

Studies on Biological Metabolism in a Meromictic Lake Suigetsu*

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Abstract: Lake Suigetsu is a typical meromictic lake having a deep anoxic layer from 8 m to the bottom at 34 m depth. Large accumulations of sulfide, total CO₂, phosphate and ammonium were observed in the deep layer. In August, two photosynthesis maxima, caused by the activity of phytoplankton and photosynthetic sulfur bacteria, were observed at the surface and the boundary between aerobic and anoxic layers respectively. In December, a marked dark carbon fixation was observed at the boundary layer, although there was no indication of bacterial photosynthesis. Sulfate reduction was found only in bottom mud, especially near the surface of sediment. Carbon and sulfur cycles and their interrelation in the anoxic layer are discussed.

1. Introduction

The biological metabolism in waters of so-called "meromictic lakes" is of great interest because of its characteristic environmental conditions, such as the permanent stagnation of water below the chemocline, oxygen deficit and accumulation of sulfide in deep water. Many classical studies have been made on the physical, chemical and biological features of such lakes, but, our knowledge concerning the processes of production and decomposition of organic matter and their relationships is still limited.

LYALIKOVA (1957) studied the assimilation of carbon dioxide in Lake Belovod, in which the water layers lying deeper than 13 m did not participate in the autumnal and vernal overturn and were high in sulfide. She found that the photosynthetic rate of phytoplankton in the upper layer was 0.13 mg CO₂/(l day), whereas the photosynthesis by Thiorhodaceae at 13 m and the chemosynthesis by *Thiobacillus thioparus* at 24 m depth were 1.5 mg CO₂/(l day) and 0.45 mg CO₂/(l day) respectively. KUZNETSOV (1966) studied Lake Sewan, a meromictic lake in the Armenian arid region. He observed the formation of calcite crystals by the reaction between the dissolved calcium and the carbon

dioxide derived from the decomposition of organic matter by sulfate reducing bacteria.

In the Black Sea, SOROKIN (1962) determined the photosynthetic production of organic matter by phytoplankton. He also observed chemosynthesis near the upper boundary of the anoxic zone at depths of 150 m-200 m. He found that the daily production of sulfide by sulfate reducing bacteria was highest in the superficial layer of the silts, while in the water column, sulfate reduction occurred in the upper part of the sulfide zone, and to a lesser extent in the bottom layer.

Recently, SOROKIN (1970) made similar but more extensive studies in three meromictic lakes. In his work, he emphasized the significance of allochthonous organic matter as the energy source for sulfate reduction and biological production in such lakes. He also showed the importance of bacterioplankton as a food source for zooplankton. In Japan, TAKAHASHI and ICHIMURA (1968) determined the amount of chlorophyll in sulfur bacteria and the rate of *in situ* photosynthetic production in ten Japanese lakes, including Lake Suigetsu. TAKAHASHI *et al.* (1970) investigated the dark carbon fixation in lakes with different trophic types, including Lake Suigetsu, and observed high rates of dark carbon fixation in meromictic and stagnant waters.

In Lake Nitinat, an anoxic fjord on Vancouver Island, RICHARDS *et al.* (1965) showed

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that sulfides and silicates accumulate in the sulfide zone in direct proportion to each other, but some of the phosphate is probably released from the organic matter earlier than other components, and some of the phosphate may be precipitated onto the bottom.

In Lake Suigetsu, where the present work was undertaken, several studies had already been conducted. YOSHIMURA (1932) reported that sulfate reducing bacteria produced a large accumulation of hydrogen sulfide in the deep layer of this lake. He calculated the amount of sulfate reduced from the difference between the actual sulfate present and the amount of sulfate calculated from chloride concentration in the deep water employing the ratio of chloride to sulfate in sea water.

In addition, JIMBO (1938) isolated the photosynthetic sulfur bacteria, *Chromatium minus* Winogradsky and *Chromatium minutissima* Winogradsky from the lake water at the boundary depth between the surface fresh water and the deep saline water. The present paper reports our studies of the production and decomposition of organic matter in Lake Suigetsu, particularly the activities of sulfate reducing bacteria and sulfide oxidizing bacteria.

2. Description of the area studied

As seen in Figures 1 and 2, Lake Suigetsu forms a part of a chain of lakes. A fresh water lake, Lake Mikata flows into Lake Suigetsu, and the latter drains into Lake Hiruga, a polyhaline lake, through an artificial channel constructed in 1801. Lake Hiruga, originally a fresh water lake, was joined to the Japan Sea in 1630. The sea water enters Lake Suigetsu through Lake Hiruga only at high tide during autumn and winter (SUDA, 1935). In Lake Suigetsu, there is another artificial channel to Lake Kugushi, a shallow haline lake, but the amount of sea water flowing into Lake Suigetsu through that channel is small (SUDA, 1935).

