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Limnological Studies of Lake Yogo-ko (III)

By Shoji HORIE

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Abstract

In this final part of the writer's limnological studies of Lake Yogo-ko, the writer has shown the general view of the physico-chemical nature in connection with the productivity of Lake Yogo-ko.

The General Aspect of the Physico-chemical Features of Lake Yogo-ko

The heat budgets of European and American lakes were discussed by Forel1),2), Halbfass3), and Birge4), and recently Hutchinson5) stated them in more detail. The writer is greatly concerned with the problem of heat budget since his chief interest is the study of lake sediment and lake history. In the investigation of the heat cycle, we can estimate the gain and loss of heat in any one lake, but such an investigation is only applicable to the present climate. On the other hand, it is a well known fact that the globe has had many fluctuations of climate amounting to several degrees centigrade of air and sea water temperature in the maximum amplitude (Flint6), Emiliani7)). It is the writer's hypothesis that the circulation pattern of lakes fluctuated in accordance with the oscillation of climate. In other words, the boundary between dimictic lakes and warm monomictic lakes shifted towards the pole or to a higher altitude during the interglacial age; similarly it moved towards the equator or to a lower altitude during the glacial age. This is an example of the fluctuation of Hutchinson's lacus-

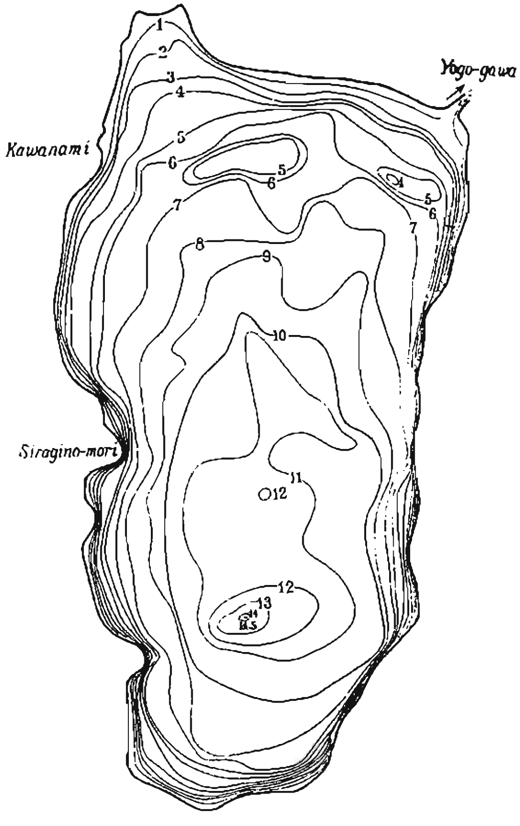

Fig. 1. Bathymetric map of Lake Yogo-ko (After A. Tanaka; Miyadi and Hazama, 1932).

trine climatic zonation, as the writer has already discussed in another paper[8]. Such a change in the circulation pattern is actually an internal accident, but at the same time there may occur oligotrophication or eutrophication due to a change of balance between precipitation and evaporation, as the writer discussed in the previous chapter. In connection with this question, the former heat budget must be different from the present one in the total number of calories necessary to warm the water body of a lake basin. It is of great interest to the writer with regard to Pleistocene ecology. Furthermore, Lake Yogo-ko might have been a closed lake, as stated before, and it is one of the most ancient lakes of Japan, so that it offers favorable conditions for the study of paleolimnology. The writer will show the heat budget of this lake today as the data fundamental to his discussion of paleolimnology.

The writer applied Birge's method, the formula for which calculation is as follows;

$$Q = A\theta_m = A\sum_{i=1}^{n}\theta_i(RT)_i$$

A detailed morphometry of Lake Yogo-ko was carried out by the writer as shown in Table 1. It became evident that the lake was warmest at the time of the September observation and coolest at the time of the February observation (Fig. 2). Thus the writer obtained temperature differences for each level between these two months (Table 2). Afterwards, the surface area of the lake was multiplied; then the annual heat budget through unit area of Lake

TABLE 1.

Detailed morphometry of Lake Yogo-ko (calculated by S. Horie).

