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Limnological Studies of Lake Yogo-ko (II)

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Abstract

The second part of the writer's limnological studies of Lake Yogo-ko, deals with the Neolimnology, based on his monthly observations during 1961~1962. The writer also gives a historical review of limnological data for the purpose of discerning the real situation of lake eutrophication or water pollution, or both, in Lake Yogo-ko.

Historical Review of Limnological Studies of Lake Yogo-ko

In recent years, changes of natural water quality have been becoming remarkable in connection with the increaed activity of people. In addition, changes of climate affect the physics of the lake causing changes in its chemistry and the biota in it. One proof is given by the change in the transparency of Lake Yogo-ko as the writer has shown in Fig. 1[1]. Thus, for purposes of discerning the real situation of lake eutrophication or water pollution, limnological data of the past are particularly important. On the basis of it, we can try to discuss the transition in lake typology and then make some recommendations concerning that problem. Of course, sporadic data of past observations is less significant for a detailed discussion[1] and therefore only a general trend can be discerned.

The chemical study of this lake's water was briefly mentioned by Yoshimura[2]. He made analyses of surface water, taken on September 27, 1930, as follows:

pH	SiO_2	Cl	Ca	$KMnO_4$ cons.	N
6.9	3.3 mg/l	6.0 mg/l	4.7mg/l	10.5 mg/l	0.175 mg/l

Yoshimura[3,4] supplemented the following chemical data of water samples, taken at the same date.

	SiO_2	Fe_2O_3	Mn	CaO
0 m	2.3 mg/l	1.0 mg/l	0.04 mg/l	(1.2)
9	3.8	1.6	0.8	
12	10.1	20.0	1.8	

A year later, he published the remaining data on water which was also sampled on September 27, 1930.

NH_3	N_2O_5	Alb. NH_3	Sum.	P_2O_5 (soluble)
80 mg/cbm.	15 mg/cbm.	80 mg/cbm.	175 mg/cbm.	60 ? mg/cbm.

On th basis of such data on nitrogenous compounds and phosphate, he regarded Lake Yogo-ko as a mesotrophic lake[5,6]. In addition, Yoshimura[7] denoted 1.0 mg/l CaO and the chemical composition of water sample on Sept. 27, 1930.

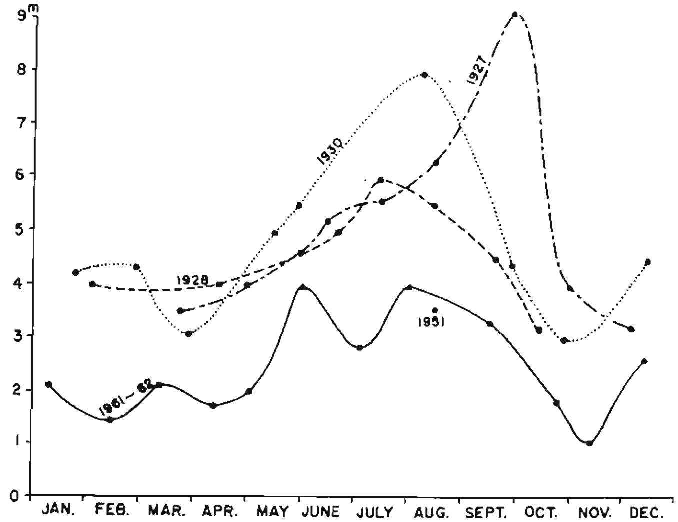

Fig. 1. Figure showing the change in the figure of transparency for Lake Yogo-ko (Compiled by Horie from various sources, including his observational data of 1961～1962). (After Horie unpublished[1])

	Free CO_2 (mg)	Fixed CO_2 (mg)	Ca (mg)
0 m	8.4	7	4.6
9	5.2	12	4.2
12	10.8	24	3.9

According to the later data puplished by the same author[8], the nitrogen content of surface water of Lake Yogo-ko on December 15, 1930 was 0.07 mg/l.

As for the physics of this lake, Yoshimura[9] cited the data obtained by the Shiga Fishery Experimental Station on August 15, 1928. Transparency was 5.5 m and $\sqrt{A}/h$ was 83.5.

Water temperature of the upper hypolimnion	16.6°C.
Thermocline	5～11 m
Thermocline gradient	1.8°C/m
Max $=\frac{de}{dz}$ layer	7～8 m
〃 gradient	3.5°C
Thermal type	Ib

As he listed[10], the winter water temperature obtained by the same Station on February 3, 1928 showed the same figure of 3.8°C throughout the whole water mass and transparency was 4.0 m. Besides, the other summer data, August 8, 1930, given by Yoshimura[11] is as follows;

Principal thermocline position	5～12 m
〃 gradient	1.7°C/m
Inflexion layer position	8～10 m
〃 gradient	3.3°C/m
Thermal type	C II