These three lakes are in a fault basin. Lake Mikata is a shallow eutrophic lake having a maximum depth of 3.6 m, whereas Lake Suigetsu and Lake Hiruga have deep basins, with maximum depths of 34.0 m and 38.0 m, and having mesotrophic character.

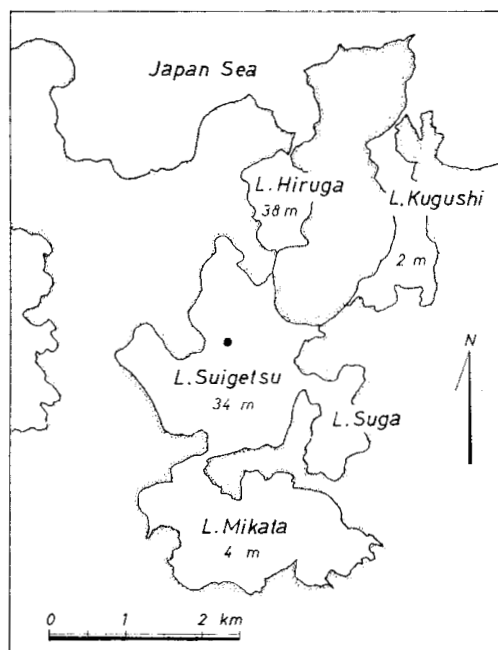


Fig. 1. Map of Lake Suigetsu and adjacent area. Solid circle indicates the station.

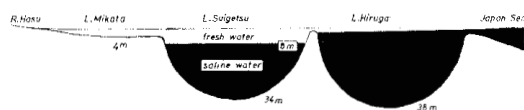


Fig. 2. Profile of Lake Suigetsu and adjacent two lakes, Lake Mikata and Lake Hiruga

The observations were made mainly on two occasions July and December, 1965.

3. Method

Water samples were taken with a 3 l non metallic Van-Dorn sampler. The samples for nitrate, phosphate and ammonium determinations were frozen in polyethylene bottles for subsequent analysis in the laboratory. For the samples containing sulfide, 10% CdCO₃ suspension was added to remove the sulfide as a precipitate before freezing for storage. The error caused by the co-precipitation with sulfide was corrected by measuring the amount of CdS precipitate, since a linear relation was found between the rate of co-precipitation and the amount of CdS precipitate for each component. The maximum correction rates were 31.4% and 28.4% of original values of ammo-

nium and phosphate for the sample from the 30 m layer having 60 mg S/l, the highest sulfide concentration. Water samples for total carbon dioxide were taken in syringes and kept in cool water. Bottom sediments were taken with a simple core sampler devised by the authors.

The methods and techniques employed for the determination of each element were as follows:

Temperature: Thermistor thermometer.

Chlorinity: Mohr-Knudsen method.

Dissolved oxygen: Winkler method described by YOSHIMURA (1936).

Total carbon dioxide: Gas chromatography. Sulfate in interstitial water of bottom sediment: After the sulfide determination, the sample was centrifuged and the sulfate in supernatant was turbidimetrically determined as BaSO_4 .

Sulfide in lake water: After precipitation as CdS , by iodometric titration.

Sulfide in bottom sediment: After adding the phosphate buffer of pH 6.5, the hydrogen sulfide was removed with a stream of nitrogen gas and absorbed as CdS by bubbling through CdCO_3 solution. After precipitation, sulfide was determined by iodometric titration.

Nitrate: Mullin-Riley (1955) method.

Nitrite: Gries-Romijn reagent method described by YOSHIMURA (1936).

Ammonium: Kraus-Mellon (1952) method using pyridine-pyrazolone reagent, modified by STRICKLAND and AUSTIN (1959).

Phosphate: Denigès-Atkins method described by YOSHIMURA (1936).

The rates of photosynthetic and dark carbon assimilation were determined by *in situ* incubation using radioactive $\text{Na}_2^{14}\text{CO}_3$. The rate of sulfate reduction was determined using radioactive $\text{H}_2^{35}\text{SO}_4$ by the technique of KOYAMA and NOMURA (1955). Briefly, 4 ml of sample water or bottom mud was taken into a sterilized syringe and $\text{H}_2^{35}\text{SO}_4$ was added immediately without exposure to air. The syringe was shaken well, and the sample was incubated for 24 hours at a temperature adjusted to that of the depth sampled. After incubation, 0.5 ml of saturated water with phenol were added to stop biological activity. The sulfide produced

during incubation was removed with a stream of nitrogen gas and absorbed as sulfidomethylene blue complex by bubbling through a methylene blue solution. The complex was absorbed on to active carbon powder and filtered off. The rate of sulfate reduction was determined by measuring the radioactivity of ^{35}S on the active carbon with a GM end window counter.

