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Winter Overturning of the Anoxic Great Ghost Lake

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ABSTRACT

The 2100 m high Great Ghost (Ta-Kuei) Lake, which has been subject to little pollution, was temperature stratified in summer (July). Dissolved oxygen showed a maximum at 8~10m, a remnant of winter water. Low dissolved oxygen saturation values and high organic matter loading caused an anoxia below 10~16 m in summer. The anoxic hypolimnion was 18 meters thick. In winter (Feburary), the lake turned over and became relatively homogeneous. The dissolved oxygen saturation level was at only 68% throughout the water column. Nutrient data also supported strong summer stratification and winter mixing.

Keywords: Great Ghost Lake, Ta-Kuei Lake, overturn, oxygen, nutrients, stratification, anoxic, acid rain

I. Introduction

Recently many reports have been published about acid rain and lake acidification in Taiwan (Hung and Chen, 1987, 1989; Chen and Hung, 1987; Chen *et al.*, 1988). The neutralization of alkaline matter by acid deposition may cause severe impact on the lakes by destroying the buffer systems of the water and reducing its pH value. The speciation of ions in water changes, following changes in pH value. Heavy metals in sediment also tend to release into water. The concentration of aluminum, for example, increases when the pH value is reduced and may deposit on the gills and impede the respiration of fish. Some fish may release too much mucus intended to clean the aluminum from their gills, and may suffocate (Oden, 1968; Cronan and Schofield, 1979). Small trout which hatch in the acid water (pH=5) may not digest all of the yolk in their eggs, reducing their survial rate because they are weak and cannot swim normally. Not only organisms in water, but also land plants may be impacted by the acid rain. Furthermore, if the acid water is used for generating electricity or for drinking, it may corrode metal pipes and generators. The released trace metals may cause additional health problem for consumers.

The Great Ghost (Ta-Kuei) Lake is situated in Moulin, Kaohsiung County, north of Yao-Bye Mt. (Fig. 1). This 2100 m high lake is one of the best preserved natural lakes in Taiwan, with little pollution because of its isolated location (it takes two days to reach it by foot from the nearest road). The aborigines have many folklores about the lake and are sometimes reluctant to go there.

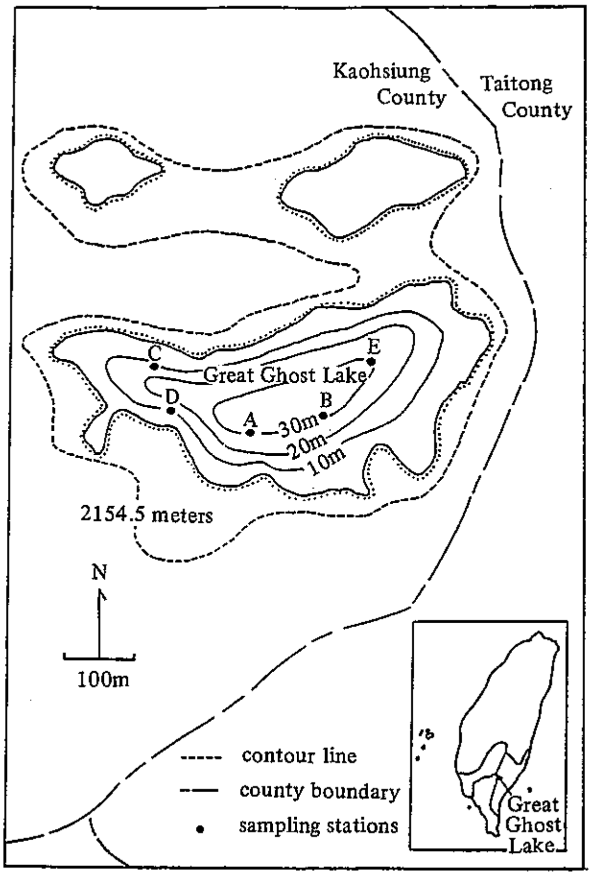

Fig. 1. Location of the lake and sampling stations.

