45. Kato- and Dichothermy during the Autumnal Circulation Period in Small Ponds of Miyagi Prefecture, Japan.\(^1\)

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There are several lakes in Japan with permanently stagnated layers. Although in some of them stagnation is due either to sublacustrine mineral springs or to entrance of sea-water (Yoshimura 1934), a few others, such as Lake Hangetu on the slope of Volcano Yōtei (Ezohuzi) and probably Lake Ooike of the Tugaru Zyūniko Lake Group, Aomori Pref., come within the class mentioned by Findenegg.\(^2\)

This paper deals with observations on two small ponds, Sindenmae Osikirenuma (abbrev. West Pond) and Gonzaemonura Osikirenuma (abbrev. East Pond), near Hatazaki, Miyagi Pref., 45 km NE of Sendai, ponds formed by water erosion following the collapse of the river bank during the great floods of 1875 and 1896. They are 5 m. above sea level, with areas only 1.1 (W. Pond) and 0.55 (E. Pond) ha, though fairly deep (11.5 and 9.1 m respectively). They are the second and third deepest lakes formed in this way in Japan.

We visited these lakes three times during November, 1934\(^3\) (Table 1). On Nov. 11, both were on the point of turning, although the last sign of the thermocline established during the summer was traced between 6 and 8 m. The water below that depth, with no dissolved oxygen, had a considerable amount of iron. Stagnation continued since the summer. At the time of the senior author’s visit on Nov. 16, the deeper W. Pond still kept up a slight thermocline between 7 and 8 m, while in the shallower E. Pond the surface layer had already cooled below 8.4°C, lower than the bottom temperature (9.0°C) five days previously. Just as the oxygen data indicated, the bottom layer was still not circulating. The bottom temperature was higher than that of the surface. There had developed a negative or katothermal thermocline with the negative thermal gradient lying between 7 and 8 m.

On the junior author’s visit on Nov. 23, conditions in the W. Pond were found to be quite similar to what they were in the E. Pond a week before. A remarkable negative thermocline had developed between 8 and 9 m. The layer below 9 m was anaerobic, showing further

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\(^1\) Contribution from the Institute of Geology and Palaeontology, Tōhoku Imperial University, Sendai.

\(^2\) I. Findenegg published several papers on some temperate lakes of Austria that have no complete circulation period. The temperature of their hypolimnion always remained above 4°C throughout the year, while the surface temperature was below 4°C during the winter. The water of the hypolimnion was stagnant even during the autumnal and the vernal circulation period. He attributed the poverty of dissolved oxygen in the bottom waters of these oligotrophic lakes to stagnation throughout the year, and called them pseudoeutrophic lakes. In some of them permanent stagnation was due to biochemical stratification established during the summer and winter stagnation periods and to the protected position of these deeply hollowed basins.

\(^3\) The lakes were surveyed on Nov. 16, with the assistance of Mr. T. Nisio and a number of students of the Institute of Geology and Palaeontology.
stagnation of that layer. On the day of his visit, the uppermost layer was warmed, the stratification being dichothermal.

The water samples collected from these ponds were analysed by the senior author at the laboratory of the Geographical Institute, College of Literature and Science, Tokyo (Table 2).