4. Results and discussion

1. Vertical distribution.

The vertical distributions of temperature, chlorinity, dissolved oxygen and sulfide in Lake Suigetsu in July and December 1965 are summarized in Figure 3. The vertical distributions of these elements clearly demonstrate the stagnation of saline water in the deep layer from 8 m to the bottom of the lake at 34 m. The chlorinity of the deep water was 7.2 to 8.4 ‰, about two fifth that of sea water. No dissolved oxygen was found at 8 m. Sulfide first occurred at this depth, and increased gradually to the bottom. The highest values of sulfide, 60 to 70 mg S/l, were found in the water of 30 m depth near the lake bottom. It is noteworthy that in the deep layer below 10 m, there were no appreciable differences in temperature and chlorinity between July and December 1965. This suggests that the stagnation of the deep water is very stable and the mixing of water between the upper aerobic and the lower anoxic layer is quite limited.

The results of the determinations of nitrate and nitrite are shown in Figure 4. This shows that the vertical distributions of nitrate and nitrite gave similar patterns. Maximum values were found at the boundary between the aerobic and anoxic layer. On the other hand, as seen in Figure 5, the concentrations of ammonium, phosphate and total carbon dioxide increased with depth from the top of the surface water to the lake bottom consistently. The maximum values of ammonium, about 23 and 27 mg $\text{NH}_4\text{-N/l}$, obtained at 30 m depth in July and December respectively were approximately 100 times those of the surface water. Since the amount of ammonium was one or two orders of magnitude higher than that of

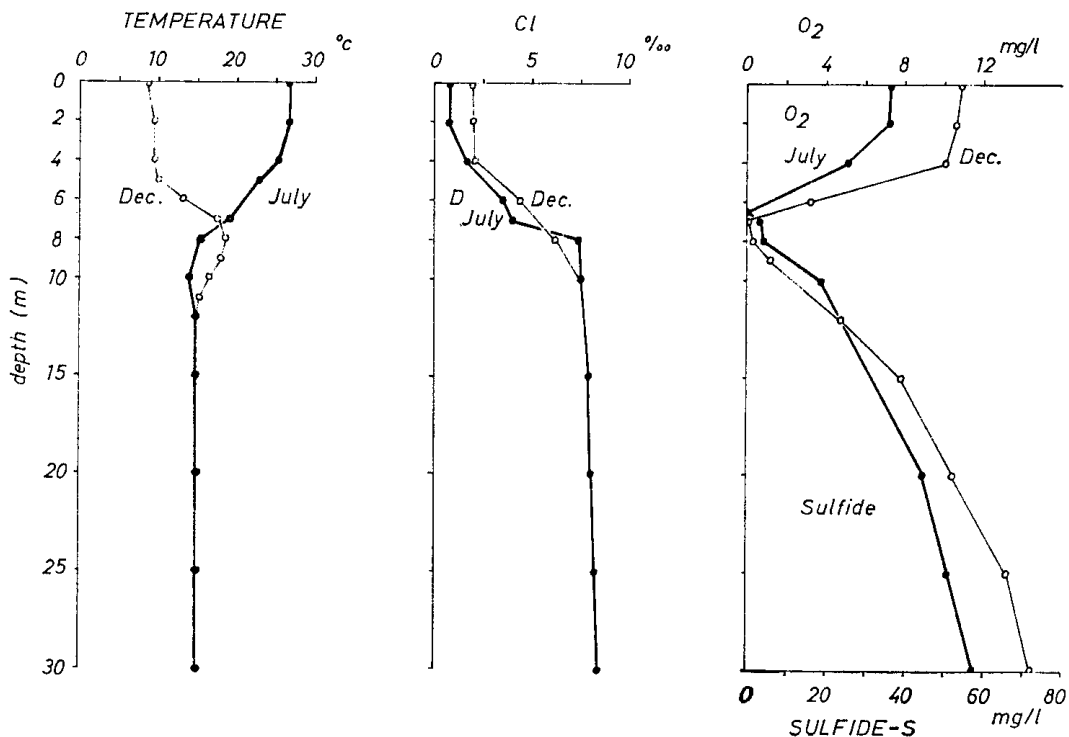


Fig. 3. Vertical distribution of temperature, chlorinity, dissolved oxygen and sulfide

nitrate and nitrite, the greater part of the inorganic nitrogen in the deep layer was composed of ammonium. These values are about 7 times higher than those observed in the deep layer of Lake Nitinat by RICHARDS *et al.* (1965), and in the 2,000 m layer of the Black Sea by SOROKIN (1964).

The maximum values of phosphate P were 1.4 mg and 0.8 mg P/l in July and in December respectively. The maximum values of total carbon dioxide, about 200 mg CO₂-C/l at 30 m depth, were approximately 20 times that estimated to have been contributed by sea water.