However, continuous observation of the limnology of Lake Yogo-ko was carried out by Miyadi and Hazama[12]. Between late October and the end of March, the water temperature was almost or completely uniform throughout the lake. The pH of lake water also showed the same figure at each level of depth between late October and the end of February, though it indicated an acidic tendency in February. At the end of March, figures between depths of 0 m and 10 m indicated 6.8~7.0, though below 11 m they remained at 6.6. Between late October and the end of March the water kept a sufficient amount of dissolved oxygen, which makes it possible to deduce that there was continuous circulation throughout the winter. The lake stratified conspicuously during the summer. At the end of May, the thermocline developed evidently and the decrease of dissolved oxygen in the hypolimnion began. Such a tendency became more obvious as the season advanced. Eventually dissolved oxygen below the depth of 11.5 m was completely depleted and there was little between 8 m and 11.5 m. Thus the thermocline was found at a depth of about 8 m in mid-summer, and pH was the lowest between about 8 m and 10 m. Transparency was maximum in August (8 m) and two minima occurred in both October and March (3.0 m and 3.1 m respectively). In other months it varied between 4.2 m and 5.5 m. These physico-chemical features of the lake offered basic data for their study in relation to the bottom fauna which indicate the eutrophication of lakes; Miyadi(13) classified Lake Yogo-ko as a *Corethra* (with *Chironomus plumosus*) lake. Such data obtained in 1930 is important for the writer's present study, since it shows the limnological characteristics of Lake Yogo-ko in its natural state, not after its artificial deformation.

Tanaka's(14,15,16) recent papers on the chemistry of the lake water showed that the amount of total Fe, Fe^{++}, Mn, P, and Si increased remarkably (Fe^{++} 6.85 mg/l, Mn 2.25 mg/l, P dissous 0.66 mg/l, Si dissous 6.1 mg/l), as the amount of dissolved oxygen in the profundal part of the lake decreased in mid-August. In the writer's opinion, it may be presumed that the redox potential in the mud-water interface drops in mid-summer and the black color of the bottom mud which was discovered by Miyadi during the summer stagnation period is a proof of the state of reduction. Conspicuous absorption of the oxygen of the bottom mud which was proved by Miyadi's study coincides with the existence of anaerobic stratum in this lake(6). The other important study was carried out by Koyama who made analyses of water and mud which were obtained in this lake on August 21 and 23, 1951, though this data is still unpublished (Table 1, 2, 3)*. At the same time, Yamaguti(17) found the transparency to be 3.5 m; it evidently decreased during the last twenty years, when we compare this with the figures given by Miyadi in 1930. Yamaguti concluded that a figure of 3.5 m at that time was reasonable because the compensation depth, which was estimated from the lower limit of vertical distribution of higher aquatic plants, almost coincides with twice the depth of transparency(18). Negoro(19) also noticed that Lake Yogo-ko showed water blooms consisting of *Lyngbya limnetica* Lemmermann and *Anabaena macrospora* Klebahn in late August. He mentioned that about 60% of the diatoms found in Lake Yogo-ko were common to those of Lake Biwa-ko, ten species among them being found only in Lakes Biwa-ko and Yogo-ko. It is of interest that *Stephanodiscus carconensis*, *Melosira italica*, and

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* The writer is much indebted to Prof. T. Koyama who gave permission for his data to be used in this paper.

TABLE 1. Chemical Composition of lake water of Lake Yogo-ko (Aug. 21, 1951, at St. 1), cited from the unpublished data of T. Koyama (mg/l).

Depth m	Ca	Mg	Cl	SO_4	unfiltered			Mn	Al	SiO_2	P	NH_4-N	NO_2-N	NO_3-N	$KMnO_4$ cons.
					Fe^{++}	Fe total	Fe soluble								
0	2.94	1.28	6.66	1.09	<0.01	0.215	0.042	<0.02	0.223	3.86	<0.01	<0.02	<0.001	<0.02	12.2
2.5	—	—	—	—	<0.01	0.244	0.047	<0.02	0.353	4.78	<0.01	<0.02	<0.001	<0.02	10.0
5	2.90	1.33	7.00	1.09	<0.01	0.265	0.070	0.12	0.243	5.27	<0.01	<0.02	<0.0015	<0.02	11.2
7.5	—	—	—	—	<0.01	0.320	0.094	0.17	0.302	5.78	<0.01	<0.02	<0.001	<0.02	10.3
10	3.40	1.44	6.58	1.87	2.66	3.58	3.28	2.05	0.288	7.07	0.392	<0.02	<0.001	<0.02	11.0

TABLE 2. Chemical composition of lake sediments of Lake Yogo-ko (Aug. 21, 1951 at St. 2), cited from the unpublished data of T. Koyama (mg/l).

Depth cm	Ca	Mg	Cl	SO_4	unfiltered			Mn	Al	SiO_2
					Fe^{++}	Fe total	Fe soluble			
0	3.49	1.50	—	0.43	6.85	—	6.90	2.25	0.438	13.0
5	3.07	1.47	6.90	1.20	6.55	—	7.70	2.18	0.302	10.0
10	—	—	—	—	6.12	—	7.05	2.17	0.287	10.0
25	3.60	1.63	6.79	0.98	6.02	—	6.45	2.02	0.263	10.0
50	—	—	—	—	6.02	—	6.18	2.12	0.284	9.2

TABLE 3. Chemical composition of core sample of Lake Yogo-ko (Aug. 23, 1951 at St. 2), cithd from the unpublished data of T. Koyama.

Core depth cm	Org. C	Total N	C/N	Fe^{++}	P	Total CO_2
0—15	% 4.03	% 0.387	10.4	mg/l 13.3	mg/l 0.85	cc/l 103.0
15—30	3.94	0.411	9.5_7	17.9	0.93	108.0
30—45	4.87	0.448	10.9	—	—	145.0
45—60	6.62	0.578	11.4	—	—	—

Melosira granulata are dominant or subdominant, making up about 90% of the diatom association. This feature extends equally to a depth of 13 cm beneath the present bottom of the lake. Negoro concluded that the conspicuous occurrence of both *Melosira italica* and *Melosira granulata* in Lake Yogo-ko suggested the eutrophy of this lake.