Depth m	Area in the isobath km²	Percentage	Isobath interval	Volume km³	Percentage	Reduced thickness m
0	1.63	100.0	0–1	0.0015897	12.9	0.98
1	1.55	95.1	1–2	0.0015200	12.4	0.93
2	1.49	91.4	2–3	0.0014597	11.9	0.90
3	1.43	87.7	3–4	0.0013997	11.4	0.86
4	1.37	84.0	4–5	0.0013300	10.8	0.82
5	1.29	79.1	5–6	0.0012497	10.2	0.77
6	1.21	74.2	6–7	0.0011033	9.0	0.68
7	1.00	61.3	7–8	0.0009085	7.4	0.56
8	0.82	50.3	8–9	0.0007229	5.9	0.44
9	0.63	38.7	9–10	0.0005375	4.4	0.33
10	0.45	27.6	10–11	0.0003339	2.7	0.20
11	0.23	14.1	11–12	0.0001144	0.9	0.07
12	0.03	1.8	12–13	0.0000146	0.1	0.009
13	0.0035	0.2	13–14	0.0000018	0.01	0.0001
14	0.0005	0.03	14–14.5	0.00000072	0.006	0.00004
			0–14.5	0.01228642	100.016	7.54914*

* In a previous paper[9] the Volume of 0.012 km³ was divided by the Area of 1.63 km² and the Mean Depth of 7.4 m was obtained in accordance with the standard of morphometry of all Japanese lakes. Mean depth of 7.54 m is a more accurate figure.

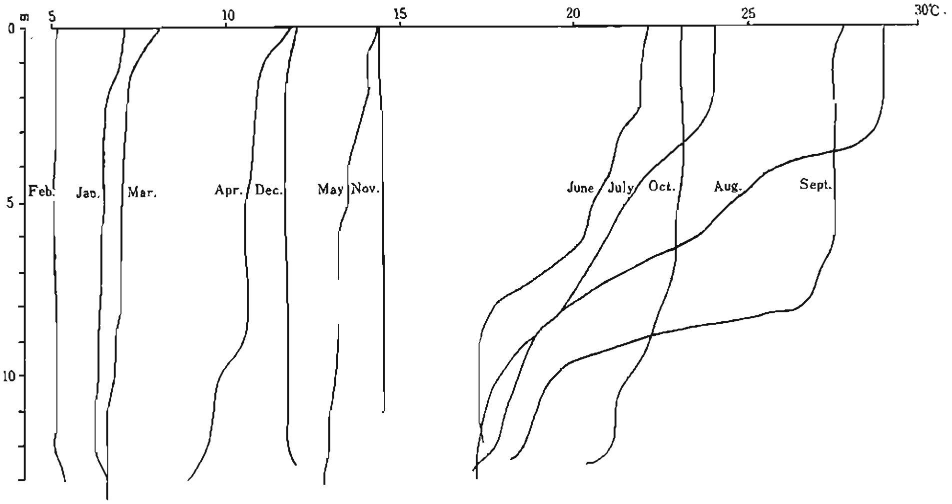

Fig. 2. Figure showing the monthly water temperature gradient for Lake Yogo-ko drawn by S. Horie.

TABLE 2.

Heat budget of Lake Yogo-ko (1962), calculated by S. Horie.

Depth m	Tm^s (Sept.) $-Tm^w$ (Feb.) θ_t °C	Reduced thickness $(RT)_t$ cm	Annual heat budget g. cal./cm²
0-1	22.5	98	2205
1-2	22.4	93	2083
2-3	22.4	90	2016
3-4	22.5	86	1935
4-5	22.5	82	1845
5-6	22.5	77	1733
6-7	22.3	68	1516
7-8	22.0	56	1232
8-9	19.5	44	858
9-10	15.9	33	525
10-11	14.3	20	286
11-12	13.9	7	97
12-13	13.4	0.9	12
			16343

Yogo-ko was computed as 16,343 g. cal/cm², thereby the total budget is 2.66×10^{14} g. cal. It is possible that such a figure is almost equal to wind-distributed heat or summer heat income, since this lake is located on the boundary between the dimictic and warm monomictic lakes, and its lowest temperature is about 5°C. at present. It is also possible to assume that the surface water temperature of this lake during the glacial age was several degrees centigrade lower, and that even in mid-winter, the temperature of the metalimnion and the hypolimnion under the condition of indirect stratification was somewhat below 4°C. Owing to such a situation, the annual heat budget and wind-distributed heat or summer heat income was below the present amount.

To assess the chemical composition of the lake water, the writer succeeded in obtaining the representative data in carrying out the research in September. The observation was made at the end of the summer stagnation period (Table 3). The data was obtained mainly by photospectrometer and represented the chemical nature of the epilimnion, the metalimnion, and the hypolimnion. Details will be discussed in the next chapter.

TABLE 3.
Chemical composition of Lake Yogo-ko (Sept. 3, 1962) (mg/l).

