The Relation between Chlorinity and Silicate Concentration of Waters Observed in Some Estuaries—IV※

By

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According to YOSHIMURA (1931 and 1936), the amount of dissolved silicate determinable easily and exactly is considered to be one of the most suitable indicators to show the mixing ratio of river water to sea water. And senior author (MAÉDA, 1952 and 1953) reported already that the relation between chlorinity (dominant in sea water) and silicate concentration (dominant in river water) of estuarine waters is represented by the following formula : $[SiO_2]+A[Cl]=B$ ····· (1) and also the relation between two constants of the above-mentioned formula is shown as follows: $B=0.807+15.9\ A$ ····· ····· (2) That is to say, the influence of a certain river upon sea at a certain time can be representable by single constant, each one of A and B. Further he and his coworkers (MAKIMOTO *et al.*, 1955) continued the study on this relation and reported in the third report of this series that, adding 16 examples of the relation formulae of the river Chikugo, Formula (2) is amended to be $B=0.0037+17.665\ A$. And in the same report, they show that both or each of two constants (A and B) in surveyed regions are arranged as follows in the order of values from lower to higher : Japan Sea Group·····Seto-naikai Group·····Pacific Ocean Group·····Ariake Sea Group.

But in spite of the fact that all examples of the Seto-naikai Group already analysed were obtained from Kojima Bay, the innermost part of this bay has been recently partitioned and artificially desalined into fresh or brackish water lake. Accordingly, it is highly probable that $[Cl]$-$[SiO_2]$ relation after damming of not only the estuarine waters of the rivers pouring into the inner parts of the dam but also those flowing into the outer parts of it may somewhat differ from those observed before the beginning of damming, even if the characteristics of the rivers themselves are rather invariable. Most constants of Lake Hamana were computed from the records obtained in 1934 and succeeding year; and it is also expected to show some different features at present. And these facts may have worth while to be studied. Moreover, most examples of the

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Pacific Ocean Group were obtained from Lake Hamana. Accordingly, the examples obtained from the other parts of the Pacific Ocean coast than Lake Hamana should be added. And for this reason, several examples obtained from the estuarine region of the river Edo are added. On the other hand, it was reported in the third report that the constants of the river Chikugo which is nominated as Ariake Sea Group were far larger than those of the other groups although they (A and B) keep still the same relation as to the others. Accordingly, the relation between chlorinity and silicate concentration of the estuarine waters of the other rivers than the Chikugo pouring into Ariake Sea or adjacent waters should be examined. For this purpose, examples obtained from the estuarine region of the river Kuma which pours into Yatsushiro Sea are employed. The examples picked up basing the abovementioned points of views are analysed and the facts deducible from the results will be shown in this report.

Before entering the subject, we wish to express here our sincere thanks to Prof. Dr. D. MIYADI of the Zoological Institute of the Kyoto University and Dr. T. TOKIOKA of the Seto Marine Biological Laboratory of the same university and Prof. Dr. I. MATSUI of the Shimonoseki College of Fisheries for their valuable advices and criticisms given on the present series of works.

Methods

All data used in this report were cited from the reports annoted in respective figures. Chlorinity and silicate concentration were determined by the method standardized by the Oceanographical society of Japan (Chlorinity : MOHR's silver titration method, silicate concentration: DIÉNERT-WANDENBULCK's colorimetric method). The data were treated by the same method as described in the second report of this series (MAÉDA, 1953). But before treating statistically, following preliminary considerations were given. Among many records of on shore observations, there are many examples, the chlorinity of which does not vary widely (usually restricted within the range from 16 to 18‰) indicating river water was not so influential or stations were located out of the course of the river water in the sea. And such examples are not employed in this report, even if silicate may vary widely, because $[Cl]-[SiO_2]$ relation in such examples shows rather that within the same water mass and results to represent the influence of the other factors than river water, against the fact that the abovementioned relation treated in this series of reports is chiefly that observed in the mixing process of river water into principal water mass in the bay. While there are also many cases, in which distribution of most points representing the chlorinity and silicate concentration of respective water samples is strongly biased into being restricted within a part in the graph, frequently around the point ($[Cl]=16\sim17$‰ and $[SiO_2]=0.5$ mg/L) or thereabout. And such case may be observable when the

water samples are taken from several depth levels at respective stations or when the stations are located out of the river in the sea. And for the purpose of making applicable to the statistical treatment, some water samples in such examples are thinned out by limiting the depth levels or localities and the biase of distribution of water samples to higher chlorinity is adjusted. On the other hand, there are some examples in which the [Cl]-[SiO_2] relation of some water samples is clearly out of that assumed from the other samples obtained at the same observation. But the author examining the localities and depth levels or topcgraphical conditions, it may be assumable that most of such water samples are strongly affected by the influence of

Table 1. Constants, A and B, of the [Cl]—[SiO_2] relation formulae.

Name of Bay	Name of River	Date	Size of Sample	F_o	F	Level of Signif.	A	B
Kojima Bay	Yoshii	Aug. 19—21, '52	7	75.10	22.79	< 0.005	0.418	9.186
	Asahi		18	189.25	10.58	< 0.005	0.843	15.361
	Sasagase		26	269.31	9.55	< 0.005	0.849	15.933
	Yoshii	Aug. 26—28, '53	8	159.77	18.64	< 0.005	0.462	8.556
	Asahi		18	100.21	10.58	< 0.005	0.454	8.478
	Sasagase		28	113.70	9.41	< 0.005	0.455	9.460
Lake Hamana		Apr. 9, '53	14	26.23	11.75	< 0.005	0.165	4.138
		June 15,	15	236.90	11.37	< 0.005	0.391	8.153
		Sept. 15,	16	11.30	11.06	< 0.005	0.242	4.884
		Oct. 12,	16	82.66	11.06	< 0.005	0.534	10.272
		Dec. 9,	16	40.35	11.06	< 0.005	0.180	3.943
		Feb. 9, '54	14	198.83	11.75	< 0.005	0.358	7.340
		Apr. 16,	16	278.26	11.06	< 0.005	0.509	9.602
		May 12,	15	290.04	11.37	< 0.005	0.788	10.412
		June 16,	15	20.15	11.37	< 0.005	0.446	7.788
		July 7,	15	87.74	11.37	< 0.005	0.311	6.303
		Oct. 4,	14	61.44	11.75	< 0.005	0.245	5.197
		Dec. 9,	15	19.71	11.37	< 0.005	0.168	4.174
		Jan. 25, '55	14	162.22	11.75	< 0.005	0.336	6.803
		Feb. 10,	16	315.44	11.06	< 0.005	0.286	5.760
		Mar. 15,	16	43.30	11.06	< 0.005	0.159	3.455
Off Urayasu	Edo	Oct. 22, '56	23	152.66	9.83	< 0.005	0.619	12.392
		Nov. 26,	11	317.06	13.61	< 0.005	0.653	12.407
		Dec. 14,	12	77.79	12.83	< 0.005	0.430	9.304
		Jan. 17, '57	24	644.21	9.73	< 0.005	0.514	9.823
		Feb. 18,	6	13.26	12.22	0.025~0.01	0.205	9.930
Yatsushiro Sea	Kuma	Aug. 30 Sept. 2, '49	40	61.28	about 9	< 0.005	0.453	8.817
		Dec. 7, '49	21	24.92	10.07	< 0.005	0.255	4.968
		July 8, '50	21	46.90	10.07	< 0.005	0.301	6.794