From these studies, two interesting points came to the writer's mind. One is that Lake Yogo-ko is either a mesotrophic or less advanced eutrophic lake type. However, this is applicable only to the present or recent (to 13 cm deep from the top of bottom) state of Lake Yogo-ko. It is problematical whether the lake has been the same type since its first eutrophication. In regard to such a discussion, two kinds of accident must be considered regarding this lake. One is the tectonic accident. As already mentioned, in tectonic lakes a basin-making crustal deformation might have been active, and therefore the oligotrophic state has persisted despite the immense passage of time. If crustal movements work out in the shallowing of the lake basin, on the contrary, eutrophication may advance in a relatively short time. Accordingly, the writer considers that such crustal deformation is extremely important for lake-trophy and must be taken into account in an unstable country like Japan. The other important factor which controls lake-trophy is climatic change. In contrast to the tectonic accident, the climatic accident happens on a wider scale. Particularly a change of proportion between precipitation and evaporation affects the trophic stages of a lake in connection with the morphology of its basin. Moreover, another combination of factors may be involved[20,21]. According to the writer's present opinion, the trophic stage of any lake is an entirely contemporary phenomenon and we can not simply estimate past and future lake-trophy from the present situation.

In Lake Yogo-ko, both accidents must be taken into account and the aforementioned distance between this lake and the glaciated district in the central Japanese mountains is significant in regard to climatic change. These problems will be discussed in detail when the writer deals with the paleolimnology of this lake. In the present paper the writer hopes to point out the previous studies which led to the conclusion that Lake Yogo-ko is of mesotrophic or less advanced eutrophic lake type.

The other interesting point in question is the stratification of lake water. Having cited A. Tanaka's opinion, Yoshimura[11] stressed that Lake Yogo-ko was located on the boundary between the temperate and tropical lakes in Japan with regard to water temperatures. This was also suggested by Miyadi and Hazama[12] who wrote as follows ;

> ……The ice cover seldom forms and the reversal stratification, if it occurs at all, is temporary and soon disturbed by the wind. The lake is homothermous in January, March, October and December……

Accordingly, if air temperature drops slightly, the lake will show indirect stratification. It is probable that such a phenomenon occurred through even a minor change of climate, which should be considered in research on the sedimentary record. It is well known that the temperature of the world has risen during the last two decades. The writer has found numerous evidences of such a rise in temperature during recent years from his trips to North America, South

America, Siberia, and Europe. Japan is not an exception to this rule. Therefore in limnological investigations carried out during these decades, attention must be paid to the climatological facts as well as the limnological nature of lakes such as lake Yogo-ko, which is located on the dimictic—warm monomictic boundary[22,23] and is sensitive to minor oscillations of climate.

Monthly Limnological Observations on Lake Yogo-ko

The writer carried out his physico-chemical studies of the water of Lake Yogo-ko from the autumn of 1961 to the end of the following summer, during which time he visited the lake every month.

a) Items of Observations and Methods Used

Water Temperature

During the two crossings, one from the northern shore to the southern shore along the length of the lake, and the other from the eastern shore to the western shore across the first course, the writer stopped his boat every 200 m and measured the water temperature at depths of 1 m intervals with a thermistor. Theremal stratification data was thus obtained, though it was complicated by the inflowing of the River Yogo-gawa (Fig. 2, 3. 4). The water samples were taken at the deepest point of the lake where the water temperature was measured again at 1 m intervals.

Transparency and Colour of Lake

At the deepest point, the writer observed these two features using a Secchi disk and a Forel-Ule colour scale.

Chemical Properties

The pH was determined colorimetrically on the boat using the indicators of phenol red and bromthymol blue, but various kinds of chemical analyses of water samples were carried out in the laboratory soon after return.

As for the dissolved oxygen, the writer used "Alsterberg's modification[24,25]". For the determination of oxygen dissolved in lake water, Winkler's method is most popular, though it gives a figure 0.24 cc/l higher than that by the gasometric method[26]. It is, however, difficult to employ Winkler's method with some lakes, including those of the eutrophic and dystrophic type, where much organic detritus and reducing substances such as ferrous oxide, nitrite, hydrogen sulphide, etc. may be present. Ruttner[27] has noticed this situation, and some Japanese scientists have published important data on the subject[28,29,30]. According to their studies, figures which were given by Winkler's method are not correct when water samples contain more than 0.1 p. p. m. nitrite, 0.5 p. p. m. ferrous iron, and also a considerable quantity of ferric iron, sulfide, sulfite, residual chlorine, and phytoplankton. As the gasometric method is not so simple and is inconvenient for field work, an appropriate modification is necessary. From this point of view, the chemical data given by Koyama (Table 1, 2, 3,) and Tanaka[14,15,16] is extremely important. After the writer had referred to this data, he planned to try Alsterberg's "Brom-Salicylsäure-Methode". However, a problem occurred to him. If a lake is dystrophic or extreme eutrophic and

