84. *Abnormal Thermal Stratifications of Inland Lakes.*

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In some of the inland lakes of the world, one meets with various kinds of abnormal thermal stratifications, for example,

A. The presence of water warmer than 4°C under a surface layer that is below 4°C , particularly under the ice cover.

B. Dichothermy, or thermal stratification, with minimum temperature in the middle layer.

C. Mesothermy, or thermal stratification with maximum temperature in the middle layer.

D. Poikilothermy, or thermal stratification, with one or more minimum and maximum temperatures in the middle layer.

Dichothermy is usually established in early spring when, although the surface layer is warming, the middle layer is still cold. In a few lakes, it lasts until mid-summer. Mesothermy is often developed during the autumnal partial and complete circulation period, when the surface layer is cooled by convection. Poikilothermy is established on warm days following a cool period.

In a certain lake, abnormal thermal stratifications appear every year, although in other lakes, they are established only in certain years. Dichothermy in a lake, in some years is not destroyed by dissipation of heat toward the middle layer until the summer, but is already obliterated by active warming in the late spring of other years.

In some lakes with abnormal thermal stratification during the stagnation periods, stratification circulates to the bottom every spring and autumn as in ordinary lakes, while in other lakes, circulation goes on only in the upper and middle layers in the circulation periods of certain years. Findenegg¹⁾ recently called lakes of the former kind, holomictic lakes, and of the latter kind, meromictic lakes. Several lakes have a deep layer that is never disturbed by the circulation regardless of the time of year. This is called monimolimnion in Findenegg's paper.

Abnormal thermal stratification is necessarily maintained by the presence of the heavier water of the deep layer. The greater density in situ of the deep layer is due to the larger amount of dissolved substances. Three kinds of chemical stratifications were designated by the writer²⁾ in inland lakes.

1) Biochemical stratification. According to the studies of Findenegg,¹⁾ in some lakes of Kärnten, Austria, their duration of stagnation was due to chemical stratifications being established by biochemical processes during the summer stagnation period. Chemical stratifications

1) Findenegg, I.: Intern. Rev. ges. Hydrob. u. Hydrogr. **32** (1935), 369-423.

2) Yoshimura, S.: Jap. Jour. Astr. & Geophys. **13** (1936), 61-120.

increase the density of the middle and deep layers of these lakes more than that of the surface layer in order to maintain the warmer water of a certain summer until the next spring or even until the next summer without being cooled by convection currents during the autumn, winter, and the following spring. The bottom water temperatures of these lakes are kept almost constant throughout the year, otherwise convection occurs and mixes up the layer, because the warming of the bottom layer reduces the density at that depth and is disturbed by convection currents. Chemical stratifications consist mainly of pH, O₂, NH₄, NO₂, NO₃, P, Fe, Mn, HCO₃, Ca, and SiO₂.

2) Non-biochemical stratifications. It has generally been accepted by many investigators that the inflowing of underground water of chemical compositions differing entirely from those of lake water (usually of higher concentration) into the deep layer of a lake, increasing the density of the bottom strata. The bottom temperature of a lake of this type does not always remain constant throughout the year, because excess warming by warm underground water reduces the density in situ to be replaced by the colder but a more diluted surface layer during the circulation period. According to the opinion of the writer,¹⁾ Cl, SO₄, and Na are the best indicators for detecting the presence of non-biochemical stratifications in an inland lake, since they are rarely stratified by biochemical processes. Marked increases in the contents of Ca, Mg, and pH also serve as further indications.

3) Combined stratifications of biochemical and non-biochemical origins.

The writer constructed a table in which he has listed lakes of the world with abnormal stratifications and other conditions for different periods of an year. Chemical stratifications that maintain the abnormal stratification were judged by those of Cl and SO₄ (Table 1).

Purely biochemical stratifications are responsible for the abnormal thermal stratifications in the lakes of Kärnten, some eutrophic lakes of Switzerland, U S S R, and U. S. A., and Lakes Masyûko (?), Hangetuko, Akanuma (Zyunsainuma), and N. Ooike of the Tugaru Zyûniko Lake Group in Japan. In the majority of lakes, non-biochemical or combined stratifications are responsible for the increase in density that follows abnormal thermal stratifications.

