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Strontium Concentrations and Strontium-Chlorinity Ratios in Sea Water of the North Pacific and the Adjacent Seas of Japan*

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Abstract: Strontium contents of 232 sea water samples collected at various stations in the North Pacific and adjacent seas of Japan were measured by the atomic absorption spectrophotometry and strontium-chlorinity ratios were determined. Mean Sr concentration is 8.08 mg/kg and mean Sr/Cl ratio is 0.425 mg/kg/‰.

Contrary to some recent reports, regional and vertical variations of Sr/Cl ratios were statistically insignificant, and presence of particulate strontium was not confirmed.

1. Introduction

In estimation of behaviours of artificial radionuclides released into the sea, the effects of dilution by their natural isotopes must be considered. Therefore, in the estimation of the behaviour of ^{90}Sr, exact knowledges on the amount, and physical and chemical properties of natural strontium in sea water are essential.

Concerning the natural strontium in the sea water, it is widely accepted that strontium is one of the major constituents of sea water and mostly in ionic form, and that the concentration is approximately 8 mg Sr per kg sea water with slight variations and strontium-chlorinity ratio is nearly constant, *i.e.* 0.42 to 0.43 (SUGAWARA *et al.*, 1962; CULKIN, 1965) and also it is assumed that radioactive and natural strontium behave similarly (MIYAKE *et al.*, 1962; NAGAYA and NAKAMURA, 1970).

But recently, as shown in Table 1, some authors reported that Sr concentration and Sr/Cl ratio are considerably lower than conventional values, especially in Atlantic Ocean (ANGINO *et al.*, 1966; CULKIN and COX, 1966; FABRICAND *et al.*, 1966, 1967; BURRELL, 1967; ANDERSEN and HUME, 1968), that the vertical and regional variations are found to be significant (MACKENZIE, 1964; ANGINO *et al.*, 1966; ANDERSEN and HUME, 1968; ROBERTSON *et al.*, 1968), and that fairly large fraction, up to 20 %, of strontium is in particulate form, greater than 0.45 μ in diameter (ANGINO *et al.*, 1966).

To ascertain whether the phenomenon are common in any regions of the sea and whether the modification of our estimation of ^{90}Sr behaviour is necessary, authors made some determination of strontium concentration and Sr/Cl ratios of sea water in the North Pacific and in the adjacent seas of Japan.

2. Collection of samples

232 sea water samples were collected from 53 stations during the cruises described in Table 2, by use of Nansen sampler or plastic sampler. Each half volume of 162 samples were filtered with GS type miliporefilter (pore size 0.22 μ) for determination of particulate strontium.

3. Analytical method

Measurement: Atomic absorption spectrophotometry was applied to strontium concentration determination. According to TANAKA *et al.* (1968), sea water were diluted 5 times with deminaralized water to achieve linear absorbance-concentration corelation. Then, to prevent the interferences due to phosphate ion etc, standard addition method was adopted as follows; each 5 m*l* of a diluted sea water were transfered into three test tubes, to each tube 1 m*l* of Sr standard solution (0, 6 or 15 mg Sr per m*l*) was added to make a set of sample solutions whose Sr concentrations are +0, +1 and +2.5 mg per m*l*. Strontium contents of the

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Table 1. Recent determinations of strontium in sea water.

Region	Sr (mg/kg)	Sr/Cl (mg/kg/‰)	Reference
Northwestern Pacific	8.06		SUGAWARA *et al.* (1962)
Indian Ocean	8.67		,,
Antarctic Ocean	9.11		,,
Atlantic Ocean	8.88*	0.449**	MACKENZIE (1964)
Worldwide	8	0.42-0.43	CULKIN (1965)
Atlantic Ocean	6.35*	0.345**	ANGINO *et al.* (1966)
Gulf of Mexico	7.25*	0.359**	,,
Worldwide		0.40	CULKIN *et al.* (1966)
Atlantic Ocean	7.90	0.409	FABRICAND *et al.* (1966)
South Atlantic		0.359	BURRELL (1967)
Atlantic Ocean	7.86	0.404	FABRICAND *et al.* (1967)
North Atlantic Ocean	6.04	0.309	ANDERSEN *et al.* (1968)
North Atlantic and North Eastern Pacific	4.85 to 8.79*	0.253 to 0.453**	ROBERTSON *et al.* (1968)

* mg/*l* ** mg/*l*/‰

Table 2. Cruise data.

Cruise	Date	Region	Station Nos.	Sample Nos.
KT-66-4**	April, 1966	Sagami Bay	1	9
KT-66-18**	Sept., 1966	Kashimanada	3	31
		off Sanriku	1	1
KT-67-6**	May, 1967	Northern Japan Sea	3	17
		off Sanriku	1	1
KT-68-11**	June, 1968	off Sanriku	2	11
Ibaragi Pref.*	Sept., 1969	Kashimanada coast	11	11
KT-69-21**	Nov., 1969	Kashimanada	2	11
KH-70-2***	April-June, 1970	North Pacific	29	140
		Total	53	232

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Table 3. Error data brought in at each step of chemical analysis.