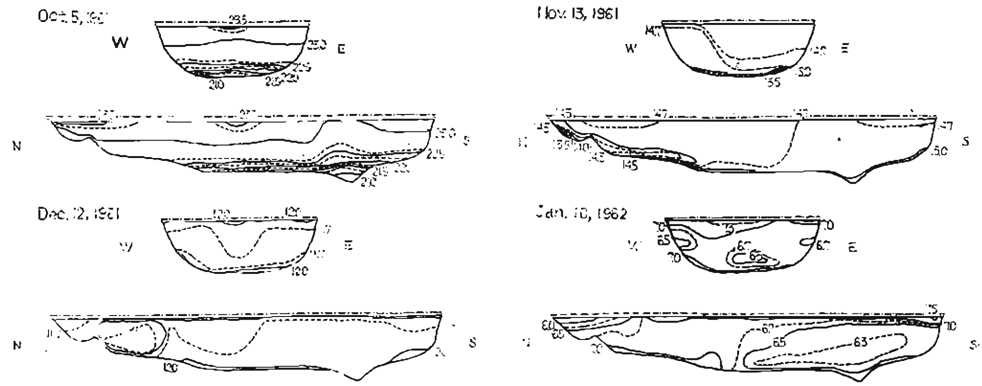

Fig. 2. Figure showing the thermal stratification (in degrees Centigrade) of Lake Yogo-ko (October-January) drawn by S. Horie. (chain line indicates natural altitude of lake level).

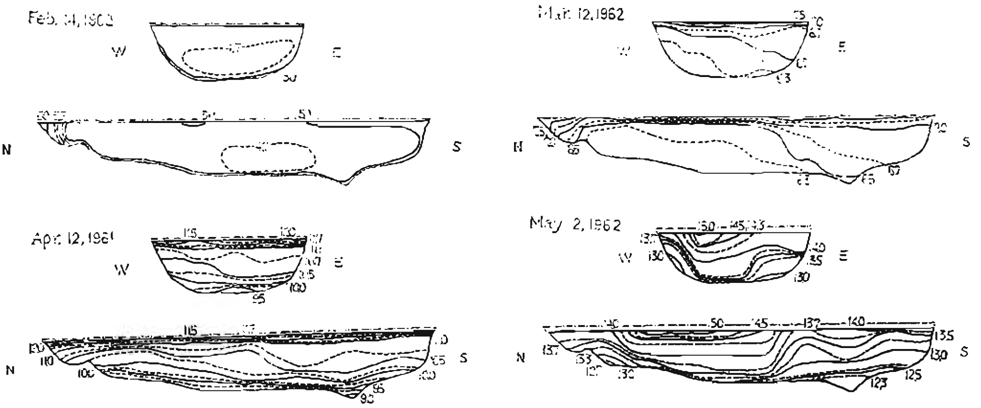

Fig. 3. Figure showing the thermal stratification (in degrees Centigrade) of Lake Yogo-ko (February-May) drawn by S. Horie. (chain line indicates natural altitude of lake level).

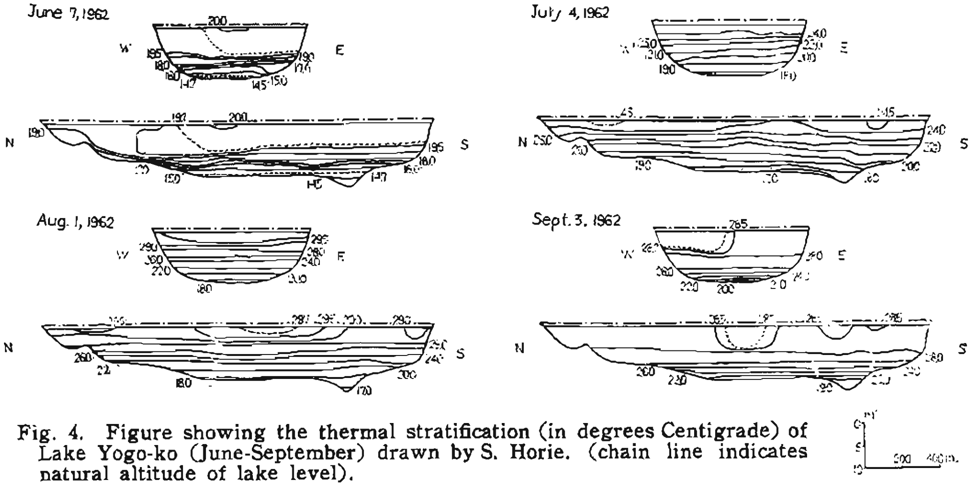

Fig. 4. Figure showing the thermal stratification (in degrees Centigrade) of Lake Yogo-ko (June-September) drawn by S. Horie. (chain line indicates natural altitude of lake level).