There is an exceptions, in which no abnormal thermal stratification has been found despite the presence of marked non-biochemical stratification. Ohle²⁾ found fine stratification of Cl in Trammersee, Holstein, but he failed to find any abnormal thermal stratification in this lake. Strong wind may disturb the deep layer and destroy such stratifications.

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

2) Ohle, W.: Arch. f. Hydrob. **26** (1934), 386-464, 584-658.

TABLE 1.

Lake	Locality	Bottom Temp. °C	Circulation		Abnormal Thermal Stratification		Chemical Stratification		
			Spring	Autumn	Summer	Winter	Biochem.	Non-bioch.	Principal Stratification
Wörthersee ^{1) 2)}	Austria	4.6	—	—	±	+	+	—	Biochem.
Millstättersee ¹⁾	"	4.5	—	—	±	+	+	—	"
Weissensee ¹⁾	"	5.1	—	—	±	+	+	—	"
Klopeiner See ¹⁾	"	4.7	—	—	—	+	+	—	"
Längsee ¹⁾	"	4.9	—	±	+	+	+	—	"
Toplitzsee ^{3) 4)}	"	5.9	—	—	+	—	+	+	Non-Biochem.
Krottensee ³⁾	"	5.0	—	—	+	—	+	—	Biochem.
Traunsee ³⁾	"	5.4	±	±	+	+	—	+	Non-Biochem.
Zugersee ⁵⁾	Switzerland	4.3	—	—	—	+	—	—	Biochem. ?
Ritomsee ⁶⁾	"	6.6	—	—	+	+	+	+	Non-Biochem.
Rotsee ⁷⁾	"	—	+	±	—	+	+	—	Biochem.
Oeschinensee ⁸⁾	"	4.8	—	±	±	+	—	—	" ?
Züricher See ⁹⁾	"	4.5	±	±	—	±	+	—	"
Lac de la Girrotte ¹⁰⁾	France	7.2	—	—	—	+	+	+	Non-Biochem.
Salzunger See ¹¹⁾	Germany	5.8	—	—	±	+	—	+	"
Ulmener Maar ¹¹⁾	"	7.2	—	—	+	+	+	+	"
Königssee ^{2) 12)}	"	5.0	—	—	+	—	—	—	?
Grunewaldsee ¹³⁾	"	—	+	+	—	+	—	+	Non-Biochem.
Hundekehlensee ¹³⁾	"	—	+	+	—	+	—	+	"
Barssee ¹³⁾	"	—	+	+	—	+	—	+	"
Rüdersdorfsee ¹⁴⁾	"	7.8	—	—	+	+	—	—	" ?
Lago Moro ¹⁵⁾	Italy	5.8	±	±	±	±	—	—	?
Walloxen ¹⁶⁾	Sweden	—	—	—	—	+	—	—	?
Beloje (Moscow) ¹⁷⁾	USSR	—	±	—	—	+	+	—	Biochem.
Gek-gel ¹⁸⁾	"	5.2	—	—	+	—	+	+	Non-Biochem.
Green Lake (New York) ¹⁹⁾	U. S. A.	8.2	—	—	+	—	—	—	Biochem.
Kensico Reservoir ²⁰⁾	"	—	+	+	+	—	+	—	"
Beasley ²¹⁾	"	—	±	+	—	+	+	—	"
Mary ²²⁾	"	4.8	—	—	+	—	+	—	"
Masyûko ²³⁾	Hokkaidô	4.2	—	—	+	—	—	—	?
Sikaribetuko ²⁴⁾	"	4.5	—	±	+	+	+	+	Combined
Hangetuko ²⁵⁾	"	5.2	—	±	±	+	+	—	Biochem.
Oonuma (Osima) ²⁶⁾	"	—	+	+	—	+	—	+	Non-Biochem.
Akanuma Basin of Zyunsainuma (Osima) ²⁶⁾	"	—	+	±	—	±	+	—	Biochem.
Ooike (Zyûniko) ²⁵⁾	Aomori	4.5	—	—	+	—	+	—	"
Towadako ²⁵⁾	"	5.0	—	—	+	+	—	+	Non-Biochem.
Okama (Zaô) ²⁷⁾	Miyagi	—	—	—	±	—	—	+	"
Gonzaemonnuma ²⁸⁾	"	—	+	+	—	+	+	+	Combined
Sindenmaenuma ²⁸⁾	"	—	+	+	—	+	+	+	"
Yarokunuma ²⁵⁾	Hukusima	—	+	+	+	—	—	+	Non-Biochem.
Bentennuma ²⁵⁾	"	—	+	+	+	—	—	+	"
Marunuma (Nikko) ²⁹⁾	Gunma	—	—	+	—	+	—	+	"
Oozirinumma ²⁹⁾	"	—	—	+	—	+	—	+	"
Sumiyosiike ³⁰⁾	Kago-sima	8.8	—	±	+	—	+	+	Combined