Note : [Cl] : ‰, [SiO_2] : mg/L.
[SiO_2] + A[Cl] = B

stagnation or are probably sampled from the different water masses. And concerning with such water samples, whether they should be rejected in the consideration or not is examined case by case.

Results

Kojima Bay The topographical and oceanographical conditions of this bay were already reported by YAMAZI (1954) in detail. And among 4 series of observations reported by him, the earlier two, when the artificial fresh water lake formation was not yet started, were already analysed and reported in the first report of this series (MAÉDA, 1952). Accordingly, here, we wish to add the analyses on the latter 2 series of observations, when the fresh water lake formation was in progress. And the results are represented in Figs. 2 and 3, which indicate that the relations of concentration of

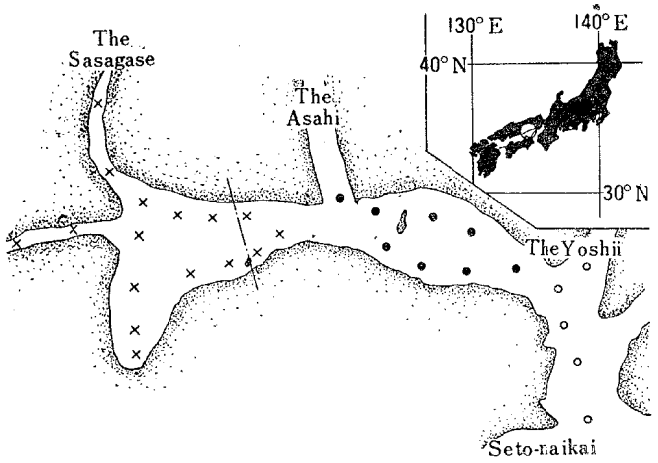

Fig. 1. Chart of Kojima Bay, showing the stations (YAMAZI, 1954)
—•— indicates the locality of dam.
○ indicates the stations retaining the water derived from the river Yoshii. ● indicates the stations retaining the water derived from the river Asahi. And × indicates the stations retaining the water derived from the river Sasagase.

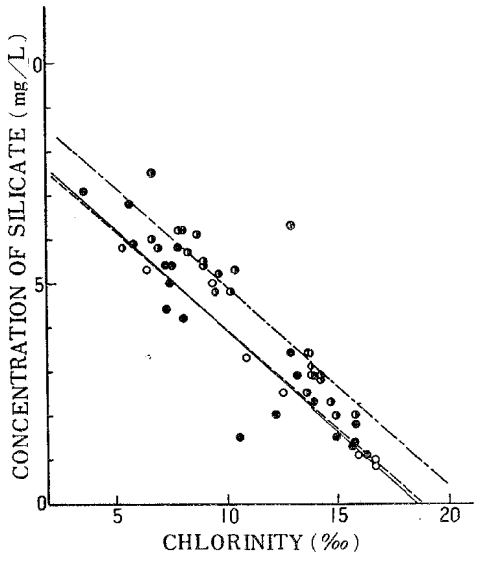

Fig. 2. Silicate-chlorine relation graph drawn on the data of observed by YAMAZI in Kojima Bay (Aug. 19—21, 1952).
Note: Symbols are the same as to Fig. 1. While × is changed into ◑.

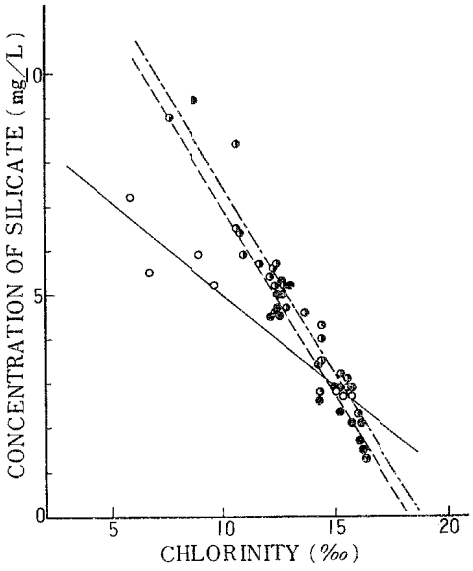

Fig. 3. Silicate-chlorine relation graph drawn on the data of observed by YAMAZI in Kojima Bay (Aug. 26—28, 1953).
Symbols are the same as to Fig. 2.

Table 2. Constant, A, of the [Cl]-[SiO_2] relation formulae obtained from Kojima Bay before and after the beginning of damming.

	Date / Name of River	Before		After	
		May 26—31,'51	Feb. 26—27,'52	Aug. 19—21,'52	Aug. 26—28,'53
out of dam	Yoshii	0.443	0.614	0.418	0.462
	Asahi	0.438	0.463	0.843	0.454
in dam	Sasagase	0.420	0.542	0.849	0.455

Note : the same as to those shown in Table 1.

chlorine and silicate near the estuaries are also representable by general formula, $[SiO_2] + A[Cl] = B$, with considerable accuracy. While as shown in Table 2, no essential difference of this relation obtained before and after the beginning of damming was observable, although some differences of extent of nourishing area and amount of dilution *etc.* might be expected.