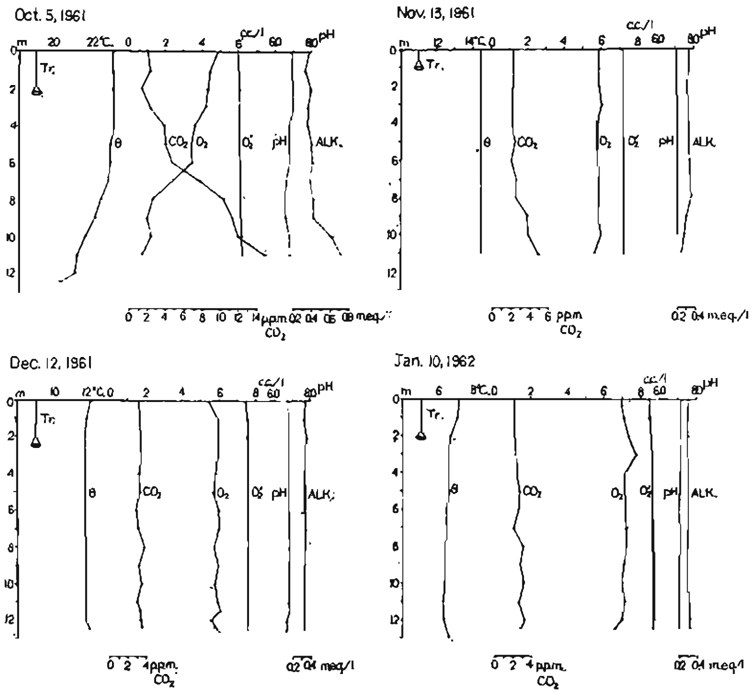

Fig. 5. Figure showing the physico-chemical features of Lake Yogo-ko (October-January) drawn by S. Horie.

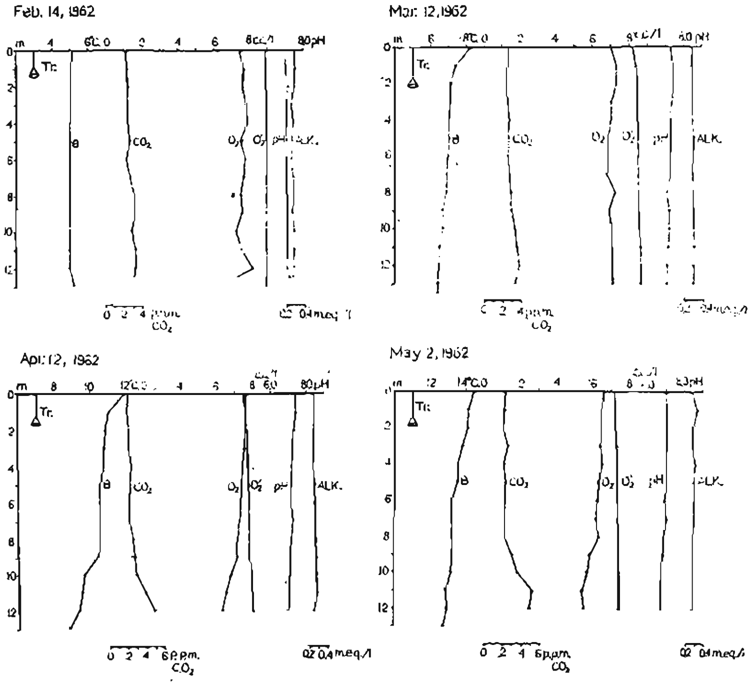

Fig. 6. Figure showing the physico-chemical feaures of Lake Yogo-ko (February-May) drawn by S. Horie.

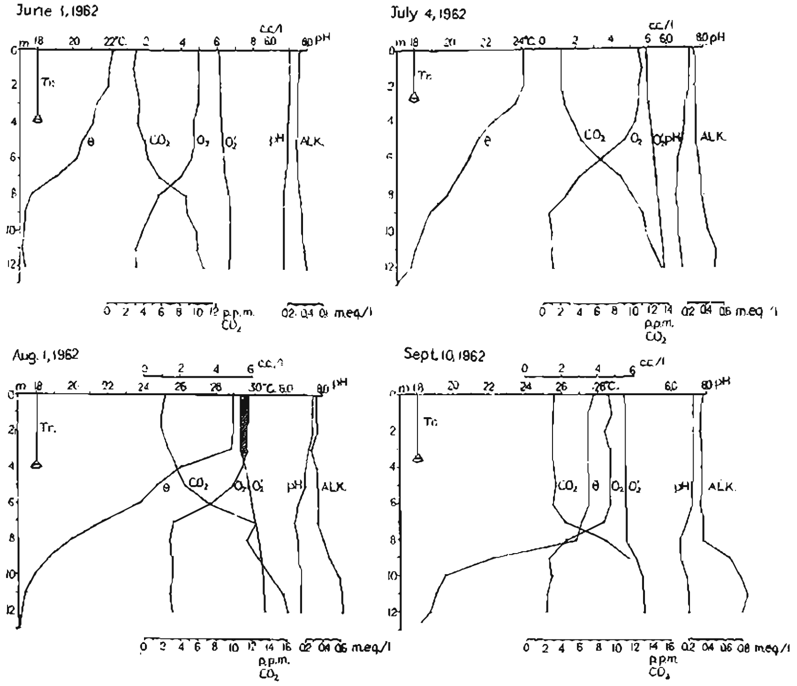

Fig. 7. Figure showing the physico-chemical features of Lake Yogo-ko (June–September) drawn by S. Horie.

always contains the above-mentioned substances, there is no immediate difficulty though some difficulties may occur with regard to monthly observations in temperate lakes or subtropical lakes (*sensu* Yoshimura[11]), or in dimictic lakes or warm monomictic lakes (*sensu* Hutchinson[22]). This is because enough dissolved oxygen is usually, though temporarily, supplied to the whole body of water during the circulation period in these lakes, but it is completely depleted during the stagnation period in some lakes of relatively small depth and with gentle slope of the bottom resulting from the sedimentation of organic material. In such lakes Winkler's method is applicable in the circulation period or soon after that, but after the appearance of thermal stratification other accurate methods might be more adequate for the determination of the amount of dissolved oxygen in the hypolimnion ; nevertheless, the epilimnion contains a considerable amount of oxygen at that time. According to the writer's unpublished data, Winkler's method is better when it is applied to lake water during the circulation period or to the epilimnion, from which figures obtained by Alsterberg's modification indicate a somewhat low amount. However, the latter method seems to be better for the determination of oxygen in the hypolimnetic water of eutrophic lakes, to which the former method gives a lower amount. Accordingly, one method alone is not applicable to all monthly observations in such lakes, but the combination of two methods in different months and at different levels is also problematical. For these reasons, the writer is at present trying Alsterberg's modification with Lake Yogo-ko, choosing between the two.

