The Solar Lake : limnology and microbiology of a hypersaline, monomictic heliothermal heated sea-marginal pond (gulf of Aqaba, Sinaï)

by

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The Solar Lake on the shores of the Gulf of Elat is a small body of 140 × 70 m with a maximum depth of 5 m. It is separated from the open sea by a bar. Seawater is seeping in through a upper pore system, and brine seeps out through a cleavage system at the bottom of the lake. The lake is independent from tidal movements since dense algae mats of the shallow parts, together with cementation processes in the pore system build up artesian water pressure around the lake. Due to extremely high evaporation rates in summer, and low evaporation rates in winter together with casual desert rainfloods, the lake level changes annually by approx. 1.00 m. The lake is shielded from wind by a mountain ridge and by the bar which is elevated about 3 m above mean lake level. The unique salinity and thermal pattern has first been described by Por [1968]. Further limnological data have been published by Eckstein [1970].

The benthic algae mats are very common in hypersaline environments and arouse interest for several reasons. These mats are best developed and preserved, when salinity, temperature and possibly low redox potentials prevent the development of a diverse community of organisms which might destroy the algae mat by grazing.

From the accumulated fossil algae mats at the bottom and borders of the lake, the development of the lake from an open lagoon can be derived. ^{14}C-age determinations of the lower parts of the mats indicate a lagoonary stage with *Perinella* sp. and *Mytilus* sp. at 4500 B.P. The lake was separated from the open sea at about 2400 B.P. Since then a layer of up to 120 cm algae mats has developed, the study of which indicates various changes in the environmental conditions [Krumbein & Cohen, 1974].

The annual limnological cycle can be described as follows : At the end of summer the lake is holomictic, the water level is low, the brine is concentrated throughout the water column to about 180 ‰ salinity; temperature : 28° C, pH : 8.7, Eh : +400 mV. In September, with decreasing temperatures, the seawater, which seeps in through the bar, builds up a chemocline. This process is accelerated by rain water floods from the mountain ridge and a nearby wadi. During winter, heliothermal heating and high stability, due to the chemocline, leads to extreme stratification and an inverse temperature profile. The temperature reaches maxima between 48.8 (1972) and 60.5° C (1974) in the metalimnion. In winter the salinity varies between a minimum of 45 ‰ at the surface and a maximum of 180 ‰ at the bottom. pH and Eh decrease from 8.2 and +430 mV at the surface to 6.8 and —180 mV at the bottom. Due to the increasing evaporation in early summer the salinity of the epilimnion is gradually increasing until turnover is completed according to the annual climatic situation, between June and the middle of August. The major limnological features are summarized in Fig. 1.

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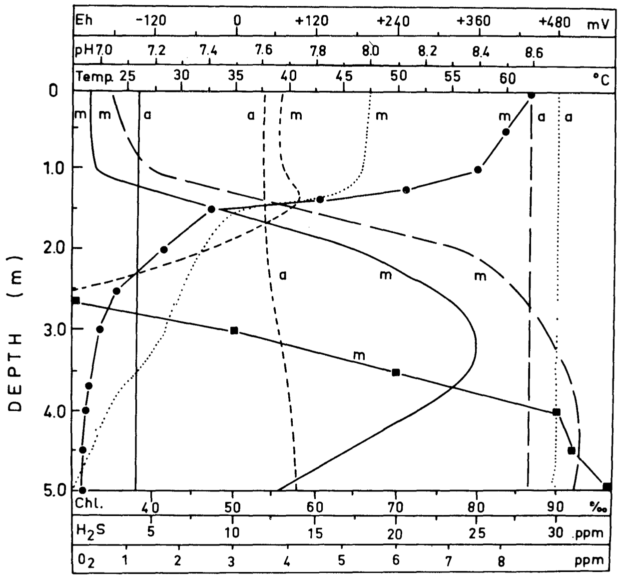

FIG. 1. — Physical and chemical limnology of the Solar Lake during holomixis (a = August) and maximum stratification (m = March). ———— = temperature; ●——● = redox potential; .... = pH; —— —— = chlorosity; ■——■ = H_2S; — — — — = dissolved oxygen.

From a detailed study of the microbiology of the Solar Lake, primary production by algae and photosynthetic bacteria, and of the bottom sediments, several interesting findings arose.

The primary productivity of the water column reaches maximum values in the metalimnion and hypolimnion during stratification. A maximum value of 4960 mg/C/m³/day was measured at 4 m water depth (November 20, 1970). This is the highest primary production recorded so far for non polluted natural water bodies. At the same time the productivity of the epilimnion is extremely low (50 mg C/m³/ day) which is in contrast to most of the warm monomictic lakes.

During the development of stratification, anoxic condition develop in the metalimnion and hypolimnion. Due to the activity of *Desulfovibrio* and other anaerobic fermentation processes, large amounts of H_2S accumulate in the hypolimnion (up to 40 ‰). In this completely anoxic zone, photosynthetic bacteria plates develop, i.e., a *Chromatium* plate in the upper zone (no oxygen, traces of H_2S) and a *Chlorobium* plate in the lower layers at a zone with approx. 15 ppm H_2S. Surprisingly, a dense bloom of benthic filamentous blue-green algae consisting of *Oscillatoria salina*, *Oscillatoria limnetica* and *Microcoleus* sp. (identified by I. DOR, Jerusalem) develops at the bottom at high H_2S concentrations.

The occurrence of blue-green algae under H_2S condition has been reported for several different environments. The occurrence of an algal bloom under these conditions together with the partial disappearance and decay of these algae during holomixis is unusual. Pure cultures of these algae grown in high H_2S concentrations showed no oxygen evolution and sulfur granule deposition along the filaments. It may be that this highly hypersaline environment present an ecological niche in which an organism occurs which is capable of utilising alternatively H_2S and H_2O as electron donors under different conditions. Thus the here mentioned *Oscillatoria limnetica* may represent an adaptation, linking the primitive bacterial photosynthesis and plant photosynthesis [COHEN, 1975].

This unusually hot, hypersaline pond, with its extreme conditions for life, its peculiar blue-green algae communities, and the rapid changes during the annual limnological cycle, is an excellent model for the study of many problems in limnology and aquatic biology. It may serve as an undisturbed natural biotope for the study of algal blooms, thermal pollution (extreme temperature changes) and adaptation of microorganisms to hypersaline conditions.

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