We have always been interested in this lake because very little is known about it aside from the knowledge that there are no fish there despite several attempts to stock it and that the oligotrophic lake has low buffer capacity (Chen *et al.*, 1988). Initially, we intended to find out whether this lake might be threatened by acid rain. But we soon discovered that this lake was unique and deserved much more study.

II. Materials and Methods

Study area – The Great Ghost Lake (22° 58'N, 120° 58'E) is a 650 X 300 m oligo-mesotrophic lake surrounded by 100 m high hills and has an area of 11.25 ha. We found a maximum depth of 34 m, a mean depth of 14.8 m, and a volume of 1.67 X $10^6 m^3$ with the help of a fish finder. The draining basin consists mainly of argillite, phyllite and slate with rich vegetation. There is no river inflow and the outflow is at the northeast corner.

Sampling and analysis – Water samples were collected with a 21 Hydro-Bios TPN sampler at stations A and B (Fig. 1) between 5~10 July, 1988 (summer) and between 3~7 February, 1989 (winter). Temperature and dissolved oxygen were measured in situ at stations A ~ E with an YSI model 58 DO meter. pH was measured with a Basic portable pH meter calibrated with NBS 4.004 and 7.415 buffers. Sulfide and nitrite were measured on site with HUN systems ISE 30-47-00 and 10-38-00 ion selective electrodes. Subsamples were then filtered with a prewashed 0.45 μm nylon 66 filter. Portions of the subsamples were acidified with distilled clean acid. Water samples were shipped back in PE bottles packed in ice for further analysis. Surface sediments were obtained with a grab and shipped back in plastic bags in ice (Wang, 1989).

Once returned to the laboratory, conductivity was measured at 25°C with a Basic Model DCM-3 digital conductivity meter. KCl solution was used for calibration. Alkalinity was measured at 25°C with a titration system consisting of a Radiometer PHM85 pH meter and a Radiometer ABU80 automatic burette (Zimmerman and Harvey, 1978; Chen *et al.*, 1988). Sulfate and chloride were measured with a DIONEX Series 2000i Ion Chromatography. Calcium, magnesium, potassium, sodium, iron and manganese were measured with a Perkin Elmer Model 2380 Atomic Absorption Spectrophotometer. Nutrients were measured with a home made flow injection analyzer. Chlorophyll a was measured with a Turner Model 100-05R fluorometer using coproporphyrin tetramethyl ester for calibration. Total suspended solids were measured by weight difference after filtration with a 0.45 μm filter. Organic content of the sediment was measured by weight difference after baking at 550°C (Wang, 1989).

III. Results and Discussion

Temperature and Water Column Stability

The temperature of the surface water was about 22°C and the bottom water was about 10.5°C at a depth of 30m in summer (Fig. 2). There was a clear thermocline between 4~12 m and the thermogradient was 1.2°C/m. The temperature of the water was homogeneous in winter, about 11°C at the surface and 10.6°C at the bottom. The temperature in winter was almost the same as it was at the bottom in summer (Fig. 2). The total dissolved salts, mainly consisting of Na^+ (49 ± 54 μ eq/l), Ca^{+2} (16 ± 5 μ eq/l), Mg^{+2} (14 ± 13 μ eq/l), K^+ (8 ± 5 μ eq/l), HCO_3^- (29 ± 26 μ eq/l), SO_4^{-2} (18 ± 7 μ eq/l) and Cl^- (61 ± 80 μ eq/l), do not show much vertical variation (Wang, 1989). Thus, temperature controlled the vertical stability. These results indicate that water column stability was low in winter, providing an opportunity for overturning. The possibility of meromixis (Berger, 1971), Pm, is 1.8. The high Pm value suggests that the lake may be poorly ventilated.