As for carbon dioxide, the writer followed the most convenient way for field work. It may be called phenolphtalein acidity(31).

As for alkalinity, the writer used brom cresol purple and 0.01N hydrochloric acid. Both carbon dioxide and alkalinity were examined in the laboratory soon after sampling.

b) *Results of Observations*

In early October, thermal stratification was clear in the entire body of lake water, but the gradient of the temperature curve was relatively steep at the deepest point. This tendency is shown in Fig. 2, 5. The dissolved oxygen indicates a conspicuous clinograde at 6~8 m in depth, and similarly carbon dioxide shows a conspicuous clinograde at the same depth. They cross each other showing an inverse relationship. This suggests that metalimnetic and hypolimnetic water was stil stable despite the steep gradient of the temperature curve. The pH performs an acidic heterograde at depths of 6~10 m, and, as with other examples, alkalinity makes a clinograde at lower depths. Such a relationship tells us that the consumption of oxygen and the production of carbon dioxide were due to metabolic processes. However, when we refer to the connection between transparency and the clinogrades of both oxygen and carbon dioxide in other months, it is noticeable that such clinogrades are lower than those which would be expected from the transparency. Presumably, one reason for this is the destruction of metalimnion according to the progress of the year. These clinogrades might have been in the upper level together with the acidic heterograde of the pH, and they were protected by the metalimnetic layer till autumnal circulation removed upper metalimnion. One peculiarity is an increment of dissolved oxygen at lower depths. At a depth of 10 m, oxygen increased slightly. The same phenomena were found at the depths of 10 m in November, 11.5 m in December, 11 m in January, 12 m in February, 13 m in March, 12 m in May, 12 m in July, and 12 m in August. Similar features were also found at 10 m depth in both January and March, and at 12.5 m depth in October, according to Miyadi and Hazama(12), and also at 12.5 m depth in August, according to Tanaka(14). The reason for this phenomenon is still unknown, but it can not be ascribed to photosynthesis because transparency has no connection with that depth. Thus, such phenomena are not of secondary but of primary origin. The writer entertains two kinds of interpretation. The first is derivation from underground water and the second is the influence of lake basin morphology. For the former, there is some evidence, such as : (1) The morphology of the deepest point suggests the existence of the mouth of a spring. (2) Actual movement of lake water caused by the spring was observed by people during the construction of the channel. At that time the level of lake was artificially lowered several meters. (3) Lake Yogo-ko has had no permanently inflowing river, although it maintained a constant volume of water and also discharged through the Yogo-gawa River suggesting the existence of springs. (4) The figures showing the thermal stratifications in October, January, February, May, and August demonstrate the actual movement of water from a cold spring. (5) After the vernal circulation, dissolved oxygen in the hypolimnion decreased, but, curiously, it increased in August (Fig. 8). A gentle gradient of the temperature curve in the metalimnion indicates stable stagnation, thereby such a phenomenon may be interpreted as the result of the derivation of water from an underground source. From this point of view, the estimation of productivity or bioactivity[32] in this lake was impossible. The second interpretation is not yet confirmed. It is, however, apparent that the area occupying the isobath of 12 m, 13 m and 14 m is no more than a very small percentage of the total area. Therefore even a small amount of horizontal movement on the gentle slope of 11 m depth, which contains a reducing substance, may cause the decrease of dissolved oxygen at one level of the hypolimnion. Accordingly, the lower part of the hypolimnion shows a relatively high amount of oxgen. As the surface level of this lake is artificially controlled at present, the above-mentioned level showing a positive heterograde in some cases is situated below the depth of 10 m. It is probable that such a level appeared through the combination of the above two factors.

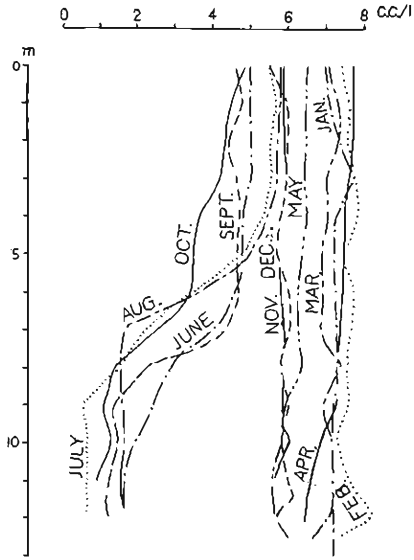

Fig. 8. Figure showing the amount of dissolved oxygen of every month in Lake Yogo-ko drawn by S. Horie.

