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"ANOMALOUS" THERMAL CONDITIONS IN A HYPERSALINE INLAND POND

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Knowledge of thermal phenomena in lakes and ponds has derived mostly from studies of relatively dilute waters. Indeed, concepts of thermal stratification and stability in lakes are based on temperature-related densities, with the water considered, for theoretical purposes, to be pure. Summer temperature profiles in a stratified lake show cold water lying below warmer water, as it theoretically should. The greatest temperature gradients are in the metalimnion, but decreases of temperature amounting to 0.1°C/cm, or more, are rare. Inverse stratification is typical of ice-covered lakes in temperate regions, with the warmer water on the bottom explained by water's maximum density (when pure) being at 4.0°C. In very deep lakes, however, pressure may modify the temperature of maximum density, and water somewhat cooler than 4.0° may be in the lowest stratum.

In saline waters, of arid regions and elsewhere, anomalous temperature profiles are common and result in part by dissolved substances imparting density, and being more important than temperature in this respect. Some saline lakes of Saskatchewan have summer temperature profiles that appear, on cursory examination, typical of temperate lakes of moderate depth (Rawson and Moore, 1944). They differ radically, however — the temperature of maximum density is depressed by high salinity, and summer stratification traps unusually cold water of vernal circulation beneath the thermocline. For example, summer temperatures below 0°C are in the hypolimnion of Manito Lake; its waters have a maximum density at —0.3°C, and a freezing point of —1.1°C. Other anomalous temperature profiles, designated as dicho-, meso-, and poikilothermous (Hutchinson, 1957), occur at times in the meromictic Hot Lake, Washington (Anderson, 1958), and in two saline Arizona ponds on the Long-H Ranch (Cole, *et al.*, 1967). Extremely abrupt temperature gradients occur under such conditions, with temperatures increasing remarkably with depth. Anderson reported an increase of 19.65°C between the subsurface depths of 1.0 and 1.5 m, a mean rate of 0.39°/cm. The Long-H Ponds also have yielded noteworthy gradients, with a maximum increase of 0.6°/cm recorded in February. Data from a 30-cm Algerian pond are comparable, implying a mean vertical increase of 0.4°/cm (Beadle, 1943). Such temperature-density conditions imply a lack of stability; however, dissolved substances compensate and considerable stability may actually exist. This paper describes additional unique temperature gradients in saline Mexican pools, and presents data on density relations that prevailed. Research was supported, in part, by NSF Grant GB-6477X.

Description of the Area. — On 11 August 1967, between 1030 and 1100 hours, two small, artificial pools were found slightly north of, and connected to, Laguna Salada, 3.5 km south and 1.5 km west of Cuatro Ciénegas, central Coahuila, México. The pools were rectangular, about 3.5x5.0 m, with vertical sides, and contained water 45 to 50 cm deep. They were man-made as part of a salt-harvesting operation. At the time we observed the pools, three species of fishes were in the upper water, *Gambusia marshi* Minckley and Craddock, *G. longispinis* Minckley, and an undescribed species of *Cyprinodon*. The bottoms were matted with bluegreen algae. One pool was disturbed before the uniqueness of the situation was realized, but the other was studied without major disturbance.

Methods and Results. — Temperature of the pool was determined *in situ* with a FT-2 Electronic Thermometer, particular care being exercised to avoid undue mixing. The surface temperature was 24.0°C, and at 46 cm the temperature was 47.0°C (Fig. 1). The thermal profile is a simple, inverse stratification; however, the temperature gradient was extreme. The mean rate of increase from surface to bottom was 0.5°C/cm, and between 15.5 and 30.5 cm the gradient amounted to 0.8°/cm. Densities that would have prevailed at each depth where temperatures were determined, if the water were pure and if density were a function of temperature alone, are contrasted in Figure 1 with the temperature profile. This depicts the seemingly anomalous condition of "lighter" water lying below "denser" water, a situation that did not exist because of salt concentration below. Water samples from the surface and from the bottom were brought to the temperature recorded at the time of collection and their specific gravities tested with a hydrometer. The surface water had a specific gravity of 1.01 rather than a theoretical 0.997 of distilled water at 24.0°C, and bottom water was at 1.075 as opposed to a theoretical 0.989 at 47°C. Total dissolved solids determined by evaporating 25-ml samples at 102°C for 30 hours (average of two samples per level) were 14.63 g/liter and 111.26 g/liter, respectively.

Stability of the vertical-walled pool was determined planimetrically assuming density to be a function of temperature alone. There was a negative stability of —1.6 g-cm/cm^2. Obviously the specific gravities caused by materials in solution had over-ridden temperature-induced instability.

The contrasting upper and lower salinities are explicable by evaporation concentrating the waters of the pool at a time when it was not connected to Laguna Salada, followed by re-connection and flooding. Perhaps rain and/or winter freezing-out effects contributed to the relatively dilute upper stratum. The high temperature in the deeper water is readily explained by direct solar radiation penetrating the upper layer. The dense, saline bottom water accumulates heat while the dilute upper stratum reduces outgoing radiation and prevents evaporation from it. Furthermore, the contrasting density prohibits mixing of the two layers. The system serves as an efficient heat trap, the mean temperature of the pool being about 37.5°C when we studied it.