### TABLE 2.

<table>
<thead>
<tr>
<th>Name of Pond</th>
<th>Date</th>
<th>Depth m</th>
<th>$K_{18}$ $10^{-4}$ ohm$^{-1}$</th>
<th>Ca$^{2+}$</th>
<th>Fe</th>
<th>HCO$_3^-$</th>
<th>CO$_2$</th>
<th>Cl$^-$</th>
<th>SiO$_3^-$</th>
<th>NH$_4^+$</th>
<th>NO$_3^-$</th>
</tr>
</thead>
<tbody>
<tr>
<td>E Pond</td>
<td>Nov. 11</td>
<td>0</td>
<td>1.19</td>
<td>3.81</td>
<td>10.1</td>
<td>0.2</td>
<td>17.2</td>
<td>18.2</td>
<td>8.6</td>
<td>0.6</td>
<td>0.20</td>
</tr>
<tr>
<td></td>
<td>Nov. 16</td>
<td>0</td>
<td>1.31</td>
<td>2.65</td>
<td>8.3</td>
<td>0.15</td>
<td>16.8</td>
<td>20.3</td>
<td>8.8</td>
<td>0.5</td>
<td>0.16</td>
</tr>
<tr>
<td>W Pond</td>
<td>Nov. 16</td>
<td>0</td>
<td>1.46</td>
<td>4.24</td>
<td>10.6</td>
<td>0.2</td>
<td>20.5</td>
<td>24.3</td>
<td>11.0</td>
<td>0.4</td>
<td>0.25</td>
</tr>
</tbody>
</table>

As the electric conductivity data ($K_{18}$ in the table show), the salinity of the bottom water in both ponds is from two to three times that of the surface. The chemical stratification of these ponds is as follows:

1) Biochemical stratification. Fe, carbonate-CO$_2$, and NH$_4$ increase considerably toward the bottom. The enormous amount of 70 mg/l iron was found at the bottom of the W. Pond. On the other hand, there was no trace of nitrate nitrogen in the anaerobic bottom layer.
Non-biochemical stratification. Both ponds had marked stratifications of chloride—those that do not depend upon biochemical processes (Yoshimura, 1933, Ruttner 1933, and Ohle, 1934). This high chloride is probably due to fossil rock salt in the ground, seeing that until quite recently the region was an estuary and that the well water in the neighborhood of these ponds is saline.

Assuming an electrical conductivity of $1 \times 10^{-4}$ reciprocal ohm to be roughly equivalent to 75 mg/l of mineral salts in solution, the salinity and the density in situ at the top and the bottom of these ponds when there was an anthermy is as follows:

<table>
<thead>
<tr>
<th>Name of Lake</th>
<th>Date</th>
<th>Depth</th>
<th>Salinity g/ml</th>
<th>Density of Distilled Water at Temp. in situ g/ml</th>
<th>Density of Pond Water in situ g/ml</th>
</tr>
</thead>
<tbody>
<tr>
<td>East Pond</td>
<td>Nov. 16</td>
<td>0</td>
<td>0.000098</td>
<td>0.999852</td>
<td>0.999950</td>
</tr>
<tr>
<td></td>
<td></td>
<td>8</td>
<td>0.000199</td>
<td>0.999819</td>
<td>1.000018</td>
</tr>
<tr>
<td>West Pond</td>
<td>Nov. 23</td>
<td>0</td>
<td>0.000109</td>
<td>0.999873</td>
<td>0.999899</td>
</tr>
<tr>
<td></td>
<td></td>
<td>10</td>
<td>0.000318</td>
<td>0.999825</td>
<td>1.000143</td>
</tr>
</tbody>
</table>

Table 3.

The added density owing to the presence of dissolved salts compensates for the decrease in density of the bottom water of warmer temperature than the surface. The density in situ is always greater at the bottom than at the surface for establishment of stable equilibrium.

The peculiar thermal stratifications on both ponds is therefore easily explained by the higher salinity of their bottom water. The higher salinity is due to the entrance of dissolved fossil salt with a high chloride content as well as to the biochemical stratification that had been established during the preceding summer stagnation period, the latter contingency has been pointed out by Findenegg. These small and deep basins are not disturbed by turbulence.

Katothermy however does not seem to last for any great length of time. The salinity of the bottom water was not high enough to resist the increase in density of the surface water accompanied by further cooling to 4°C. There were besides many chances of the katothermy being nullified by strong wind until the formation of an ice-cover and the water becomes stagnated towards the end of December. We observed a colder temperature of 4.7–5.1°C at their bottoms under the ice on Jan. 27, 1935, the whole layer being aerated.

References.

Yoshimura, S.: Proc. 9 (1933), 156-158.

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