2. Assimilation activity of CO₂.

Results of the determination of CO₂ using the ¹⁴C technique are given in Figure 6. As clearly seen in this figure, two photosynthetic peaks were observed in July, one was at the surface and another at 8 m depth in the boundary layer between aerobic and anoxic zones. Daily rates of photosynthesis at the surface and 8 m depth were 113 mg C/m³ and 133 mg C/m³ respectively. The upper peak was caused by the photosynthesis of phytoplankton,

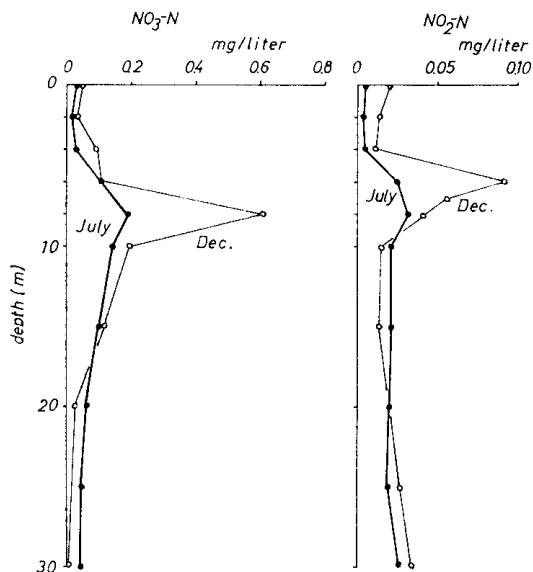


Fig. 4. Vertical distribution of nitrate and nitrite.

whereas the lower peak was by that of sulfur bacteria, *Chromatium* sp.. A large accumulation of this organism was recognized even with the naked eye by the pinkish colour of

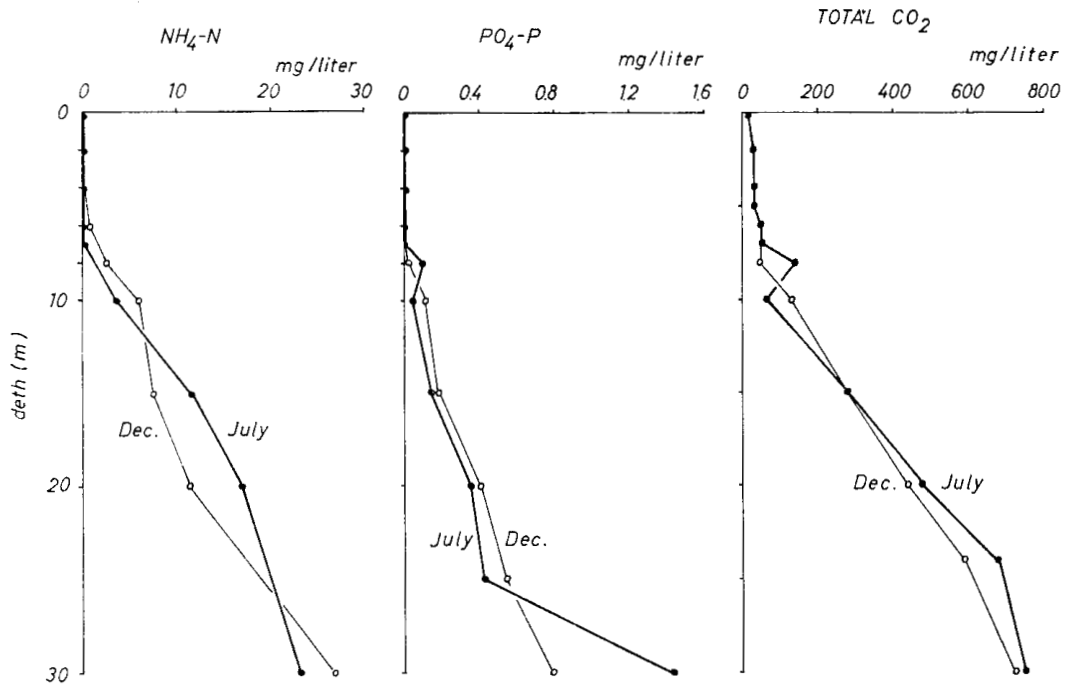


Fig. 5. Vertical distribution of ammonium, phosphate and total carbon dioxide.

sample water taken at 8 m depth.

In December, there was no indication of second maximum of photosynthesis corresponding to that of *Chromatium* sp. in July, probably due to the insufficiency of solar radiation at the depth of the boundary layer. However, a marked fixation of CO₂ in a dark bottle was found in the same layer. Probably, this may be derived from the chemosynthetic activity of sulfur bacteria, *Thiobacillus* sp.. In this case, the daily rates of photosynthesis at the surface and dark carbon fixation at 8 m depth were 84 mg C/(m³ day) and 485 mg C/(m³ day) respectively. It is noteworthy that the rates of CO₂ assimilation in the boundary layer showed comparable or higher values than those in the surface layer in July as well as in December. The rate of dark carbon fixation in the boundary layer in winter especially showed the highest rate through all of the observations.

