86. *Limnology of Lake Wakuike, Nagano Prefecture, Japan.*

By Shinkichi YOSHIMURA.

Geographical Institute, College of Literature and Science, Tokyo.

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Wakuike is a little lake at the south-eastern side of Sai-River among the mountains of Tertiary formations about 15 km west of Nagano city. It was formed by the famous land-slide of Mt. Iwakura on the occasion of the great Zenkôzi Earthquake of May 8, 1847. Since Nov. 1, 1849, the lake-level has been raised artificially for irrigation purposes.

The lake was first surveyed by Viscount A. Tanaka on June 1, 1925 using a raft. The morphometrical data at the highest water-level are quoted below from his paper.¹⁾

TABLE 1.

Height above sea-level	580 m	Maximum depth.....	10.8 m
Area.....	33,380 sq. m	Mean depth.....	6.7 m
Length of shore line	670 m	Volume	156,850 cbm

Tanaka also made some hydrographical observations that summer and found a large amount of calcium dissolved in the lake water.

On July 21, 1933, a very hot and calm day, the writer and Dr. M. Uéno made a limnological study of this lake, using a portable rubber boat. The water was ca. 3 meters lower than the maximum level. The results obtained are in Table 2.

TABLE 2.

Air Temperature 30.0° C					Transparency 0.8 m			
Depth M	Temp. °C	pH	CO ₂		H ₂ S mg/l	O ₂		%
			Free mg/l	Fixed mg/l		Dissolved c.c./l	Deficit c.c./l	
0	30.6	8.8	-11.2	60.8	0.0	8.05	3.13	164
0.5	28.93	—	—	—	—	—	—	—
1	26.89	8.7	-13.0	61.2	—	9.60	4.34	182
1.5	25.05	8.7	—	—	—	12.62	7.17	232
2	17.06	7.3	6.2	104	0.0	1.82	-4.52	29
2.5	13.23	7.2	—	—	—	—	—	—
3	9.88	6.9	—	—	4.1	0.00	-7.40	0
4	7.30	6.9	16.8	129	4.2	0.00	-7.85	0
5	6.87	6.9	—	—	9.6	—	-7.94	—
6	6.87	6.7	35.6	175	16.4	—	-7.94	—
6.6	6.93	6.7	35.6	175	18.9	—	-7.94	—
7	6.92	—	—	—	—	—	—	—

The water was turbid owing to water-bloom of blue-algae. A white disc became invisible at a depth 0.8 meters. The metalimnion was very

1) A. Tanaka, 1926: Limnological studies of Lake Noziriko and of lakes of its vicinity, pp. 58-87 (in Japanese).

well developed and found at a very shallow layer. The temperature dropped to 17.0°C between 1 and 3 meters depth. The maximum drop per meter was 11.8 between 1.5 and 2.5 meters. It is the greatest temperature drop ever observed in Japanese lakes.¹⁾ Such steep thermocline resulted from the removal of partially warmed water of the middle layer through the water-gate that is situated 1 meter below the surface. The deeper layers contained cold water.

The surface water was strongly alkaline due to assimilation of the algae just mentioned, while a marked depression of pH was found between 1.5 and 2 meters, corresponding to position of the thermocline. The bottom-water was nearly neutral. By the same reason, dissolved oxygen was astonishingly supersaturated in layer above 1.5 meters; the saturation at 1.5 meters amounted to even 232%. Below 1.5 meters, it disappeared abruptly and the bottom water below 5 meters was devoid of oxygen, and replaced by a large amount of hydrogen sulphide. Such an amount of H₂S (18.9 mg/l) in a mountain lake like the present is surpassed by only a single case of Lake Ritom in Switzerland; H₂S is at present lost due to artificial regulation of water-level for hydroelectric. Carbon dioxide was abundant in the anaerobic layer.

The analysis of the water made by the water is given in Table 3.

TABLE 3.

Depth in meters	0	2	4	6.5
K ₁₈ $\times 10^{-4}$ ohm. ⁻¹	7.88	8.22	8.11	8.69
Total residue mg/l	517.3	—	—	548.6
Na	25.4	—	—	27.5
K	—	1.9	—	2.9
Ca	76.2	93.4	93.7	103.4
Mg	3.6	5.4	3.6	0.8
Fe	0.07	0.1	0.2	0.8
Mn	0.08	—	—	0.3
SO ₄	169	156	163	194
HCO ₃	79	137	175	238
Cl	0.0	—	—	0.0
SiO ₂	21.3	24.4	27.1	32.5
NH ₄ -N	0.00	0.17	0.90	2.3
NO ₃ -N	0.04	0.04	0.04	0.03
Albuminoid N	0.51	0.08	0.18	0.22
P soluble	0.00	0.00	0.044	0.16
P total	0.13	0.12	—	—
Consump. KMnO ₄ (alkaline digestion)	26	22	26	29

Very large amounts of salts were found dissolved in the water. The total residue was slightly more than 500 mg/l, or beyond the limit of the amounts of salts dissolved in freshwater lakes. Lake Wakuike may be designated as the only salt-water lake in Japan, which has no relation to active volcanoes or to thermal springs.²⁾

The chief constituents were Ca, SO₄, and HCO₃ of which CaSO₄ occupied half of total salinity. It is yet not clear whether the sandstone or shale formations surrounding the lake are rich in gypsum. Many volcanic lakes of Japan are rich in CaSO₄. It is worthy of notice that lakes containing a large amount of hydrogen sulphide at their anaerobic

1) Far greater amounts were detected in brackish-water lakes.

2) In Japan, there are several salt lakes influenced by active volcanoes.

strata are always rich in sulphate (brackish-water lakes, and L. Ritom for examples). It is probable that H_2S may be reduced from sulphate by means of sulphate-reducing bacteria. 53 mg/1 sulphate is necessary to generate 18.9 mg/1 H_2S which was detected at the bottom of the lake.¹⁾ As the solubility of CaSO_4 is fairly large, it can not be precipitated too readily as hydrocarbonate of calcium. CaO in the bottom deposits collected by Tanaka was only ca. 5%. Gypsum lake may prove to be quite different in characters from the ordinary Ca-rich lake ($\text{Ca}(\text{HCO}_3)_2$) which are designated gypsotrophic or alkalitrophic type according to the nomenclature of E. Naumann.²⁾

Stratifications of both iron and manganese were not so evident as in other Japanese lakes with anaerobic strata. The total amounts of nitrogen and phosphorus were 0.55 and 0.13 mg/1 respectively, i. e., the superpolytypes of them. High production of phytoplankton is due to their high contents. Much ammonia nitrogen and soluble phosphate phosphorous were accumulated at the bottom layer.

Lake Wakuike can be classified as the eutrophic type on the basis of chemistry of water. It is uncertain that the lake may be called the gypsotrophic facies or modification of eutrophic type, as there are no investigations concerning the effect of calcium sulphate upon the productivity of freshwater lakes.

1) S. Yoshimura, 1932: *Geophys. Mag.*, **6**, 315-321.

2) E. Naumann, 1932: *Grundzüge der regionalen Limnologie*.