In the middle of November, this lake was homothermal, indicating that com-

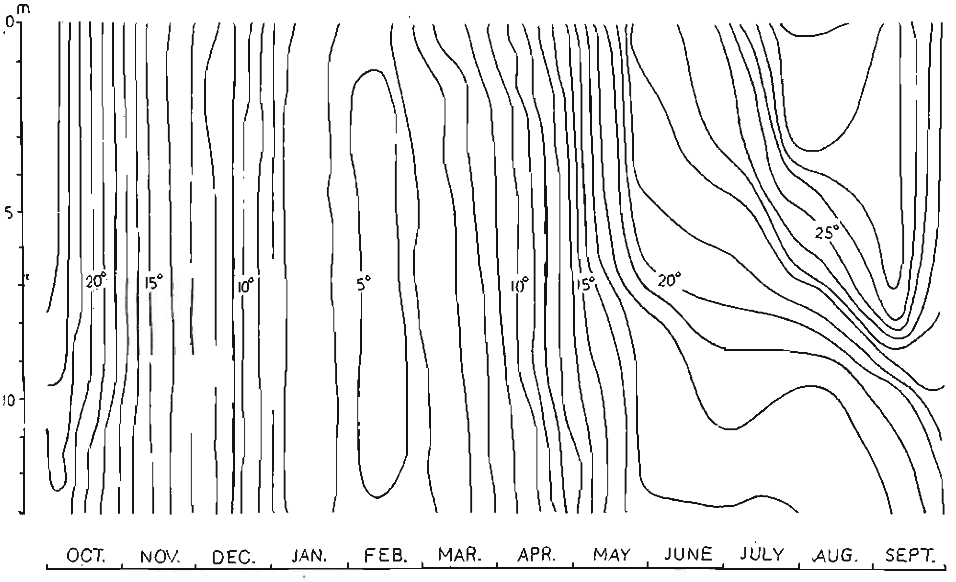

Fig. 9. Figure showing the annual situation of water temperature in degrees Centigrade in Lake Yogo-ko drawn by S. Horie.

plete circulation occured at 20°C. (Fig. 9). The data of Miyadi and Hazama[12] suggested that complete circulation occurred at 17~18°C, and such a fact denoted that the hypolimnion was more warmed by solar radiation than it was in 1930. As a result of circulation, the stratification of the pH was destroyed, and the decrease of alkalinity was observed. The presence of a clinograde carbon dioxide curve suggests that certain oxidative activity was still continuing in seston falling from an upper level. In general, transparency figures were small during the winter, i. e. during the circulation period, but the minimum value was observed in this month. Besides, it should be noticed that cold water derived from the Yogo-gawa River was creeping along the bottom of the northern half of the lake in November (Fig. 2).

In mid-December, the limnological nature of this lake was simple, though some points should be mentioned. The cold water from the Yogo-gawa River created an independent water mass in the northernmost part of the lake. Presumably, this water mass moved towards the gate on the eastern shore that we find in the E-W cross-section. The relatively higher temperature of the bottom water during the winter is due to heat which has been retained during the summer stagnation period. The weak positive heterograde of dissolved oxygen and the negative heterograde of carbon dioxide in the depths of several meters mutually correspond, and they might be caused by biological activity.

In mid-January, the appearance of an independent water mass occupying the southern half of the lake basin was distinct. Its coldness might be derived from springs. The other water mass in the northernmost part of the lake was rather indistinct, but the presence of a warm inflowing stream was noticed in the southernmost part of the lake. It is a tiny stream but its temperature is higher than the surrounding area ; it had been used for hatching purposes[33]. In the E-W cross-section, a lower water temperature was recognized at both ends. Presumably, the eastern one was caused by the existence of the reservoir gate and the current of cold water from the Yogo-gawa River while the western one was due to the spring at the bottom. Such a possibillity is strengthened by other cross-sections for November, December, March, and May. In the curve of dissolved oxygen, a positive heterograde was recognized at a depth of 1~4 m, and the pH had an alkaline tendency. In connection with the transparency figure, a possible interpretation is that it was the result of photosynthesis. A negative heterograde of carbon dioxide and an acidic heterograde of the pH were also found at a depth of several meters. They must all be considered with the biological data, further discussion of which should be avoided at present.

In mid-February, circulation was complete, the whole body of lake water being cooled down. The water from the Yogo-gawa River, which flowed down the flat river bed, showed a relatively higher temperature, the same as that in March. The dissolved oxygen curve formed a conspicuous positive heterograde at the deepest level, as the writer has already pointed out. The date of observation in February was soon after the melting of the thin ice which covered almost the whole surface of the lake.

In mid-March, the uppermost level showed a high temperature and was regarded as a film-shaped phenomenon. That fact was recognized in April, too. A positive heterograde oxygen curve was found at a depth of 7~9 m, though its orgin was unknown. The weak clinogrades of carbon dioxide and pH curves were also found.

In mid-April, various kinds of analyses produced different results indicating that the circulation period had finished and stagnation begun. Thermal stratification became obvious throughout the whole body of water, the metalimnion having been formed at a depth of 9~10 m. Clinograde curves of both dissolved oxygen and carbon dioxide coincided with the phenomenon of the metalimnion ; oxidation was very active in the hypolimnetic water. It is of interest that the uppermost level showed supersaturation of dissolved oxygen.