Dark carbon fixation in the boundary layer was considerably higher even in July, showing the value of 62 mg C/(m³ day), i.e. 37.4 % of the photosynthesis value in the same layer. Compared with low rates of dark carbon fixa-

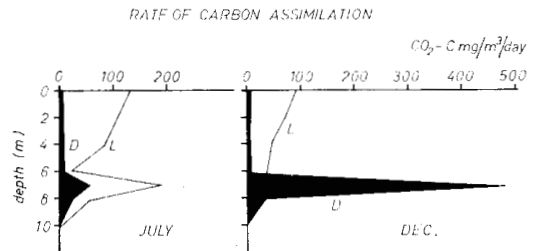


Fig. 6. Rate of carbon assimilation.
L: light bottles, D: dark bottles.

tion in the aerobic layer, i.e. 14.7 and 18.2 % in July and in December respectively, the above high rate in the boundary layer seems to suggest that the rate of dark carbon fixation is not negligible even in summer. Recently, TAKAHASHI *et al.* (1970) tried to distinguish algal and bacterial carbon fixation using antibiotic techniques in Lake Suigetsu, and found high rates of dark carbon fixation by bacteria in winter as well as in summer. The rates were comparable to our own data. However, they observed considerable amounts of bacterial photosynthesis even in winter at the boundary

depth. This might be because of rise in boundary layer from 8 m to 5 m, due to influx of massive sea water into the deep layer.

Daily rates of carbon assimilation in a unit area of this lake were 0.77 g C/(m² day) and 1.18 g C/(m² day) in July and in December respectively. These values are similar to those obtained in some eutrophic lakes, Lake Suwa, 1.38 g C/(m² day) and Lake Kasumigaura, 0.72 g C/(m² day) (SAKAMOTO, 1966) and higher than those in some mesotrophic lakes, Lake Kizaki, 0.23 g C/(m² day) and Lake Haruna, 0.12 g C/(m² day). But it is interesting that in July the daily photosynthesis by *Chromatium* sp. accounted for 34 % of the total photosynthesis, while in December, the dark carbon fixation reached 58 % of the total carbon uptake through all of the water column. These results show the importance of sulfur bacteria in organic matter production in meromictic lakes. Similar high rates of chemosynthesis, about 50 %, were reported by LYALIKOVA (1957) in Lake Belovod and also by SOROKIN (1970) in Lake Gek Gej in Caucasus. TAKAHASHI and ICHIMURA (1968) estimated the contribution of sulfur bacteria in the organic matter synthesis in some Japanese lakes rich in sulfide, including Lake Suigetsu, as 9 to 25 % of total annual production by algae and bacteria.

In Lake Belovod, SOROKIN (1970) obtained the chemosynthesis value of 20 to 27 mg C/(m³ day) at depth of 10 to 12 m. But he found that the chemosynthesis value changes depending on the time of sampling, for in this zone there was a strong competition between purple bacteria and thiobacilli for H₂S as a substrate. The former oxidized about all the H₂S in this zone during the second part of the day. So in the sample taken at this time the dark carbon fixation value was about twice as low. In the case of Lake Suigetsu, we have no data on the daily change of chemosynthesis in the boundary layer, however results showed an appreciable rate of photosynthesis in summer and a much higher rate of dark carbon fixation in winter in the same layer. This change in the type of CO₂ assimilation will be important to consider the organic matter production in a meromictic lake or in an anoxic basin in coastal

water.

3. Reduction of sulfate.

Since presumably most of the sulfate in the deep layer of this lake originated from sea water, it is possible to calculate the initial content of sulfate at each depth from the data on the chlorinity given in Figure 3. In the deeper part of the anoxic layer, the measured amount of sulfate decreases with depth, but as seen in Figure 7, less sulfide is present than can account for the difference between the calculated and observed sulfate contents. It is probable that all the decrease in sulfate was due to its reduction to sulfide and much of

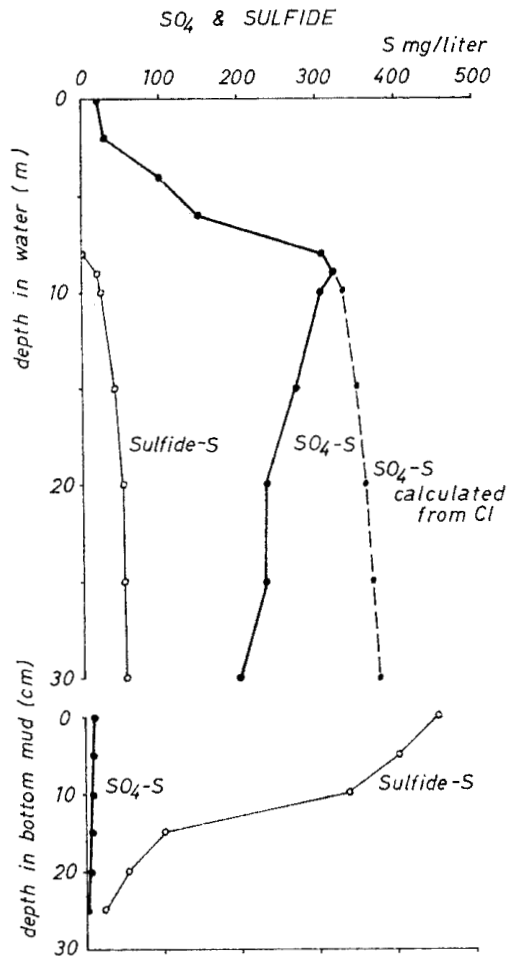


Fig. 7. Vertical distribution of sulfate and sulfide in lake water and bottom sediment. Broken line shows the sulfate concentration calculated from chloride using the ratio in sea water.