Dissolved oxygen and sulfide concentrations

The summer oxygen content was about 6mg/l at the surface, with a maximum of about 7mg/l at 8~10m. Oxygen was sharply reduced between 10m and 16m and became anoxic below 16m (Fig. 3), due to the respiration of organic matter both in water and in the sediments, which contained 27% organic material (Wang and Chen, this issue). The dissolved oxygen in winter showed dramatic change within a short time. The measurement at 12:00 on 5 February showed that the oxygen content was 6.54 mg/l at the surface, was reduced between 18 m ~ 20m, and became anoxic at 24m (Fig. 4). The dissolved oxygen concentration increased significantly near the bottom but decreased at 15m at 16:00. It seemed that the anoxic bottom water was overturning. The oxygen concentration measured at 9:00 on 6 February became

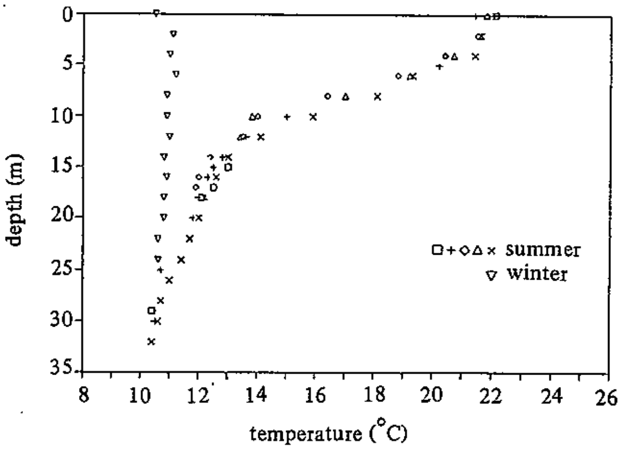

Fig. 2. Temperature profiles in summer (July) (□ + ◇ △ X) and winter (▽).

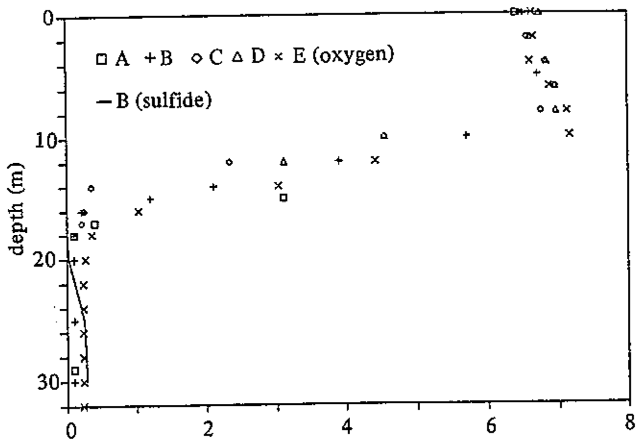

Fig. 3. Profiles of oxygen and sulfide content in summer.

almost homogeneous vertically, after completing the apparent overturning. The surface value was reduced to about 5.7mg/l, lower by 0.4mg/l than the concentration of the previous day. This was caused by mixing with the anoxic water. The percent of oxygen saturation reduced from 73% on 5 Feburary to 68% on 6 February.

We do not know whether the lake turns over every year or whether it turns over several times in a winter. Repeated sampling is required to answer these questions.

As a first approximation, the lake may be considered a closed system in winter when the water temperature decreases so quickly there is not sufficient time for air-water exchange of oxygen (Chen, 1985; 1988). Consequently, the total oxygen content of the lake should remain conservative during turnover. The estimated averaged dissolved oxygen concentration before turnover was 5.14 mg/l, which is 0.54 mg/l lower than the concentration observed after turnover. The 10% discrepancy could be caused by an error in the water volume estimation, error in the dissolved oxygen measurements, or some oxygen could have entered the water column through the air-water interface.

