Evidence for physical and chemical stratification in Lake Untersee (central Dronning Maud Land, East Antarctica)

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Abstract: Lake Untersee is the largest freshwater lake in the interior of East Antarctica. It is a perennally ice-covered, max. 169 m deep, ultra-oligotrophic lake. In contrast to earlier studies, we found clear evidence for physical and chemical stratification in the summer of 1991–92. However, the stratification was restricted to a trough, c. 500 m wide and up to 105 m deep, in the south-western part of the lake. There, the water body was distinctly stratified as indicated by sharp vertical gradients of temperature, pH, dissolved oxygen, and electrical conductivity. The water column was anoxic below 80 m. The chemical stratification is also indicated by changes of ionic ratios. Moreover, there was some evidence for methanogenesis and bacterial sulphate reduction in Lake Untersee.

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Introduction

Lake Untersee (71°20’S 13°26’E) is the largest freshwater lake in the interior of East Antarctica (Hermichen et al. 1985). Only 30 years after the discovery of Lake Untersee by the German Antarctic Expedition 1938–39 (Ritscher 1942), a first reconnaissance study of the lake was carried out by Kosenko & Kolobov (1970) during a Russian geographic-geological field party at the beginning of 1969. Since that time, there has been increasing interest in the unique lakes of the Gruber Mountains (in particular lakes Untersee and Obersee) among Russian and German scientists (e.g. Hermichen et al. 1985, Kaup et al. 1988, Loopmann et al. 1988). However, when compared to other Antarctic lakes (for instance those of the southern Victoria Land Dry Valleys), Lake Untersee is only poorly studied. We report here on new findings concerning the lake’s water chemistry and physical structure.

Lake Untersee

Lake Untersee lies in the Gruber Mountains of central Dronning Maud Land (Fig. 1) at a surface elevation of 563 m a.s.l. It is 6.5 km long and 2.5 km wide, has a surface area of 11.4 km² (Loopmann et al. 1988) and is permanently covered with ice ranging in thickness between 3.8–2.2 m (average 3.0 m) in the summer (Loopmann et al. 1988, Wand et al. 1994). Recent detailed bathymetric mapping (Wand et al. 1996) shows that the maximum water depth is 169 m, 22 m greater than that given by Loopmann et al. (1988). The lake lies in a deep cirque-like valley, which is dammed at its northern end by the termination of Anuchin Glacier.

Fig. 1. Sketch map showing the location of Lake Untersee in central Dronning Maud Land, East Antarctica.
Untersee is primarily fed by glacier melt, mostly supplied by subaquatic melting of Anuchin Glacier. Because there is no outlet from Lake Untersee, it loses water only through evaporation/ablation of the ice cover (Hermichen et al. 1985).

Limnological, hydrochemical and physico-chemical investigations by the above authors have shown that, compared to other freshwater lakes of central Dronning Maud Land (see Richter & Bormann 1995), the water body of Lake Untersee exhibits a number of peculiarities such as a relatively increased salt content (c. 300 mg l⁻¹), extremely high pH values (10.3–10.8), oversaturation with dissolved oxygen (up to 150%), Na⁺ and SO₄²⁻ as the prevailing ions, very low primary productivity (0.107–1.059 mg C m⁻³ d⁻¹), very high transparency (extinction coefficient K of PhAr: 0.022 m⁻¹ at 25–35 m depth), water temperatures generally below 1°C, rather high silica content (up to 14.1 mg l⁻¹ Si) and very low concentrations of PO₄⁻P (1 µg l⁻¹ and below).

Results and discussion

Earlier studies found no significant variations in water chemistry or physico-chemical parameters within the water column, so Lake Untersee was considered to be a well mixed, unstratified lake. As a result of our field studies in the 1991-92 summer, however, this general opinion must be revised, because we found clear evidence for physical and chemical stratification. In the course of lake sediment sampling we measured additional physical parameters (water temperature, electrical conductivity, pH value, concentration of dissolved O₂) with increasing water depth at nine sampling stations well distributed over the whole lake area. For these in situ measurements, instruments and probes attached with 100 m long cables (WTW Weilheim/Germany) were used.

Apart from only minor changes immediately below the ice cover and just above the lake bottom, the water column was found to be homogeneous at all but one site with respect to the above parameters. At this exceptional site water depth was much higher (94 m) than recorded on the bathymetric map of Loopmann et al. (1988), and there was evidence for chemical and physical stratification. This interesting part of the lake must have been overlooked during former measurements, because of wide-meshed bathymetric sounding and sampling. The site was located in a trough c. 500 m wide and up to 105 m deep (see Wand et al. 1996), in the south-eastern part of the lake. There, the water body was distinctly stratified as indicated by sharp vertical gradients of temperature, pH, dissolved O₂, and conductivity (Fig. 2). With increasing depth a thermocline (between 40–50 m) was followed by an oxycline (70–80 m) and a chemocline (80 m to bottom). Below 70 m the pH value decreased markedly from 10.4 to 6.1 near the bottom. The water column was anoxic below 80 m. Water samples taken from this bottom layer smelled distinctly of hydrogen sulphide. The origin of the latter may be ascribed to bacterial sulphate reduction within the water column which is supported by decreased sulphate concentrations and characteristic variations of the Cl/SO₄ ratio (Table I). The temperature increase between 40–50 m (thermocline) is doubtless a consequence of the density effect, whereas the temperature peak (4.6°C) at 80 m seems to have another cause. It is interesting to note that the Cl/SO₄ ratio also peaked at 80 m (maximum of sulphate reduction?). Thus, energy release due to microbial processes might be a possible explanation.

The chemical stratification of the water column is not only indicated by increasing salinity below 80 m depth, but also by changes of ionic ratios (see Table I). The concentrations of NH₄ and PO₄ in the anoxic bottom waters are very high for Antarctic anoxic sites. The presence of both components in the anoxylimnion is certainly a result of diffusion from the sediment, where they have been formed by degradation of organic matter. This is underlined by high δ¹⁵N values of the
dissolved ammonium (+21.5%). The conditions observed were favourable for methanogenesis. Indeed, the uppermost decimeters of sediment cores (C last 1.5-4.5 wt.%) taken at this site degassed strongly upon recovery (Wand et al. 1994). The evolved gas (most likely methane) was burnable. There are only a few reports on the occurrence of methane in Antarctic lakes (e.g. Ellis-Evans 1984, Franzmann et al. 1991, Smith et al. 1993). The extremely high δ13C value (+25‰) of dissolved inorganic carbon (DIC) in the anoxic limnion can be attributed to a certain pathway of methanogenesis (cf. Nissenbaum et al. 1972). In contrast, the isotopically very light DIC (δ13C -17.9‰) in the oxylimnion is evidently a result of oxidation of organic material.

In summary, although the majority of the lake appears to be well mixed there was striking evidence for physical and chemical stratification in one limited trough area of Lake Untersee.

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