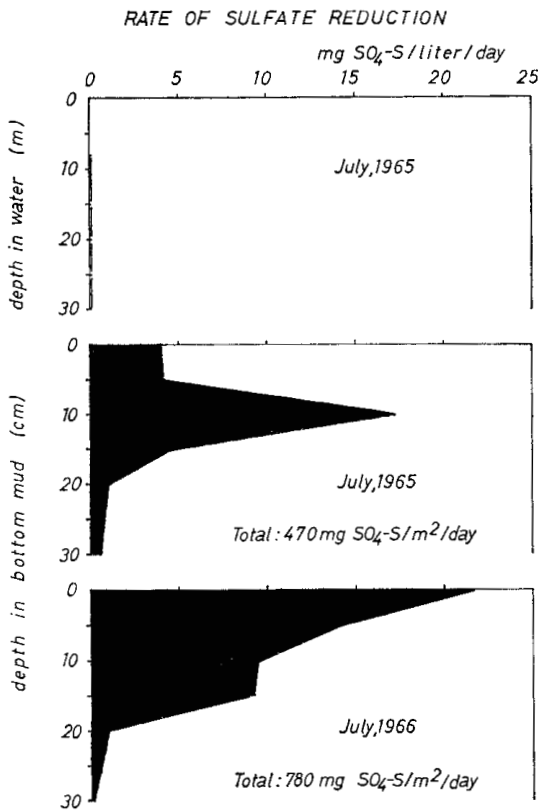


Fig. 8. Rate of sulfate reduction in lake water and bottom sediment.

that sulfide had been precipitated from the water reacting with allochthonous metallic substances. The vertical distributions of sulfate and sulfide in the water and the bottom sediments are summarized in Figure 7. These data show that sulfate reduction takes place more actively in the bottom sediment than in the water layer.

The results of the experiments measuring the activity of sulfate reduction by the radioisotope technique seem to confirm the view above mentioned. The vertical distribution of the rate of sulfate reduction is illustrated in Figure 8. As denoted in this figure, the sulfate reduction occurred only in the lake sediment, not in the water layer, and the maximum activity (16 mg S/(l day)) was obtained at or near the surface layer of the bottom sediment. The daily rates of sulfate reduction per unit area of the lake were 470 mg S/(m² day) and 780 mg S/(m² day in July) 1965 and in July 1966,

respectively.

SOROKIN (1964) determined the daily rate of the sulfate reduction at many stations in the Black Sea. He found that the most intensive sulfate reduction, 1500 to 2000 mg H₂S/(m³ day), took place in the superficial layer of the deposit of the continental slopes, while in the central part of the sea, lower values of 20 to 80 mg H₂S/(m³ day) were observed. In the water column, he found that the sulfate reduction takes place in a layer about 150 m thick near the upper boundary of the anoxic zone giving values of 0.007 mg H₂S/(l day).

In Lake Belovod, IVANOV (see KUZNETSOV, 1958) determined the rate of sulfate reduction and obtained the value of 0.12 mg H₂S/(l day) in bottom silt but none in water. SOROKIN (1970) repeated the experiment precisely in the same lake and found two layers of sulfate reduction. One was observed just under the layer of high photo- and chemosynthesis at depths of 6 to 13.5 m, another was at the bottom. The rates of sulfate reduction were 0.03 μg S/(l day) in water and 0.14 μg S/(l day) at the bottom of 23 m depth.

The sulfide produced in the bottom sediment appears to diffuse into the water layer up to the chemocline, where the sulfur bacteria convert carbon dioxide into organic matter using sulfide as hydrogen donor. VAN NIEL (1941) showed that the photosynthesis of *Chromatium* sp. gave a ratio of carbon assimilated to sulfide oxidized as 25:10. From the carbon assimilation activity of *Chromatium* sp. in July 1965 (Figure 6) and the above mentioned ratio, it can be estimated that about 100 mg S/(m² day) were oxidized by the photosynthesis of *Chromatium* sp.. At the same time, the rate of sulfide supply from bottom sediment to the upper lying water can be calculated as 170 mg S/(m² day) from the determined rate of sulfate reduction.