Lake Hamana The results of the observations pursued by the Hamamatsu Meteorological Observatory about 20 years ago were analysed in the second report of this series (MAEDA, 1953). But here we wish to analyse the recent oceanographical conditions offered by the Shizuoka Prefectural Fisheries Station.

As shown in Figs. 5—19, [Cl]—[SiO_2] relation in most examples is representable by the general formula, $[SiO_2] + A[Cl] = B$, although there are many examples in which the relation of some water samples obtained from the deeper layers where stagnation becomes influential (deeper parts of St. 6, because all other stations are less than 5 m deep) or from the stations located in the eastern inlet (St. 1 and St. 7) does not follow the general formula and such water samples are rejected because it is highly probable that they are sampled from the different water masses. While among other 9 examples obtained during the same period as to those represented in the figures but not used in this study, there are 4 examples in which the same relation is suspected but not analysed because it is not so clear as that illustrated in figures or the points representing the concentration of chlorine and silicate of

Table 3. Comparison of constants, A, obtained from Lake Hamana.

Year \ Month	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1934											0.750	
35	0.880			1.036					0.800*			
1953				1.165	C	0.391	St.	St.	0.242	0.534	C	0.180
54	+	0.358	+	0.509	0.788	0.446	0.311	St.	+	0.245	+	0.168
55	0.336	0.286	0.159									

Notes : the same as to those shown in Table 1.
+ : linear relation is alluded but not so clear.
C : variation of SiO_2 is small.
St : stagnation is strong.
* : obtained from the results of observation pursued after heavy rain.

respective water samples are strongly restricted within two parts consequently the relation results to show not the mixing process but rather inter water masses one. There are two examples in which the concentration of silicate is rather invariable and unable to analyse. And other three examples are also not analysed because the strong influence of stagnation is alluded.

Against the fact that the relation formulae represented in the second report of this series were obtained partitiond the lake into 4 parts because plentifully much stations were set in all over the lake, we were obliged in this report to estimate the influence formula lake as a whole, because of scarcity of water samples taken. Accordingly, some differences due to this fact are presumablly expected. But it may safely be described as one of the most conspicuous differences observable between the results of observations passing 20 years that, as shown in Table 3, in spite of high values of A in 1934 or succeeding year, those in 1953—1955 are lower and take the values as high as or a little lower than those obtained in Seto-naikai Group.

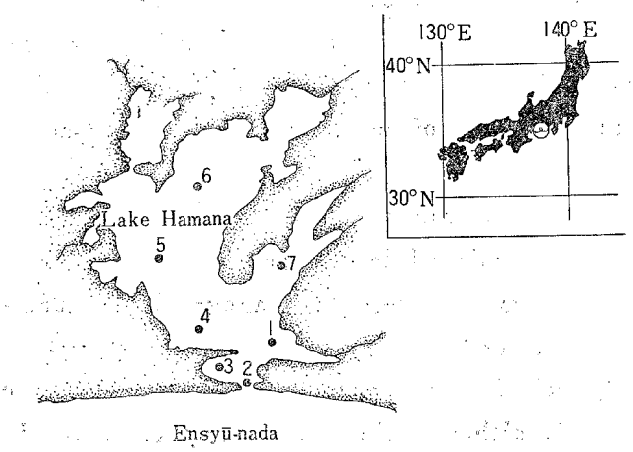

Fig. 4. Chart of Lake Hamana, showing the stations (Shizuoka Prefectural Fisheries Station).

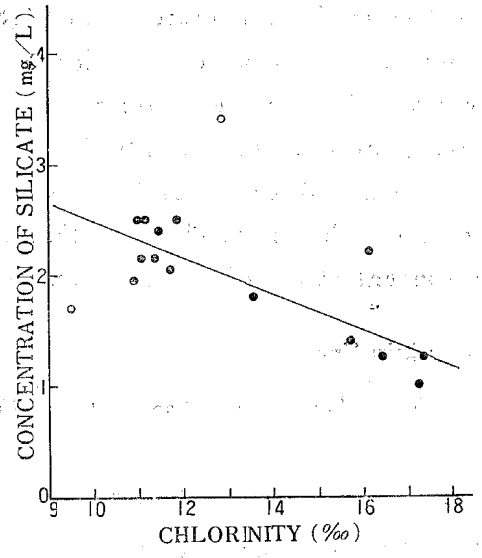

Fig. 5. Silicate-chlorine relation graph drawn on the data of observed by the Shizuoka Prefectural Fisheries Station in Lake Hamana (Apr. 9, 1953).
Remarks: The upper open circle (St. 1—0m) and the lower one (St. 7—0m), which seem to be apart from regression line, are omitted from estimation.

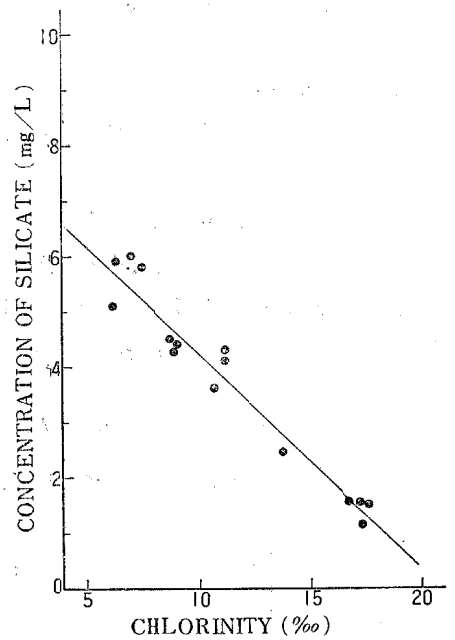

Fig. 6. Silicate-chlorine relation graph drawn on the data of observed by the Shizuoka Prefectural Fisheries Station in Lake Hamana (June 15, 1953).
Remarks: Open circle (St. 7—0m), which seems to be apart from regression line, is omitted from the estimation.

