LAKE VANDA

Lake Venda, a permanently ice covered lake in Wright Valley near the centre of the dry valley system of Victoria Land, Antarctica, is 15 miles east of the Polar Ice Plateau and 30 miles west of the Ross Sea. The climate is cold and extremely arid with frequent strong winds. Four moraines are distinguished near the lake by the trend of their ridges and by their degree of weathering. Weathering that is attributed to the effect of salts blown in from the sea has entirely destroyed surface granite on the oldest moraine. None of the moraines were deposited by glaciers from the Polar Ice Plateau. Scree formation has planed steep moraines into even slopes that extend down for 200 ft to the flat bottom of the lake. Lag gravels with wind faceted stones cover all except the steepest slopes, and two square miles of gneiss at the east end of the lake has been worn into sharp ridges by salt weathering and wind erosion.

Old lake terraces, developed only in steep scree, show that the lake once stood 150 ft higher than at present. The development of the terraces in scree is attributed to the persistence of the "edge crack", a kind of frost polygon that follows the steepest part of the lake shore and is absent where the lake is gentle and the shore is ice covered by normal frost polygons.

The ice on the lake is about 12 ft thick. From the average thickness of the ice above and below lake water level and from the height of frozen pools it is estimated that about a foot of the ice surface is evaporated each year, and about the same thickness added to the bottom by freezing. Water equal to a thickness of about three feet forms within the ice and the edge of the ice melts back over the shallow parts of the lake during the summer. The observed lowering of water level and the previous summer and winter lake levels indicate that the total annual evaporation took place during sunny days with strong westerly winds. Evaporation is replenished by the Onyx River which flows west from the Wilson Piedmont Glacier for a few months in summer.

The water temperature at the bottom of the lake at 217 ft is 25° C, about 47° C higher than the mean annual temperature at the lake surface. The temperature difference is attributed to solar heating. From the observed temperature gradients in the strongly density-stratified lower part of the lake, from the downward heat flow through the bottom of the lake, and from the observed attenuation of solar energy through the ice and upper lake water it is inferred that the annual radiant heat flux per cm² at the lake surface is about 100,000 calories, a value close to that recorded at Scott Base. The effectiveness of solar heating is attributed to the lake water being almost as clear as pure sea water, and to the ice being clear with negligible snow cover.

Samples at 5 ft intervals were tested for chlorinity on the ground, and 30 samples taken back to New Zealand for more complete analysis. Chlorinity increases downwards at an irregular rate, over half the chlorinity being within 25 ft of the lake bottom. The maximum chlorinity is 83,500 parts per million and the average if the water were mixed about 1,000. The bottom concentration and the irregularities in downward increase in chlorinity are attributed to the lake having risen and having been evaporated down several times in the past. The "chlorinity" age of the lake, determined by assuming past annual chlorinity inflow at its present value, is about 30,000 years.

The major constituents of the water are calcium, sodium, magnesium, and potassium as cations, and chlorine, bicarbonate, and sulphide as anions. As equivalent parts expressed as a percentage of total cations, sodium decreases from 30 at the surface to 15 near the lake bottom, potassium from 5 to less than 1, and bicarbonate from about 15 to 0. Calcium remains about constant. Sulphide is
mostly below 170 ft and does not exceed 7%. The major changes in composition are attributed to sodium bicarbonate having crystallized out on the lake shore, and having been blown away.

From chlorinity ages and from the degree of weathering of the moraines it is inferred that the oldest moraine is considerably more than 10,000 years old, and that Wright Valley was not filled by a through glacier from the Polar Ice Plateau during the last Glaciation. Wright Valley and the other dry valleys of Victoria Land are considered to pre-date the last Glaciation and to contain moraines that represent an appreciable part of the Pleistocene Period.
LAKE VANDA
AN ANTARCTIC LAKE, A SOLAR ENERGY TRAP

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Lake Vanda is shown to be a natural example of the trapping
and storing of solar energy by a salt water density gradient. The
bottom of this lake (218 ft) is maintained at 28°C despite a mean
annual air temperature of about -20°C, the solar heating being limited to
the short Antarctic summer.

Lake Vanda (Lat. 77° 36' S, Long. 161° 39'E) is permanently
covered with about 12 ft of ice and is five miles long and a mile
wide. It occupies a depression in the lowest part of the Wright
dry valley, Victoria Land, Antarctica. In the summer of 1960/61
an American biological party discovered that its bottom waters
were warm and highly saline. (1)

The authors studied the physics and chemistry of the lake and the
geology of the surrounding area during the first half of
December, 1961. This communication deals with the heat balance of the
lake.