4. Mineralization of organic matter.

The relation of the reduction in sulfate, which was calculated as described above, to ammonium and total carbon dioxide at each depth of the water layer are summarized in Figure 9. In this figure, the values of observation in July were plotted. As readily seen, ammonium and

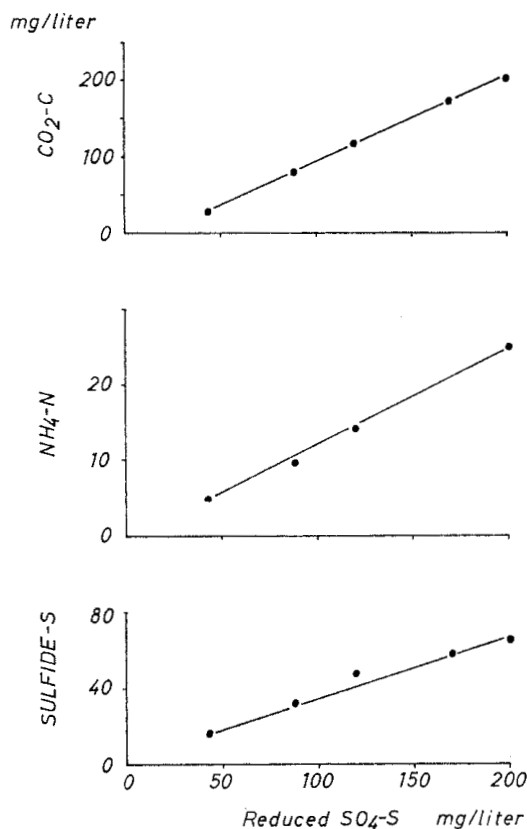


Fig. 9. Relation of sulfide, ammonium and total carbon dioxide to reduced sulfate in the anoxic layer.

total carbon dioxide both showed linear relation to the reduction in sulfate. This fact suggests that the mineralization process of organic matter was closely related to the process of the sulfate reduction, that is to say, most of the mineralization in the anoxic layer occurred in conjunction with sulfate reduction by the sulfate reducing bacteria at the surface of the bottom sediment.

Assuming mineralization by sulfate reducing bacteria alone, then the gradient of the graphs in Figure 9 would give the following ratios.

$$S:C:N=1.000:1.08:0.13$$

According to SAKAMURA (1958), the ratio between carbon and sulfate in sulfate reduction, assuming that the hydrogen donor is glucose, shows $S:C=1:0.75$ by weight. This ratio is similar to that ratio obtained above, and will

confirm the above assumption. Using the above assumption, the rate of mineralization at the bottom of the lake can be calculated as $510 \text{ mg C}/(\text{m}^2 \text{ day})$ or $830 \text{ mg C}/(\text{m}^2 \text{ day})$. These values are comparable with the total amount of carbon assimilation by phytoplankton and sulfur bacteria: $770 \text{ mg C}/(\text{m}^2 \text{ day})$ in July and $1180 \text{ mg C}/(\text{m}^2 \text{ day})$ in December (Figure 7).

However, recent information (OHLE, 1962, TOYODA *et al.*, 1968) on the decomposition of organic matter in lakes showed that a considerable part of organic matter produced by photosynthesis of phytoplankton is generally decomposed in the euphotic layer itself. Furthermore, the process of decomposition will take place in the anoxic layer though the rate of decomposition might be slower than in the aerobic layer. Combining the relevant information described above, the amount of decomposition in bottom deposit might be thought to exceed the supply of autochthonous organic matter to the bottom. This can be explained by the supply of allochthonous organic matter, especially by the inflow from Lake Mikata which is eutrophic in character. In his study of Lake Gek Gel, SOROKIN (1970) pointed out the importance of allochthonous organic matter from the surrounding forests as a source of energy for biological production.

The rate of CO_2 supply by decomposition processes was estimated as 190 to $310 \text{ g } CO_2/(\text{m}^2/\text{year})$ from the data of sulfate reduction. If we assume that the vertical distribution of CO_2 is in equilibrium state, the turnover time of carbon in the anoxic layer can be estimated from above data as 9 to 14 years. Although this calculation is only a rough approximation, it gives some idea of the slowness of turnover rate of carbon as well as nutrients in meromictic lakes.

5. Conclusion

In a meromictic lake, an appreciable part of organic matter production is carried out photosynthetically or chemosynthetically by sulfur bacteria in conjunction with the process of sulfide oxidation in the boundary between aerobic and anoxic layer. On the other hand, the process of organic matter decomposition is

mainly performed by sulfate reducing bacteria related to the process of sulfate reduction in bottom mud or in water under anoxic conditions. Namely, in such environment of oxygen deficiency, the carbon cycle is closely related to sulfur cycle.

Results of our investigation suggest that in the case of Lake Suigetsu, the supply of organic matter from Lake Mikata and the inflow of sulfate contained in sea water through Lake Hiruga contribute to this system as an energy source to induce continuation of the above cycles.

To elucidate the interdependency of carbon and sulfur cycle at each stage of biological metabolism in the meromictic lake much more detailed studies are necessary.