Laguna Salada, the source of water for the two pools, has been discussed elsewhere (Minckley and Cole, 1968). It is the most saline of the known Cuatro Ciénegas waters; however, its chemistry varies with inflow that is controlled in part by man. On 11 August 1967 the laguna was separated incompletely by a low dike. The northern part, relatively isolated from inflow, contained 12.89 g/liter of total dissolved solids, while the southern part had 6.42 g/liter. Plankton from the north side consisted of *Diaptomus connexus* Light and corixid bugs. There were no plankters in collections from the southern part; *Cyprinodon* and *Gambusia* were throughout the laguna. On another date, in April 1965, when Laguna Salada contained more than 300 g/liter, the only metazoan was an harpacticoid copepod, *Cletocamptus albuquerquensis* (Herrick).

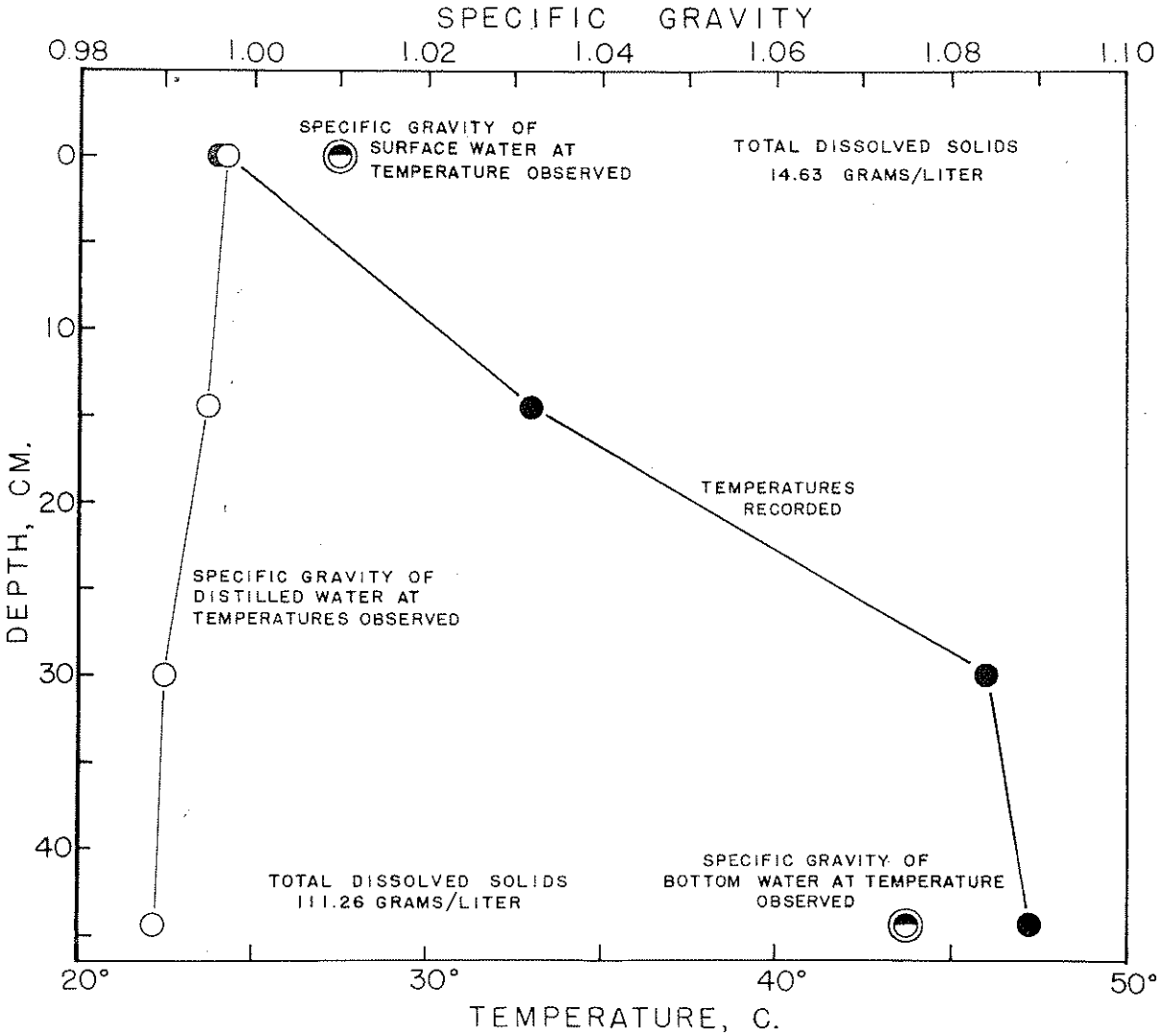

Figure 1.—Environmental features of a small, hypersaline pool in Coahuila, México, 11 August 1967; see text for explanation.

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