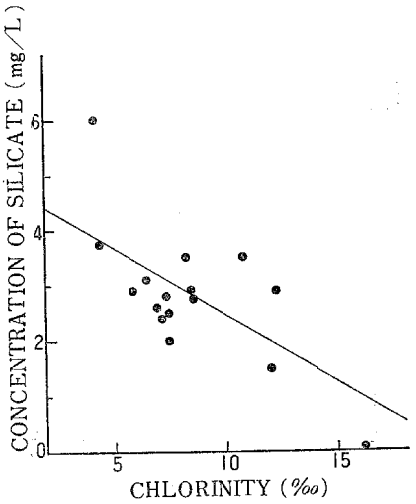

Fig. 7. Silicate-chlorine relation graph drawn on the data of observed by the Shizuoka Prefectural Fisheries Station in Lake Hamana. (Sept. 15, 1953).

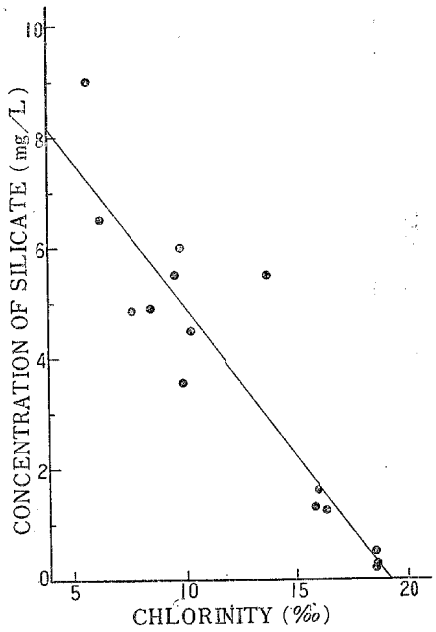

Fig. 8. Silicate-chlorine relation graph crawn on the data of observed by the Shizuoka Prefectural Fisheries Station in Lake Hamana (Oct. 12, 1953).

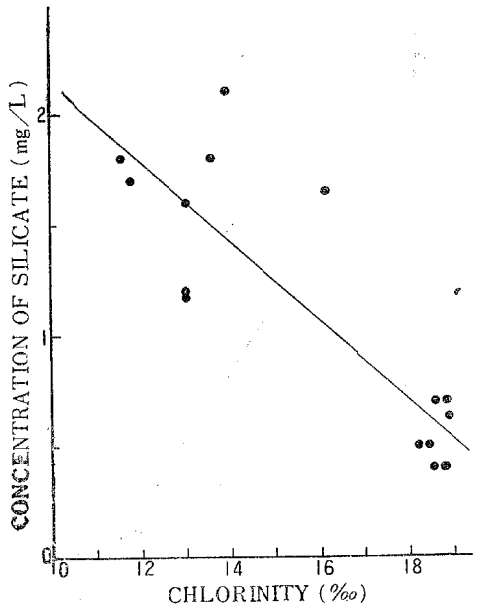

Fig. 9. Silicate-chlorine relation graph drawn or the data of observed by the Shizuoka Prefectural Fisheries Station in Lake Hamana (Dec. 9, 1953).

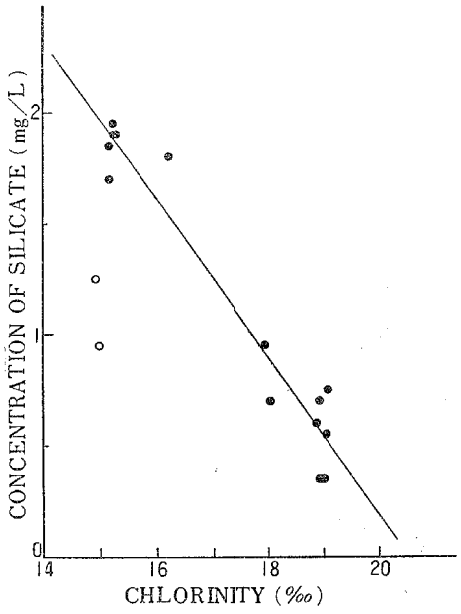

Fig. 10. Silicate-chlorine relation graph drawn on the data of observed by the Shizuoka Prefectural Fisheries Station in Lake Hamana (Feb. 9, 1954).
Remarks: Open circles (St. 7—0m, St. 7—1.7m), which seem to be apart from regression line, are omitted from the estimation of regression line.

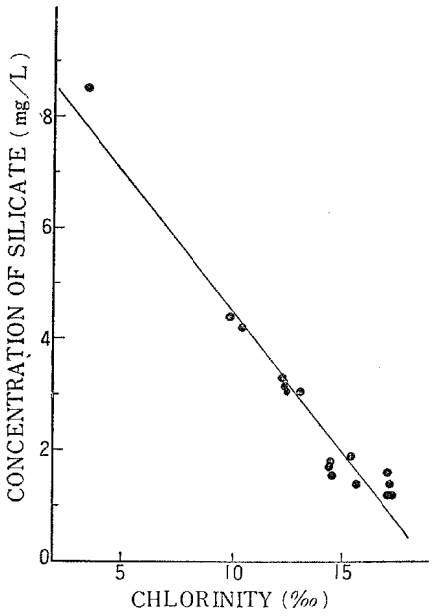

Fig. 11. Silicate-chlorine relation graph drawn on the data of observed by the Shizuoka Prefectural Fisheries Station in Lake Hamana (April 16, 1954).

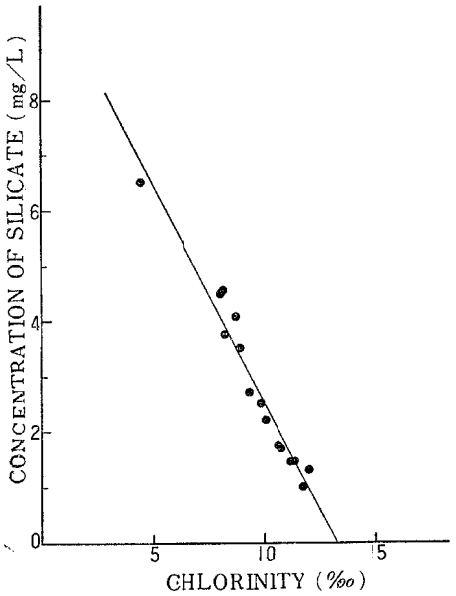

Fig. 12. Silicate-chlorine relation graph drawn on the data of observed by the Shizuoka Prefectural Fisheries Station in Lake Hamana (May 12, 1954).
Remarks: Open circle (St. 6—10m), which seems to be apart from regression line, is omitted from the estimation of regression line.