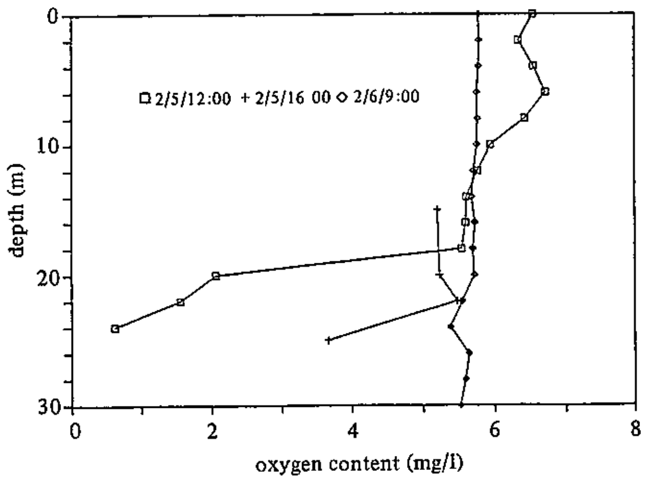

Fig. 4. Profiles of oxygen content in winter.

We used the equation generated by Chen (1981) to calculate the oxygen solubility:

$$\mathrm{ln}C = -1268.9782 + 36063.19/{}^{\circ}K + 220.1832 \times \mathrm{ln}\,({}^{\circ}K) - 0.351299 \times {}^{\circ}K + S(6.229 \times 10^{-3} - 3.5912/{}^{\circ}K) + 3.44 \times 10^{-6} \times S^{2}$$

where C is the solubility in ml/l at STP, K is the temperature in degrees Kelvin and S is the salinity in parts per thousand. S can be calculated by dividing the total dissolved solids by 1.00488 (Chen and Millero, 1986; Chen and Chen, 1988).

The oxygen consumption rate in the deep layer could be estimated using the difference between the summer and the winter concentrations. The result, 349 μ mole/l/yr, however, is probably good only to a factor of 2. More data are needed to improve this estimation.

The oxygen maximum at between 8~10 m in summer could be the result of photosynthesis by phytoplankton, or could simply be the remnant of the more oxygenated water from late winter (Fig. 5). If it was

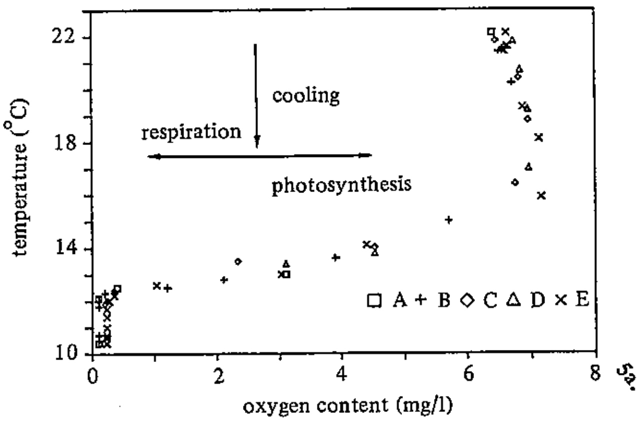

Fig. 5a Temperature vs oxygen content.

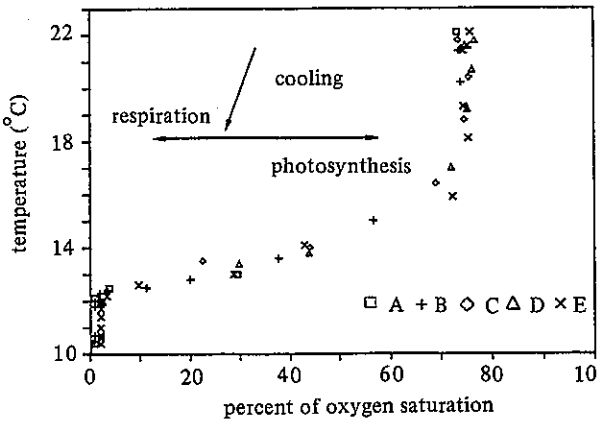

Fig. 5b. Temperature vs percent of oxygen saturation.