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References

- JIMBO, T. (1938): Beobachtung einiger thiotropher Seen Japans mit besonderer Berücksichtigung der Schwefelbakterien. Science Report of Tohoku Imperial Univ., Ser. biology, **13**, 259-269.
- KOYAMA, T. and M. NOMURA. (1955): Preparation of ³⁵S compounds. Kagaku-no-Ryoiki. Nankodo Special No. 10, Ser. **1**, 100-106. (in Japanese).
- KRAUS, J. and M. G. MELLON. (1952): Colorimetric determination of free ammonia with a pyridine-pyrazolone reagent. Sewage Industrial Wastes, **24**, 1098-1100.
- KUZNETSOV, S. I. (1958): A study of the size of bacterial populations and of organic matter formation due to photo- and chemosynthesis in water bodies of different types. Verh. internat. Ver. Limnol., **8**, 156-169.
- (1966): Die Rolle der Mikroorganismen bei der Bildung von Calcitkristallen im Schlamm der Sewan-Sees. Z. allg. Mikrobiol., **6**, 239-295.
- LYALIKOVA, N. N. (1957): The study of the process of utilization of carbon dioxide by purple bacteria in the Lake Belovod. Microbiologia, Moscow, **26**, 92-98. (in Russian).
- MULLIN, J. B. and J. P. RILEY. (1955): The spectrophotometric determination of nitrate in natural waters, with particular reference to sea-water. Anal. Chim. Acta, **12**, 464.
- OHLE, W. (1962): Der Stoffhaushalt der Seen als Grundlage einer allgemeinen Stoffwechselfeldynamik der Gewässer. Kiel. Meeresforsch., **18**, 107-120.
- RICHARDS, F. A., J. D. CLINE, W. W. BROENKOW and L. P. ATKINSON. (1965): Some consequences of the decomposition of organic matter in Lake Nitinat, an anoxic fjord. Limnol. Oceanog., **10**: R185-201.
- SAKAMOTO, M. (1966): Primary production by phytoplankton community in some Japanese lakes and its dependence on lake depth. Arch. Hydrobiol., **62**: 1-28.
- SAKAMURA, T. (1958): Plant physiology, Shokabo, 1015 pp. Tokyo. (in Japanese).
- SOROKIN, Yu. I. (1962): Experimental study of the reduction of sulfates by bacteria in the Black Sea with the use S³⁵-sulphate. Microbiologia, Moscow, **31**: 402-410. (in Russian).
- (1964): On the primary production and bacterial activities in the Black Sea. J. Conseil Intern. Explor. Mer, **29**, 41-60.
- (1970): Interrelation between sulphur and carbon turnover in meromictic lakes. Arch. Hydrobiol., **66**, 391-446.
- STRICKLAND, J. D. H. and K. H. Austin. (1959): The direct estimation of ammonium in sea water with notes on "reactive" iron, nitrate and inorganic phosphorus. J. Conseil Intern. Explor. Mer, **24**, 446-451.
- SUDA, K. (1935): Consideration on abnormal phenomena in Lake Suigetsu. Umi to Sora, **15**, 369-379. (in Japanese).
- TAKAHASHI, M. and S. ICHIMURA. (1968): Vertical distribution and organic matter production of photosynthetic sulfur bacteria in Japanese lakes. Limnol. Oceanog., **13**, 644-655.
- , Y. YAMAGUCHI and S. ICHIMURA. (1970): Dark fixation of CO₂ in the lake with special reference to organic matter production. Bot. Mag. Tokyo, **83**, 397-410.
- TOYODA, Y., S. HORIE and Y. SAIJO. (1968): Studies on the sedimentation in Lake Biwa from the viewpoint of lake metabolism. Mitt. Internat. Verein. Limnol., **14**, 243-255.
- VAN NIEL, C. B. (1941): The bacterial photosynthesis and their importance for general problem of photosynthesis. Advances in Enzymology, **1**, 263-328.
- YOSHIMURA, S. (1932): Vertical distribution of the amount of sulphate dissolved in the water of Lake Suigetsu and Hiruga with reference to the origin of hydrogen sulphide in their bottom water. Geophys. Mag., **6**, 315-321.
- YOSHIMURA, S. (1936): Limnology, Sansendo, 426 pp. Tokyo. (in Japanese).

不完全循環湖水月湖における物質代謝に関する研究

松山 通 郎 ・ 西 條 八 束

要旨 水月湖は代表的な不完全循環湖で深度 8 m から 34 m の湖底に及ぶ厚い無酸素層がある。深層では硫化物、全炭酸、磷酸塩及びアンモニアの著しい蓄積が観察された。8 月には 2 つの光合成の最大層が表層及び酸素含有層と無酸素層の境に見出された。前者は植物プランクトン、後者は光合成イオウバクテリアによるものであ

る。12 月にはバクテリアによる光合成は見られなかったが、同じ境界層に著しい炭酸暗固定が測定された。硫酸還元は湖底泥の中、特に堆積物の表層付近のみで観察された。無酸素層における炭素とイオウの循環及びそれらの相互関係を論じた。