- 1) Findenegg, I.: Intern. Rev. **28** (1933) 295-311, **32** (1935) 369-423, Arch. f. Hydrob. **24** (1932) 253-262, **27** (1934) 621-625, **30** (1936) 337-344, Mitt. Ver. Naturk. Landesmuseum Kärnten 121/122 (1932) 41-54, Sonderheft Ver. Naturk. Landesmuseum Kärnten **2** (1933), **4** (1935), Biokl. Beiblätter 1934, 160-165, (1936) 57-63, 2) Richter, E. Geogr. Abhandl. **6** (1897) 2, 1-71, 3) Ruttner, F.: Geogr. Jahresber. Oesterr. **16** (1933) 73-87, 4) Morton, F.: Arch. f. Hydrob. **24** (1931) 263-268, 5) Brutschy, A.: Arch. f. Hydrob. **8** (1912) 43-108, 6) Bachmann, H.: Zeit. f. Hydrol. **4** (1924) 21-28, Collet, L. W.: Les lacs, 1925, 7) Bachmann, H.: Zeit. f. Hydrol. **5** (1931) 39-81, 8) Groll, M.: Der Oeschinensee. Inaug. Diss. Bern 1904, 9) Minder, L.: Vierteljahrschr. Naturf. Ges. Zürich **79** (1934) 40-62, 10) Delebecque, A.: Les lacs française. 1898, 11) Halbfass, W.: Globus **81** (1902) 7-12, Thienemann, A.: Ver. Naturh. Ver. preuss. Rheinlande u. Westfalens **71** (1915) 281-389, 12) Ule, W.: Wiss. Veröff. Ver. Erdk. Leipzig **5** (1901), 13) Nötlich, F.: Veröff. Inst. Meereskunde Univ. Berlin N. F. A Reihe **30** (1936) pp. 168, 14) Röhler, E.: Arch. f. Hydrob. **17** (1926) 395-404, 15) Ricci, L.: Riv. Geogr. Ital. **18** (1911) Fasc. 7, VIII 1-31, 16) Hamberg, A.: Peterm. Mitt. **57** (1911) II 310-312, 17) Rossolimo, L. L.: Arb. Biol. Station Kossionno **10** (1929) 3-41, 18) Fortunatov, M. N.: Arch. f. Hydrob. **24** (1932) 449-484, 19) Eggleton, F. E.: Ecol. Monogr. **1** (1931) 231-332, 20) Hale, F. E., Dowd, J. E.: Jour. Ind. & Eng. Chem. **9** (1917) 370-374, 21) Birge, E. A., Juday, C.: Bull. Wisconsin. Geol. & Nat. Hist. Surv. **64** (1911), 22) Juday, C., Birge, E. A., Meloche, V. W.: Trans. Wisconsin Acad. Sci. **29** (1935) 1-82, 23) Takayasu, S. etc.: Rep. Hokkaidô Fish. Exper. Station **35** (1934) 1-46 (Jap.), 24) Takayasu, S. etc. ibid. **29** (1933) 1-48 (Jap.), 25) Yoshimura, S.: Jap. Jour. Astr. & Geophys. **13** (1936) 61-120, 195-200, **14** (1936) 57-83, Watanabe, M.: Geogr. Rev. Japan **43** (1931) 129-137, 228-230 (Jap.), 26) Takayasu, S. etc. Rep. Hokkaidô Fish. Exper. Station **40** (1936) (Jap.), 27) Anzai, T.: Jour. Saitô Hô-on-kai, **85** & **86** (1934) (Jap.), 28) Yoshimura, S., Masuko, K.: Proc. **11** (1935) 146-148, 29) Yoshimura, S.: Jap. Jour. Geol. & Geogr. **11** (1934) 257-271, 30) Yoshimura, S.: Sea & Sky **17** (1937) 237-254, 289-301, (Jap.).
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