Depth m	Fe^{++}	Mn	SiO_2	Ca	Cl	H_2S-S	Total Sulfide	NH_4-N	NO_2-N	NO_3-N	Total -N	PO_4-P	Total -P	COD	Total Residue	Ignition Loss
0	—	(Trace)	6.00	3.00	5.61	—	—	0.11	0.000_4	0.020	0.375	0.003_6	0.010_7	13.40	54.0	11.1
8	—	(0.20)	6.70	5.48	5.69	—	—	0.20	0.001_8	0.036	0.510	0.012_4	0.020_4	13.33	64.5	14.5
12	4.000	(1.10)	12.00	7.16	6.36	0.01	0.055	2.00	0.004_2	0.760	2.050	0.810	4.800	13.82	86.5	16.8

Discussion of the Productivity of Lake Yogo-ko

Since the classification of lake types was made by Naumann and Thienemann, many investigators have been wholly or partly engaged in such a study. In Japan, too, thanks to many authors, particularly to Uéno, Miyadi, and Yoshimura, the various trophic stages of most Japanese lakes have been clarified. But in the writer's opinion, the immediate question to be solved is what kind of mechanism produces the various stages of lake-trophy.

Having discussed productivity, Ohle[10] has stated that the trophic stage of a body of water is a function of its overall productivity. Thus we have to deal with productivity before we can discuss the trophic stage problem. Lake Yogo-ko has been assigned to the *Corethra* (with *Chironomus plumosus*) lake, or less advanced eutrophic lake type, based on the benthic fauna or plankton, as already explained. Therefore, the writer would like to discuss the productivity of Lake Yogo-ko from both the physical and chemical points of view. The relationship between the oxygen deficit and productivity has been discussed by Hutchinson[11] and Ohle[12]. This is a good way to estimate values of production as well as chlorophyll and C^{14}, the method for which the writer would like to discuss. The first thing to be clarified is the stability of different layers of lake water. The thermal stratification appeared in April, but complete separation into three layers occurred sometime before early June and was maintained until early October[13]. The rest of the year is the circulation period so that the computation of oxygen deficit is only possible during the summer stagnation period.

Since the volume of the hypolimnion is very small

TABLE 4.

Summary of the physico-chemical features of Lake Yogo-ko during 1961-1962.

	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.
Thickness of epilimnion (m)	(0—5)	—	—	—	—	—	0—9	0—8	0—4	0—2	0—3	0—7
Volume of epilimnion (%)	59.4	—	—	—	—	—	91.9	86.0	48.6	25.3	37.2	78.6
Thickness of metalimnion (m)	(5-10)	—	—	—	—	—	9-10	8-10	4—8	2—9	3-10	7-10
Volume of metalimnion (%)	36.9	—	—	—	—	—	4.4	10.3	37.4	66.6	59.1	17.7
Thickness of hypolimnion (m)	10-12.5	—	—	—	—	—	10-13	10-13	8-12	9-12.8	10-13	10-12.5
Volume of hypolimnion (%)	3.7	—	—	—	—	—	3.7	3.7	13.9	8.1	3.7	3.7
Depth of O_2 clinograde (m)	6—8	—	—	—	—	—	9-12	8-11	6—9	4—9	3—7	7—9
Depth of O_2 positive heterograde (m)	—	—	5—8	1—4	10-12.5	7—9	—	—	—	—	—	—
Depth of CO_2 clinograde (m)	6—8	6-11	—	—	—	7-12	10-12	8-11	6—8	3—9	4—7	6->9
Depth of CO_2 negative heterograde (m)	—	—	5—8	6—8	—	—	—	—	—	—	—	—
Depth of pH clinograde (m)	—	—	—	—	—	1—8	0—5	—	6—8	2—5	2—5	—
Depth of pH acid heterograde (m)	6-10	—	—	5—7	—	—	—	—	—	5—9	5—8	6-10
Depth of alkalinity clinograde (m)	9-11	8-11	—	—	—	—	—	—	6-12	5-11	7-10	8-11
O_2-CO_2 intersection/Tr. (m)	(2.8)	—	—	—	—	—	—	—	1.9	2.1	1.5	2.1
Thickness of trophogenic layer (m)	0—4	0—2	0—5	0—4	0—3	0—4	0—3	0—3	0—7	0—5	0—7	0-7
Volume of trophogenic layer (%)	48.6	25.3	59.4	48.6	37.2	48.6	37.2	37.2	78.6	59.4	78.6	78.6
Thickness of tropholytic layer (m)	4-12.5	2-11	5-12.5	4-13	3-13	4-13.5	3-13	3-13	7-12	5-12.8	7-13	7-12.5
Volume of tropholytic layer (%)	51.4	73.7	40.6	51.4	62.8	51.41	62.8	62.8	21.3	40.6	21.4	21.4
Colour of Lake	XI	XII	XI	XI	XII	X	XI	XII	X	X	X	XI

TABLE 5.