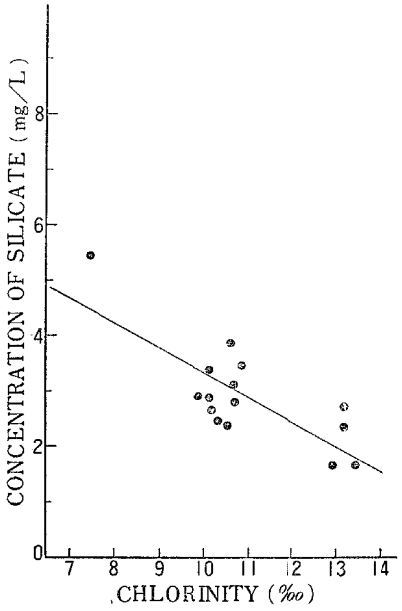

Fig. 13. Silicate-chlorine relation graph drawn on the data of observed by the Shizuoka Prefectural Fisheries Station in Lake Hamana (June 16, 1954).
Remarks: Open circle (St. 6-10m), which seems to be apart from regression line, is omitted from the estimation of regression line.

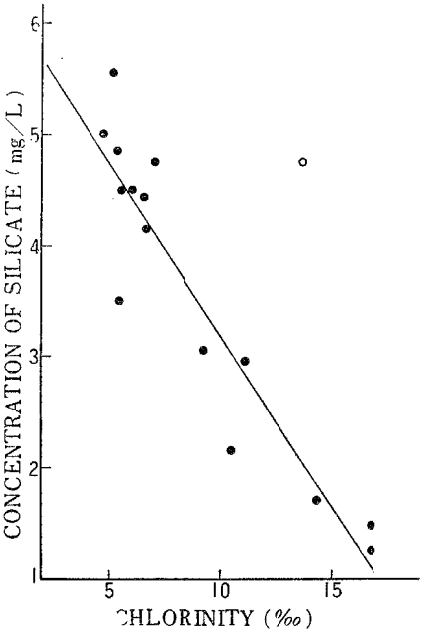

Fig. 14. Silicate-chlorine relation graph drawn on the data of observed by the Shizuoka Prefectural Fisheries Station in Lake Hamana (July 7, 1954).
Remarks: Open circle (St. 6-10m), which seems to be apart from regression line, is omitted from the estimation of regression line.

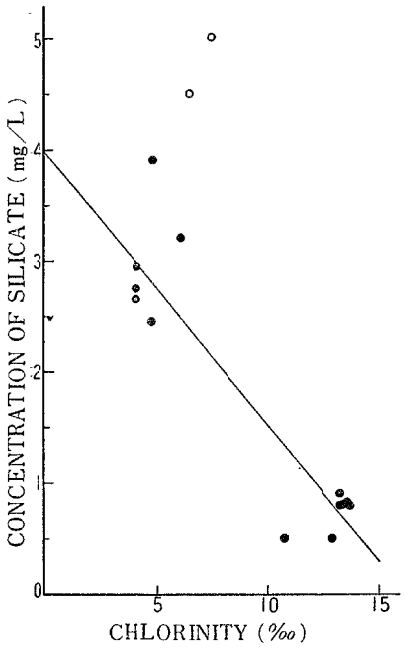

Fig. 15. Silicate-chlorine relation graph drawn on the data of observed by the Shizuoka Prefectural Fisheries Station in Lake Hamana (Oct. 4, 1954).
Remarks: Open circles (St. 6—6m, St. 6—10m), which seem to be apart from regression line, are omitted from the estimation of regression line.

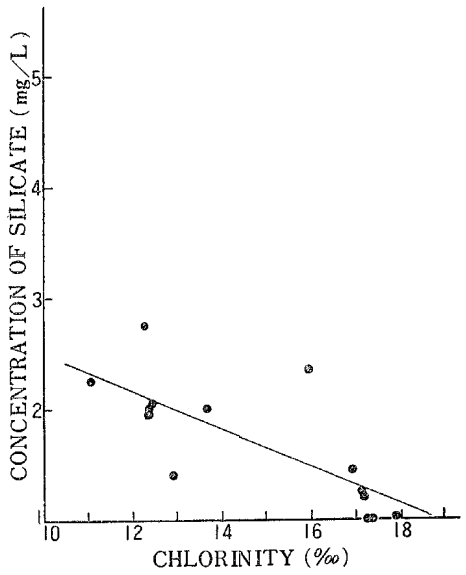

Fig. 16. Silicate-chlorine relation graph drawn on the data of observed by the Shizuoka Prefectural Fisheries Station in Lake Hamana (Dec. 9, 1954).
Remarks: Open circle (St. 6—10m), which seems to be apart from the regresion line, is omitted from the estimation of regression line.

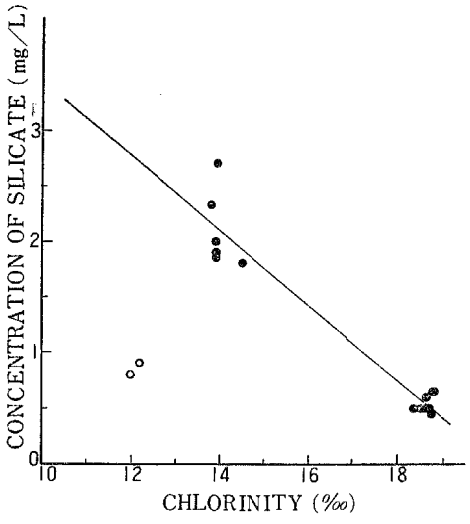

Fig. 17. Silicate-chlorine relation graph drawn on the data of observed by the Shizuoka Prefectural Fisheries Station in Lake Hamana (Jan. 25, 1955).
Remarks: Open circles (St. 7—0m, St. 7—1.4m), which seem to be apart from regression line, are omitted from the estimation of regression line.