Twelve holes were drilled at 1000 ft intervals along two
lines, one along the length of the lake and the other across its
widest part. Water temperatures were measured to ± 0.05°C at 5 ft
intervals, using a copper-constantan thermocouple and a potentiome-
ter. The thermocouple was checked against a reversing
thermometer of the type used in oceanography. Density and chemical
composition were measured at 5 ft intervals through one hole in the
central part of the lake. The lower region of the lake below
160 ft is strongly density-stratified saline water which we consider
to be non-convective. The in situ density increases from 1.007
g/cm³ at 160 ft to 1.100 g/cm³ at 215 ft.

| Depth below
| Temperature versus Depth Profiles
| for lower part of Lake Vanda
| (Temperatures in degrees centigrade) |
| (ft) | *1 | 2 | 3N | 26 | 3 | 4 |
| 160 | 12.4 | 12.4 | 12.6 | 12.5 | 12.5 | 12.5 | 1.003 |
| 165 | 14.3 | 14.3 | 14.5 | 14.3 | 14.2 | 14.3 | 1.014 |
| 170 | 16.1 | 16.1 | 16.3 | 16.1 | 16.1 | 16.1 | 1.024 |
| 175 | 17.7 | 17.8 | 18.0 | 17.9 | 17.8 | 17.8 | 1.034 |
| 180 | 19.3 | 19.4 | 19.5 | 19.4 | 19.4 | 19.4 | 1.044 |
| 185 | 20.8 | 20.8 | 20.9 | 20.8 | 20.8 | 20.8 | 1.054 |
| 190 | 22.1 | 22.1 | 22.3 | 22.1 | 22.2 | 22.2 | 1.064 |
| 195 | 23.3 | 23.3 | 23.4 | 23.4 | 23.4 | 23.4 | 1.074 |
| 200 | 24.2 | 24.1 | 24.3 | 24.3 | 24.3 | 24.3 | 1.080 |
| 205 | 24.8 | 24.7 | 24.8 | 24.8 | 24.8 | 24.8 | 1.087 |
| 210 | 25.2 | 25.2 | 25.2 | 25.2 | 25.2 | 25.2 | 1.091 |
| 215 | 25.4 | 25.4 | 25.6 | 25.6 | 25.6 | 25.6 | 1.096 |

*Positions of holes 1, 2, 3, 4 are on an east-west line at 100 ft
intervals. 24 and 28 are at positions 1000 ft north and 1000 ft south respectively of position 2.

The temperature gradient in the soft mud at the lake bottom was measured near the centre of the lake by driving in a geothermal gradient probe. This probe consisted of 76 copper constantan couples connected in series and mounted on a wooden rod with their junctions 26 cm. apart. The probe was calibrated by placing it at the 170 ft level in the lake where the gradient was known from the thermal profile measurements. This calibration agreed with that calculated theoretically to within ten per cent. Two feet below the bottom of the lake the temperature was found to be decreasing downward with a gradient of 0.04°C per foot. Heat is thus being conducted downwards from the lake. Assuming the thermal conductivity of the mud salt water mixture at the lake bottom to be similar to that of water, the annual heat flow would be about 50 cal/cm²/yr.

Bolometer measurements of the solar energy flux were made through five holes under a variety of cloud conditions and at depths up to 50 ft below water level.

The heat balance of the lake presents some interesting problems. The temperature gradient at the 165 ft level is 0.37°C/foot. This means that the non-convective lower part of the lake is losing heat at 550 cal/cm²/yr by conduction upwards. To this must be added the 50 cal/cm²/yr that is being lost downward by conduction through the bottom of the lake.

There are five possible heat sources:-

1. Biological activity within or at the base of the lake.
2. Chemical heating.
3. Hot springs in lake bottom.
4. Abnormally high geothermal gradient under lake.
5. Radiant energy from the sun penetrating into the lake and being absorbed.

According to Zobell et al. (2), biological activity would not produce more than an extremely small part of the heat required even under the most favourable conditions.

Coring of the bottom yielded no solid soluble salts. The bottom waters of the lake contain in solution calcium chloride with smaller amounts of sodium and potassium chlorides. Even if these salts did occur on the bottom of the lake, consideration of their heats of solution (3) rules out any appreciable heating from this source. There is no evidence for any other chemical reactions that are producing appreciable heat.

There is no geological evidence for hot springs in the area surrounding the lake. The temperature gradient is positive at all depths in all profiles measured. In the lower half of the lake the temperature versus depth profile is remarkably similar (± 0.1°C) over an area at least 3000 ft by 2000 ft (Table I) whereas hot spring areas are characteristically non-uniform in lakes.