The oxygen deficit is an important matter together with chlorophyll, and the C^{14} method in order to study the estimation of lake productivity. A lake showing an orthograde oxygen curve during the summer stagnation period seems to have low productivity. In a lake showing a clinograde oxygen curve, the estimation of productivity can be based on the oxygen deficit, but standards differ and are debatable. Thienemann[34)] referred to the oxygen deficit as the difference between the concentration actually observed and the saturation concentration at the temperature of the layer from which the sample was obtained. This is an actual deficit according to Alsterberg[35)], but the determination of various conditions is difficult, as Hutchinson[22)] explained in detail. Another definition of the oxygen deficit was given by Alsterberg[35,36)], whose discussion is applicable to Lake Yogo-ko. If a lake is completely saurated with dissolved oxygen during the circulation period, the difference in it between that time and later is a good indicator of metabolic oxidation and productivity, but when saturation is incomplete during the circulation period, such a difference is comparatively meaningless. For instance, in a dimictic lake circulation takes a short time. In either a warm or a cold monomictic lake, circulation may take a longer time in some cases, but may be incomplete under unfavourable climatic conditions. Thus a lake like Yogo-ko, situated on the present dimictic—warm monomictic lake bounday, seems to be quite an important one in this connection. As mentioned above, this lake has continued its circulation for several months (Fig. 9) but has not been saturated. Accordingly, the relative deficit of Strøm[37)] and Hutchinson[22)] is significant. The appearance of supersaturation and relatively high pH showing a clinograde curve in mid-April and early August suggest the result of photosynthesis.

In early May, it was noticed that the hypolimnetic water was warmer than in previous months, indicating that heating of the hypolimnion was active during the last three weeks. The gradient of the temperature curve became steeper, but the stability of the epilimnion as well as the hypolimnion was retained, as the two clinograde curves of dissolved oxygen and carbon dioxide denoted. Thermal stratification during this month resembled that of October ; it may support a hypothesis concerning the presence of a spring in the southern part of the lake.

In early June, the writer carried out his studies over two periods. The earlier one was made at the deepest point, and the later one was done on thermal stratification. The lake water stratified well, and transparency was at its highest figure, compared with a reading taken in early August. A comparison of each level at the deepest point between May and June clearly demonstrated that the water temperatures rose remarkably in the whole lake. It is therefore possible to say that solar radiation was so active between March and June that the temperature rise of the hypolimnion was very conspicuous in this season compared to the rest of the year. After June, the hypolimnetic temperature rose gradually and finally complete circulation occured in autumn at 20°C of the hypolimnion, as the writer has already stated. Such a fact indicates that the high heating rate in the hypolimnion between March and June was caused by two factors, namely the indistinct metalimnion in spring and the rainy season. In the former, the temperature gradient was steep in spring in making sufficient heat exchange between the epilimnion and the hypolimnion, but after the formation of the metalimnion vertical turbulence could not carry heat below the metalimnion. In the latter, the usual rainy season, which occurs in the southwestern half of Honshu between late May and mid-July, influenced the heating rate together with the former factor. The amount of evaporation during this rainy season was, of course, small, for which reason heat was not lost in this way. The consumption of dissolved oxygen as well as the production of carbon dioxide advanced under the protection of metalimnion. Thus their curves crossed again after the previous October. The weak clinograde curves of the pH and alkalinity coincided with such features.

In early July, the thickness of the metalimnion shared the annual maximum with the August reading. This condition was caused by the heating of both the upper and the lower part of the metalimnion. The two clinograde curves of dissolved oxygen and carbon dioxide became more obvious, so that the intersection of the two curves shifted upward about 1.5 m. It may be said that such a shift was possible because of the protection afforded by the thick metalimnion. The acidic heterograde of the pH curve and the increase of alkalinity in the hypolimnion were evident.

In early August, summer stagnation continued, isotherms showing horizontal phenomena like those of July. It is, however, suggested that a spring supplies cold water around the deepest point. Heating was conspicuous in the epilimnion and upper metalimnion, where the most gentle slope was produced in the temperature gradient as a whole. The amount of dissolved oxygen increased in the hypolimnion, probably due to the water supply from a spring at the deepest point. An obvious supersaturation of dissolved oxygen which occurred in the epilimnion was due to active photosynthesis in mid-summer, as is suggested by an advanced acidic heterograde of the pH which was given by a change to alkalify the epilimnion. However, such a supersaturation was not seen in the upper part of the metalimnion. It is expected that the metalimnion maximum of dissolved oxygen might appear since the transparency was 4 m at that time. The oxidation process in the seston was probably very active in such a warm metalimnion as the intersection of the two clinograde curves of dissolved oxygen and carbon dioxide remained at the same level as in July. The production of carbon dioxide progressed after early July ; the clinograde curve of alkalinity became more gentle.

In early September, the writer tried carrying out observations at two different times. The water temperature in the middle of the lake was higher ; colder water derived from the spring at the southern end as well as from the Yogogawa River flowing down towards the reservoir gate at the eastern shore was seen. Transparency had decreased slightly, though it was still more than 3 m. It is of interest that the epilimnion had expanded due to the result of the heating of the deeper level and latter cooling of the shallower level since the last observation. The hypolimnion had also become warmer in retaining the features of stagnation. Owing to the expansion of epilimnion, the metalimnion became thinner. The increase in dissolved oxygen and the decrease in carbon dioxide at a depth of several meters, that is the drop of these two clinograde curves, was due to such a change in the thickness of the metalimnion. It was impossible to assess the exact amount of carbon dioxide below 9 m level because of too cloudy water samples. It is, however, certain that the amount increased considerably at deeper levels. The drop in the heterograde curve of the pH after the last observation might be explained in terms of the above discussion (to be continued).

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