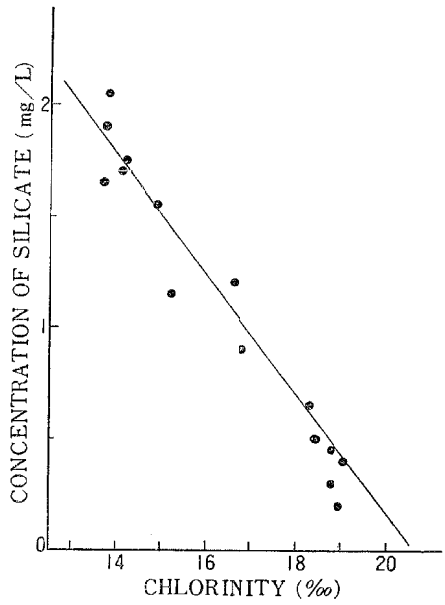

Fig. 18. Silicate-chlorine relation graph drawn on the data of observed by the Shizuoka Prefectural Fisheries Station in Lake Hamana (Feb. 10, 1955).

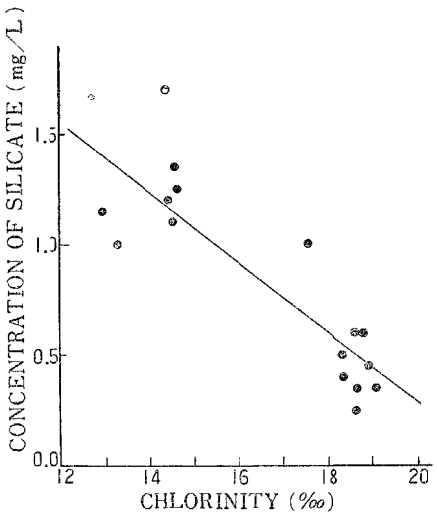

Fig. 19. Silicate-chlorine relation graph drawn on the data of observed by the Shizuoka Prefectural Fisheries Station in Lake Hamana (Mar. 15, 1955).

Off Urayasu Urayasu, having wide tideland where is prominent culturing ground of shell fish and laver, is located at the innermost part of Tokyo Bay and poured by the river Edo. And although this region is classified into Pacific Ocean Group, this area shows some common features of biological, oceanographical and topographical conditions as to the estuarine region of the river Chikugo. But the computed constants from this region do not take the similar values but are showing the values of the same magnitude as to those of Pacific Ocean Group newly added.

Yatsushiro Sea Yatsushiro Sea is located at the middle of the west coast of Kyushu Island and separated from Eastern Sea by the Amakusa Islands. And Udo Peninsula separates it from Ariake Sea. The largest source of land water is thought to be the river Kuma. But in spite of the fact that this and Ariake Sea are adjoined each other, quitly the different pattern from that of Ariake Sea is observable, *i. e.* constants of the formulae are far lower and take the values between those of Japan Sea Group and Seto-naikai Group.

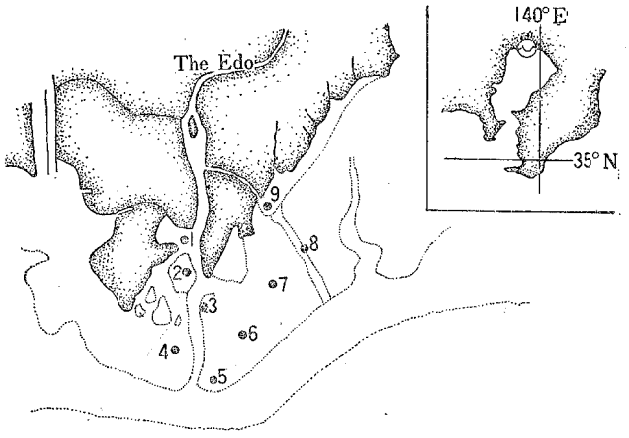

Fig. 20. Chart of the estuarine region of the river Edo (Off Urayasu), showing the stations (Chiba Prefectural Fisheries Station).

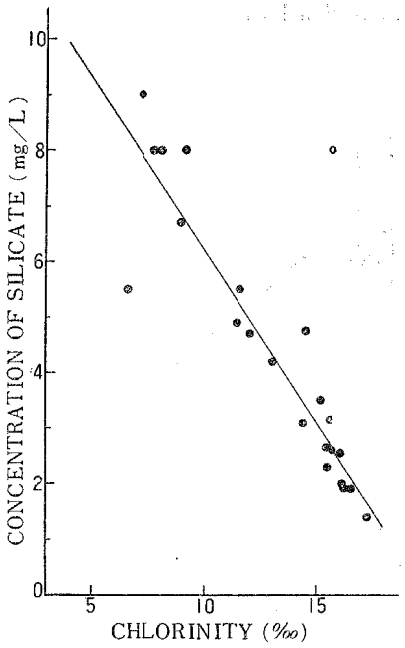

Fig. 21. Silicate-chlorine relation graph drawn on the data of observed by the Chiba Prefectural Fisheries Station in the estuarine region of the river Edo (Oct. 22, 1956).
Remarks: Open circle (St. 6), which seems to be apart from regression line, is omitted from the estimation of regression line.

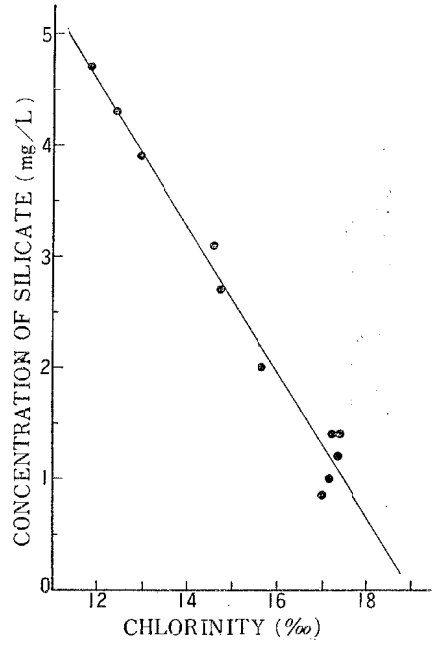

Fig. 22. Silicate-chlorine relation graph drawn on the data of observed by the Chiba Prefectural Fisheries Station in the estuarine region of the river Edo (Nov. 26, 1956).