Specific Electric Conductivity of the water of Lake Yogo-ko (September 3, 1962).

0 m	5.35 10^{-5} mho	7 m	5.52 10^{-5} mho
1	5.35	8	5.68
2	5.36	9	7.52
3	5.39	10	8.35
4	5.40	11	8.42
5	5.38	12	9.24
6	5.45		

(Table 4), a conspicuous consumption of oxygen there was expected. However, a supply of organic detritus from the epilimnion was not to be expected because of stable stratification. In this connection, we must consider the thickness of the trophogenic layer which can be determined by discovering the compensation depth. It may be defined by an oxygen balance experiment or an estimation of the lower limit of effective carbon dioxide assimilation. Yoshimura(4) reached the conclusion that the compensation depth of photosynthesis was roughly 1.2 times as deep as the Secchi disk transparency, while Hogetsu(5) and Yamaguti(6) proposed twice such a depth instead of 1.2 times as deep as the writer has mentioned already. In the case of Lake Yogo-ko, as systematically noted before, two clinograde curves for oxygen and carbon dioxide cross each other during the summer stagnation period. Such an intersection caused by the discontinuous curves for both oxygen and carbon dioxide indicating a rapid increase of oxygen consumption and carbon dioxide production, may be useful as a crude indication of compensation depth, if such a point is situated in the stable metalimnion. Having tried to divide the depth of that intersection by transparency, the writer obtained figures between 1.5 and 2.1. The figure of 2.8 for October is not included, since the epilimnion was expanding downwards at that time. An average value of 1.8 was multiplied by the transparency for each month; then the thickness of both the trophogenic and tropholytic layer was thus tentatively obtained (Table 4). During the three months of June, July, and August, the stable metalimnion was situated in the lower trophogenic and upper tropholytic layers, so that the amount of seston falling into the hypolimnion was not disturbed by epilimnetic water movement. In September, the upper limit of the metalimnion was at the same level as the compensation depth; it is equally possible to use these data. A comparison of the oxygen deficit thus became possible (Fig. 8 of Part (II)(13)). However, there is the difficulty of tracing the derivation of the underground water, as already noted. In August dissolved oxygen in the hypolimnetic water increased, probably due to the underground water which might be supplied in other months, too. Consequently, computation of the areal deficit of the hypolimnion became impossible. However, the depth of 7 m seems not to be affected by disturbance from either the epilimnion or hypolimnion between June and August. The oxygen deficit of this level suggets the production of the lower half of the trophogenic layer, which was kept in the stable metalimnion. These data suggest a relatively high production in the trophogenic layer between June and July.

Judging from the chemical composition of the lake water (Table 3), the effect of stratification is obvious. Such stratification was already noticed for water temperature, dissolved oxygen, carbon dioxide, pH, and alkalinity. But the other evidence to be noted is the specific electric conductivity (Table 5), which was determined at the time of water samplings. Below the depth of 8 m, the increment of dissolved chemical components was noticed. A conspicuous rise in ferrous iron, manganese, nitrogen compounds, phosphorus, silicate, sulfide-S, total sulfide, calcium, and total residue in the hypolimnetic water indicates the geochemical change which occurred in the interface between the surface of sediment and deep water. Although the writer has had no opportunity of using a redox-potentiometer, a strong reduction had probably occurred at this level of the lake in accordance with the progress of thermal stratification and the depletion of dissolved oxygen. That stagnation must have continued until early October when the dissolved chemical components were still able to maintain a stable hypolimnion despite the steep temperature gradient. This is shown in the curves for dissolved oxygen, carbon dioxide, the pH, and alkalinity.

When the chemical data given by Yoshimura, Koyama, Tanaka, and the present paper are compared, an increase is observed in the amount of nitrogen, silicate, and chemical oxygen demand. Calcium also increased, though only in the hypolimnion. Presumably, this is a result of the falling of calcium carbonate particles from the warm epilimnion down to the cold hypolimnion in consequence of active photosynthesis during the summer. As noted in an earlier chapter, the fact that the transparency of Lake Yogo-ko has strikingly decreased during the last twenty years seems to support the hypothesis that the productivity of this lake has been increasing during the last twenty years. An increase in chemical oxygen demand also suggests such a situation. Presumably, many more nutrients having been supplied to the water from both outside the lake and the anaerobic lake sediments in recent years. As Ohle[10] has discussed, the amount of primary production per unit volume as well as per unit surface area of a lake is independent of the shape of the lake basin. But filling up of the lake basin and the allochthonous supply of nutrients may finally cause the increase of productivity when we observe the lake not in the stagnation period but over a period of some years. The decrease in transparency, which might be caused by higher primary and secondary production as well as the present chemical data support such an interpretation.

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