the former reason, however, a maximum should also exist in the temperature vs percent of saturation plot (Chen, 1985) and it did not. Consquently, it can be concluded that lake water in late winter contained more oxygen than in summer because of higher solubility at lower temperature. Subsequently, summer warming of the surface water reduced the oxygen content because the surface water remained at near equilibrium with the atmosphere (76% saturation at 2100m). The top layer blocked the subsurface layer from exchanging with the atmosphere and preserved the more oxygenated remnant of winter water, resulting in a maximum. Note that photosynthesis should also create a pH maximum, but this was not found (Wang and Chen, this issue).

The verticle profiles of S^{-2} in summer are shown in Fig. 3. The concentrations in the aerobic zone were below detection limit. They increased in concentration with depth in the anoxic zone. We did not have S^{-2} data in winter because of operational difficulty. The deep samples, however, had no detectable odor in winter, whereas in summer the odor was strong.

Nutrients

The nutrients, nitrate, nitrite, ammonia, phosphate and silicate, were generally stratified in summer (Wang, 1989). Fig. 6 shows the vertical distribution of silicate, which increased with depth in the bottom anoxic layer and existed at a concentration as high as 4.66 mg/l in the bottom layer in summer. The distribution was relatively homogeneous in winter with concentrations between 1.52 and 1.79 mg/l. Winter mixing of the bottom, higher silicate water with the top, lower silicate water resulted in higher silicate concentration than in summer in the top layer but vice versa in the bottom layer.

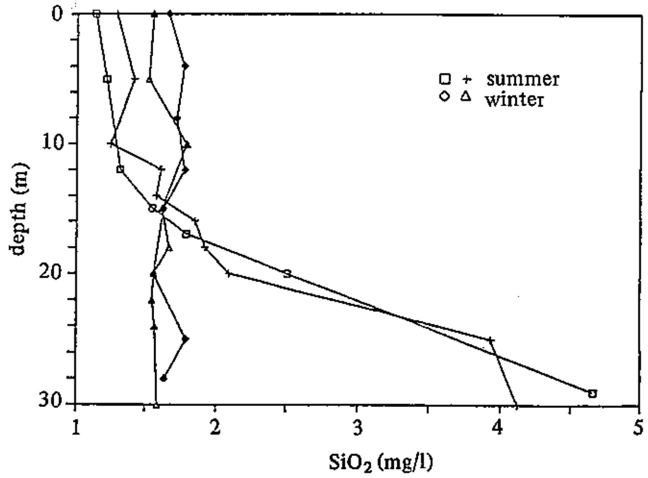

Fig. 6. Profiles of silicate content in summer and winter.

IV. Conclusions

The 2100 m high Great Ghost Lake showed strong stratification in summer (July) with a thermocline between 4 and 12 m. The temperature gradient was 1.2°C/m. The water turned over and the temperature became homogeneous in winter (February).

There was a strong oxycline in summer when the water below 16 m became anoxic. The bottom layer was reoxygenated in winter and remnant winter water caused an oxygen maximum at 8 ~ 10 m in summer. Nutrients also showed strong gradients in summer, higher in deeper waters. Winter overturning illiminated the gradients.

Acknowledgments

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大鬼湖於冬季時之缺氧湖水上下翻滾

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摘要

大鬼湖爲一個位於海拔２１００公尺，少有人爲污染的高山湖泊。夏天（七月）水體有溫度層化現象。溶氧量在８～１０公尺間有極大值，乃由冬天冷水沈於該處所致。低溶氧飽和程度與高有機質，使得夏天水層在１０～１６公尺以下完全缺氧，無氧層厚達１８公尺。冬天（二月）水體完全翻滾，上下水溫及各離子含量較一致，整個水層溶氧飽和程度只達６８%。營養鹽的資料也顯示，水體在夏天層化、冬天混合。