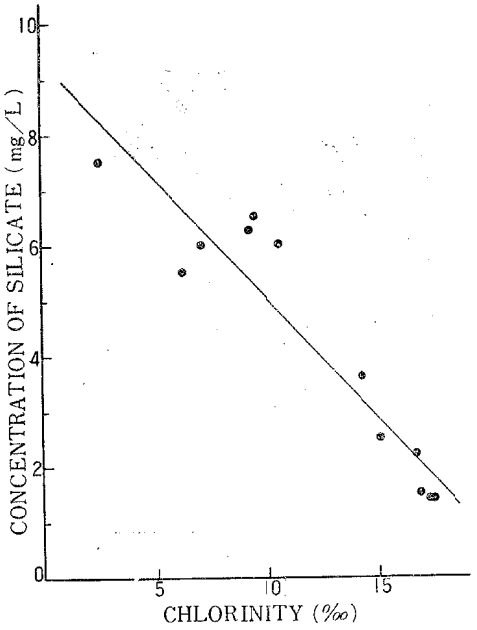

Fig. 23. Silicate-chlorine relation graph drawn on the data of observed by the Chiba Prefectural Fisheries Station in the estuarine region of the river Edo (Dec. 14, 1956).

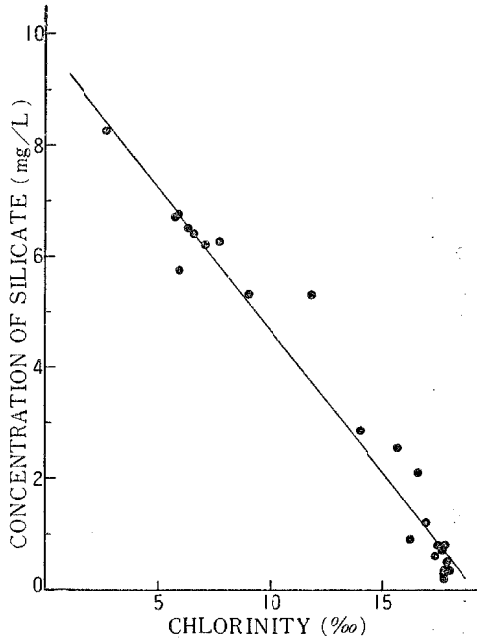

Fig. 24. Silicate-chlorine relation graph drawn on the data of observed by the Chiba Prefectural Fisheries Station in the estuarine region of the river Edo. (Jan. 17, 1957).

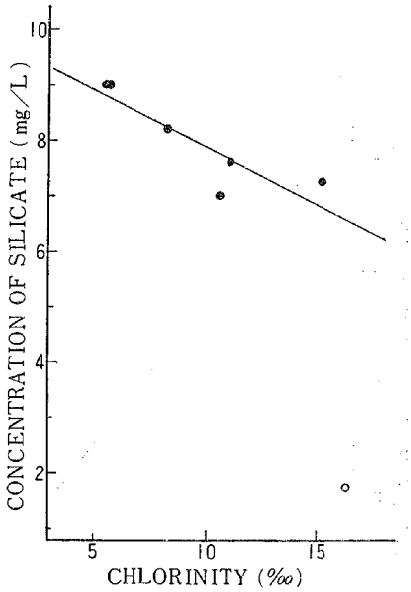

Fig. 25. Silicate-chlorine relation graph drawn on the data of observed by the Chiba Prefectural Fisheries Station in the estuarine region of the river Edo (Feb. 18, 1957).
Remarks: Open circle (St. 5), which seems to be apart from regression line, is omitted from the estimation of regression line.

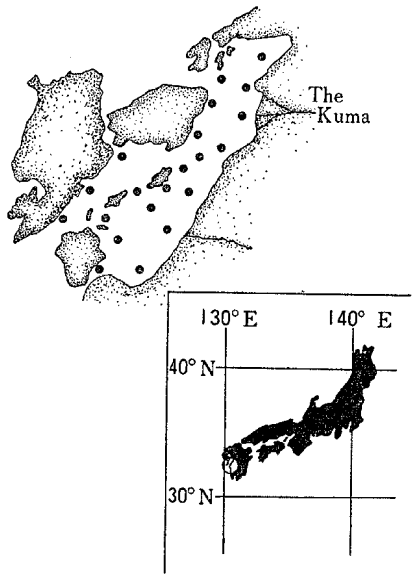

Fig. 26. Chart of Yatsushiro Sea, showing the stations(IKESUE *et al.*).

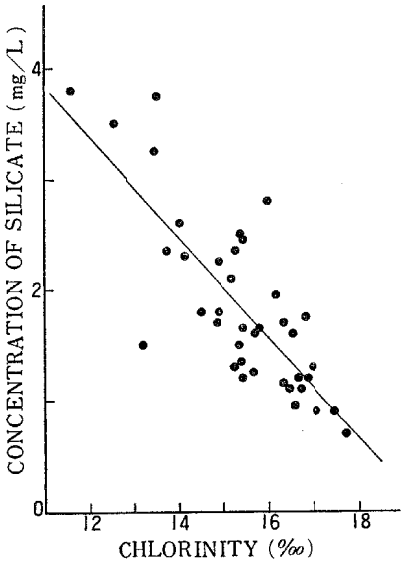

Fig. 27. Silicate-chlorine relation graph drawn on the data of observed by IKESUE *et al.* in Yatsushiro Sea (Aug. 30—Sept. 2, 1949).

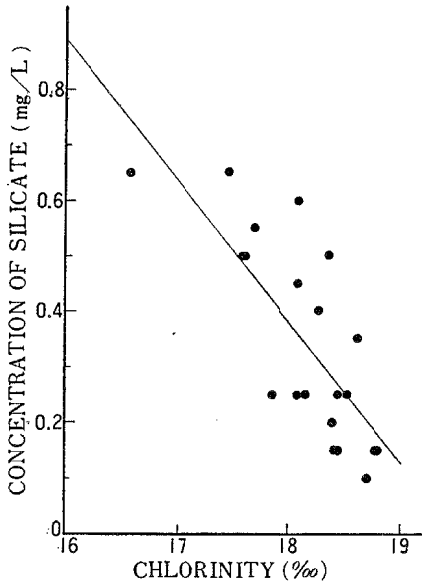

Fig. 28. Silicate-chlorine relation graph drawn on the data of observed by IKESUE *et al.* in Yatsushiro Sea (Dec. 7, 1949).