The possibility of a high geothermal gradient is ruled out, since the temperature gradient probe showed that heat is being conducted out through the bottom of the lake. Other evidence is that the temperature gradient decreases from 160 ft downward. This
is not a salinity effect since the thermal conductivity of water decreases as the salt concentration increases (4), and implies that the heat flow increases as one goes upwards.

Thus we are left with radiant energy from the sun as the only possible heat source. No data is available on the total annual radiant solar energy flux at Lake Vanda, but it is known (5) that the solar energy flux at Scott Base, 80 miles due east of Lake Vanda, is 31,000 cals/cm²/yr. The fraction of the incident solar energy which penetrates the twelve feet of ice was determined with a bolometer. With a cloudless sky, live per cent, and with a cloudy sky, eight per cent of the radiant energy flux enters the water below the ice. Measurements in the upper 50 ft of the lake showed that 45 ft of water reduced this energy flux to one half. By adopting a six per cent value at the bottom of the ice and assuming that the water maintains the same attenuation value, the quantity of energy reaching the 165 ft level would be 850 cals/cm²/yr, which is in reasonable agreement with the 600 cals/cm²/yr, calculated above as the heat loss from the lake water below 165 ft.

As additional evidence of a solar heating mechanism, the temperature gradient below 160 ft has been calculated using the above data and is compared with the observed data in Table II.

### TABLE II

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It is seen that above 190 ft the temperature gradient versus depth profile is as would be expected from a solar heating mechanism. At 195 ft the temperature gradient falls off more rapidly than is predicted from theory, but it was observed while sampling that the water below 195 ft is brown in colour.

It is interesting to speculate on the construction of similar installations for the trapping and storing of solar energy in the more temperate latitudes. The heat could then be used for the heating of buildings or for evaporation processes such as salt production from sea water. Some experimentation along these lines has been carried out in Israel (6).

The authors wish to thank Mr. C. J. Banwell and Mr. I. G. Donaldson and other members of the staff of the D.S.I.R. for helpful advice and for the loan of equipment; also Dr. Angino of the University of Kansas, the United States Navy and U.S.A.R.P. personnel without
whose cooperation the expedition would not have been possible.

REFERENCES


AN INTERESTING ECOLOGICAL SITUATION IN AN ANTARCTIC LAKE

During a recent study of the chemistry and heat balance of Lake Vanda, Antarctica, Phormidium and other blue-green algae were accidentally collected on a nylon line. The algae were collected only in a strongly convective layer. We wish to report this interesting ecological situation and also the novel manner by which these algae were collected.

Lake Vanda (Lat. 77° 35′ S., Long. 161° 39′ E) is permanently covered with about 12 ft of ice and is five miles long and a mile wide. It occupies the lowest part of Wright Valley, a dry valley in Victoria Land, Antarctica. Armitage and House (1), during a limnological survey in the summer of 1960/61, found that the water at the bottom of the lake was at 22°C and strongly saline. They obtained only one organism, a chlorella-like alga, from the filtration of more than 100 gallons of lake water.

Our work in the summer of 1961/62 (2) made it likely that the bottom water is warmed by solar radiation. The bottom water is prevented from convecting by its strong density stratification.

The main layers in the lake are shown by Fig. 1. The top layer is the 12 ft of ice. The waters from 12 ft to 55 ft and from 125 ft to 160 ft have a salt gradient and are weakly density stratified. From 55 ft to 125 ft the temperature and chemical composition are uniform and this part is considered to be most strongly convective.

(Fig. 1)

While making measurements on the heat balance of the lake, equipment was frequently suspended from nylon monofilaments. If these lines were allowed to remain in position for 24 hours a red material was found to accumulate on that part of the line that had been between 55 ft and 125 ft. This material froze as it came into the air and accumulated at the eyelet of the winding reel. A sample of this material was examined by the biological staff at McMurdo base and was identified as being principally Phormidium with a few Chroococcus, and a few Analagena. One live rotifer was present.

It appears that these algae live in a strongly convective layer isolated from the surface of the lake (mean annual temperature -20°C) by 50 ft of colder less saline water and by 12 ft of ice. Their environment is an almost uniform 7.8°C, their nutrient medium almost isotonic, with 600 p.p.m. Cl-, 120 p.p.m. Na+, 37 p.p.m. K+, 14 meq/1 Ca++, 3 meq/1 Mg++, and 1.3 meq/1 HCO3; its available energy from sunlight is about 1000 cal/cm²/yr, mostly in the blue part of the spectrum and all during the summer months.

The authors wish to thank David Mason, John Hunt and Dr C. R. Goldman for identifying the micro-organisms and the United States Navy and U.S.A.R.P. personnel, without whose cooperation the expedition would not have been possible.

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REFERENCES
