forest Coast Guard Station, about 3 km from station.

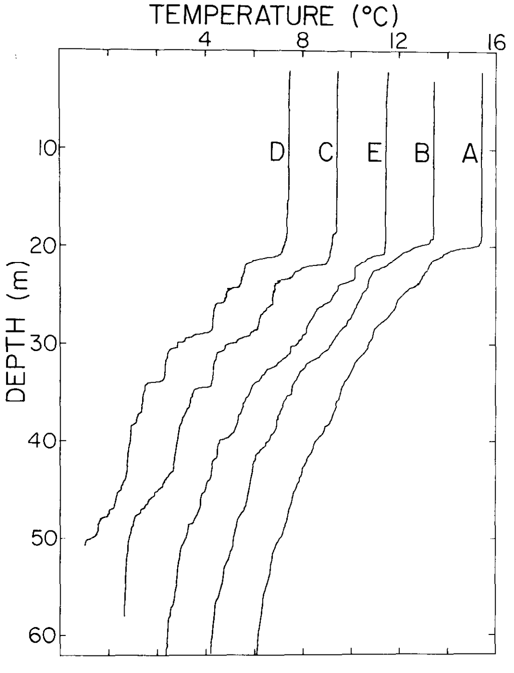


Fig. 2. Profiles of temperature vs. depth. Scale given is for profile A, others being displaced 2° progressively to left. Mixed-layer temperature does not vary appreciably between stations. Order of letters represents order in which stations were taken, all within 2 h in time.

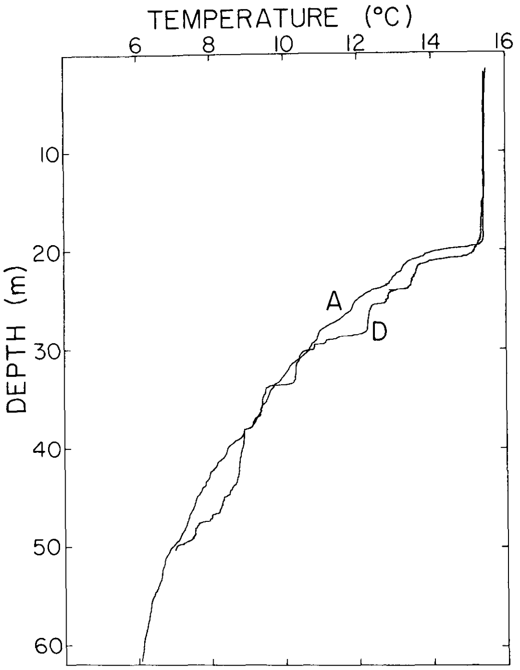
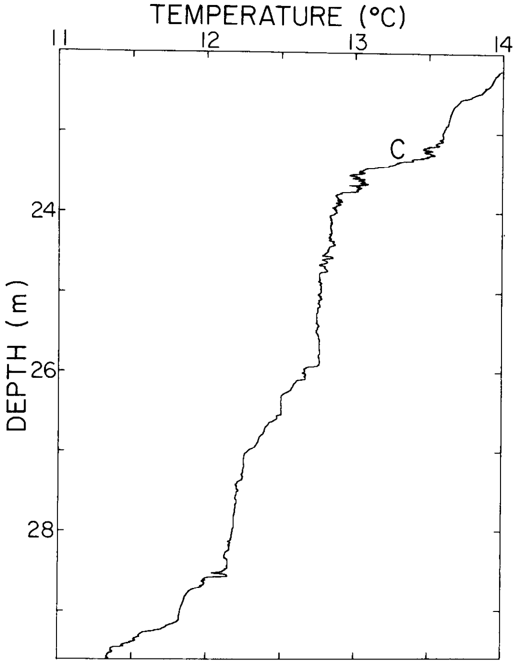


Fig. 3. "Steppy" profile and smooth profile plotted on same temperature scale to show warming in shallower water. Instrumental precision in temperature was better than 0.01°C.

chione and Wunsch (1974) for mixing associated with internal waves on a slope could well cause this structure. Waves which have their energy traveling at nearly the same angle to the horizontal as the topography cause especially intense mixing and steplike structure. On a slope as steep as that of Lake Tahoe the frequencies of such waves would be a large fraction of the buoyancy (Brunt-Väisälä) frequency, the rays curving downward as the waves approach the slope because the buoyancy frequency decreases with depth.

If this mecahnism acted alone, the total heat content of the water column would not change from profile to profile. But the heat content appears somewhat greater in shallower water (Fig. 3), at least just below the mixed layer. Some water from the mixed layer is probably entrained downward at the slope (the lower boundary of the mixed layer intersects the slope), but obviously not enough to account for the



heat differences seen. Perhaps some bottom warming effects produce the extra heat. Lake Tahoe is quite clear and substantial solar heat penetrates to these depths. In fact, 10% of the downwelling solar irradiance present just below the water surface is still in the water column at 40-m depth (Smith et al. 1973).

A high resolution plot of one section from one of the inner profiles shows that the steps are produced on scales as small as a few centimeters (Fig. 4). Active mixing can be seen. A feature characteristic of a Kelvin-Helmholtz roll can be seen at 28.5-m depth.

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