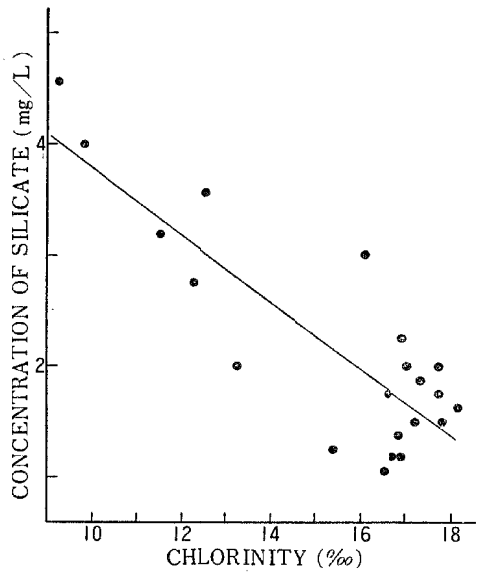

Fig. 29. Silicate-chlorine relation graph drawn on the data of observed by IKESUE *et al.* in Yatsushiro Sea (July 8, 1950).

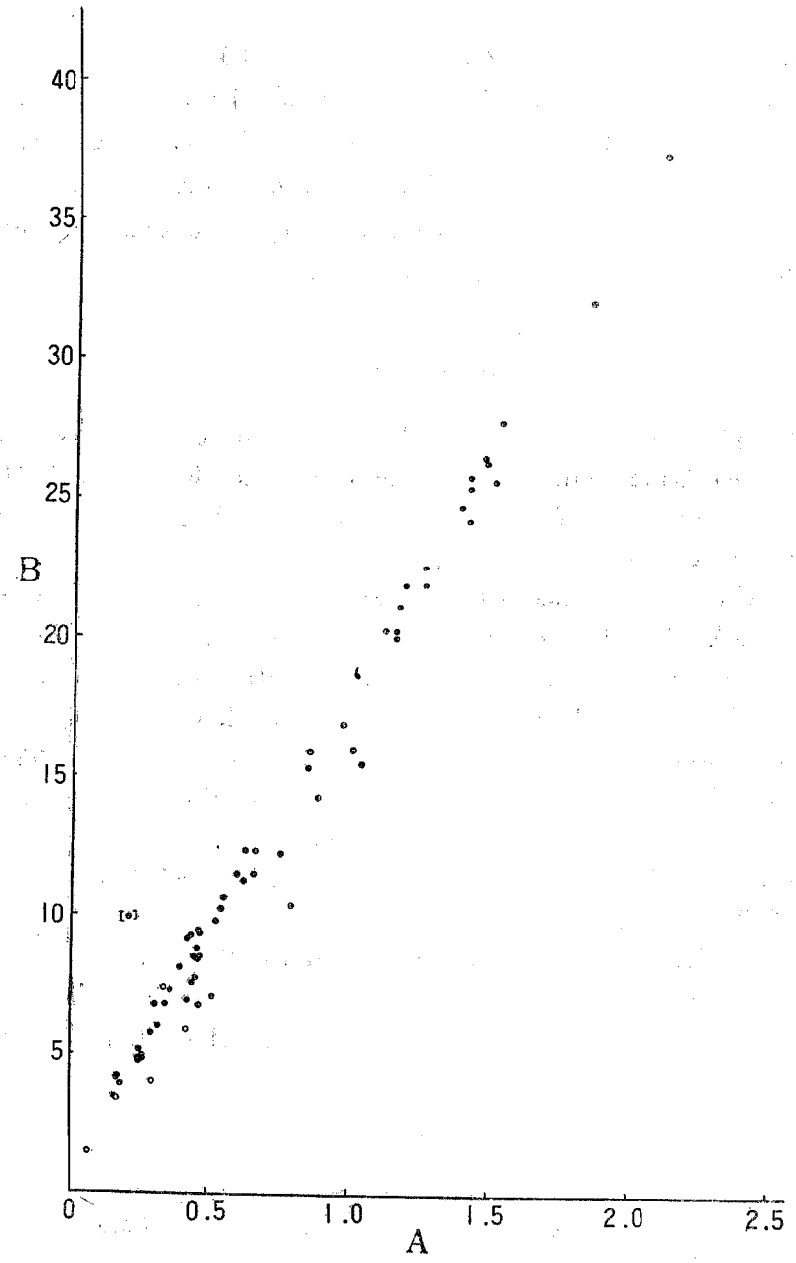

Fig. 30. Relation graph of Constants, A and B, of silicate-chlorine relation formula, $[SiO_2]+A[Cl]=B$.

Remarks	Already reported	Newly added
Japan Sea Group :	○	
Seto-naikai Group :	●	⊕
Pacific Ocean Group :	◐	⊖
Ariake Sea Group :	◑	⊕

The point enclosed in brackets is omitted from the estimation of A–B relation formula.

Discussion and Conclusion

The relation between two constants of relation formulae was already discussed in the second and the third reports of this series. But adding newly computed values, this is amended to be

$$B=0.755+17.07\ A \qquad (F_0=2576,\ n_1=1,\ n_2=65)$$

Senior author and his coworkers (MAKIMOTO *et al.*, 1955) reported in the third report of this series that constants show regional specificity. But preceeding the study, this fact becomes to be circumscribed within the lowest values. And it may well be said that A under ordinal conditions, except the examples of the river Chikugo, take 0.5 or thereabout (from 0.15 to 1.0).

Summary

1. Additional examples of $[Cl]-[SiO_2]$ relation of the estuarine waters observed in Kojima Bay and Lake Hamana and the examples obtained off Urayasu and Yatsushiro Sea are examined for the purpose mentioned in the introduction. And the results are represented in Table 1.
2. $[Cl]-[SiO_2]$ relations of these regions were representable also by the general formula, $[SiO_2]+A[Cl]=B$, like as the other inlet bays already reported.
3. In Kojima Bay, no essential difference of this relation was observed between the examples obtained before and after the beginning of damming.
4. Concerning with Lake Hamana, constants A observed in 1953—1955 are lower than those obtained in 1934 and succeeding year and take the values as high as or a little lower than those obtained in Seto-naikai Group.
5. Adding newly computed constants, $A-B$ relation is amended to be
$$B=0.755+17.07\ A$$
6. The regional specificity of constants reported in the third report is circumscribed within the lowest values.
7. Under ordinal conditions, A takes 0.5 or thereabout (from 0.15 to 1.0).

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