Source of error	Date of measurement	Sample Nos.	Relative standard error (%)		
			Max.	Min.	Means
Absorbance	Jan., 1969	71	3.0	0.6	1.6
measurement	Sept., 1969	45	2.6	0.8	1.7
(triplicate)	Mar., 1970	66	2.4	0.3	1.8
	July, 1970	280	0.9	0.04	0.3
Sample preparation (triplicate)	Mar., 1970	22	3.3	2.0	2.5

above solutions were measured by use of a Perkin-Elmer Model 303 atomic absorption spectrophotometer equipped with Sr hollow cathode lamp, using acetylene and air as fuel and oxidizer respectively. Atomic absorbances on 4607 A line were measured, then original Sr concentration was calculated by least square method from absorbances and added strontium concentrations. Each set was measured three times and mean concentration was used for the computation of final Sr concentration of the sea water.

Analytical errors: Calibration of volumetric glassware showed errors of 0.01% to 0.52%

(means 0.15 %). Estimated error of Sr concentration in the standard solution is less than 1 %. Errors in measurement are shown in Table 3. Maximum relative standard errors in the triplicate measurements were less than 3 %, remarkably high accuracy in measurement on July, 1970 was achieved by use of a three-slot burner. Triplicate sample preparations showed mean relative standard error of 2.5 %, including error due triplicate measurement, and indicated good reproductivity on samples preparation.

4. Results and discussion

Results of analysis are shown in Figs. 1, 2, Tables 4, 5 and 6. The 95 % confidence limits in the tables indicate the statistical ranges of the mean values and are calculated by the following equation, 95 % C.L. $= s \cdot t\sqrt{n}$, where s is standard deviation, n is numbers of samples and t is "Student's t". In calculation of the 95 % confidence limits, no consideration was given to the analytical errors.

Mean Sr/Cl ratios of surface waters are 0.428 mg/kg/‰ in the adjacent seas of Japan and 0.418 mg/kg/‰ in the North Pacific, with 95 % confidence limits of 0.003 and 0.004 mg/kg/‰ respectively. The difference beyond 95 % confidence limits is less than 3 %. Among the means in adjacent seas of Japan, the differences beyond 95 % confidence limits are less than 0.5 % and also among the samples of the adjacent seas of Japan and of the North Pacific, maximum variations beyond 95 % confidence limits from the regional means are less than 0.3 % of the mean values.

Considering the errors in measurement, it could be said that the Sr/Cl ratios of surface waters have no significant differences.

As shown in Table 5, vertical mean Sr/Cl ratios of stations on Kashimanada and Northern Japan Sea in the adjacent seas of Japan, and of stations of the North Pacific showed no statistically significant variations from the re-

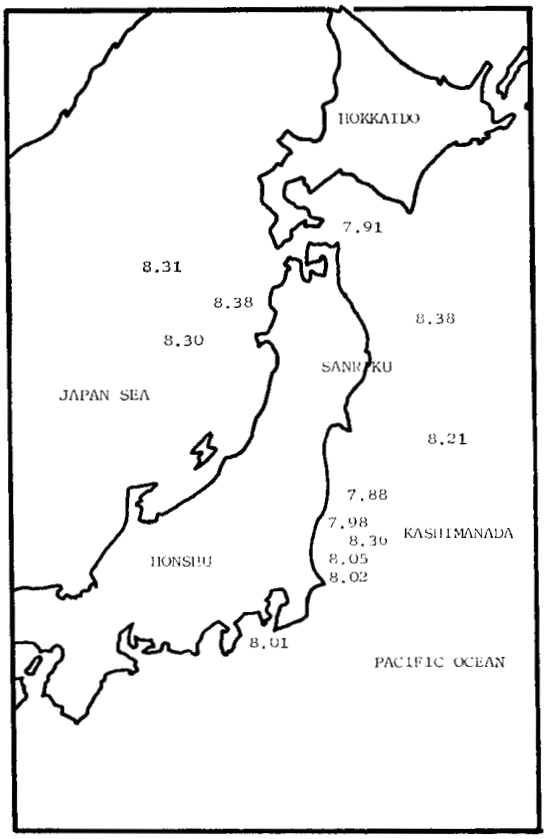

Fig. 1. Sr concentrations in surface water of adjacent seas of Japan.

Table 4. Mean Sr concentrations and Sr/Cl ratios of surface waters.

Region	Sample Nos.	Sr (mg/kg) Means ± 95 % C.L.*	Sr/Cl (mg/kg/‰) Means ± 95 % C.L.*
Adjacent seas of Japan			
Sagami Bay	1	8.01	0.421
off Sanriku	4	8.10 ± 0.37	0.434 ± 0.025
Kashimanada	4	8.10 ± 0.27	0.426 ± 0.019
Kashimanada Coast	11	7.81 ± 0.27	0.423 ± 0.014
Northern Japan Sea	3	8.33 ± 0.10	0.441 ± 0.002
Regional means	23	7.99 ± 0.08	0.428 ± 0.003
Northe Pacific, Regional means	29	7.84 ± 0.08	0.418 ± 0.004
Total means	52	7.91 ± 0.04	0.422 ± 0.002

* 95 % confidence limit without consideration of analytical errors.

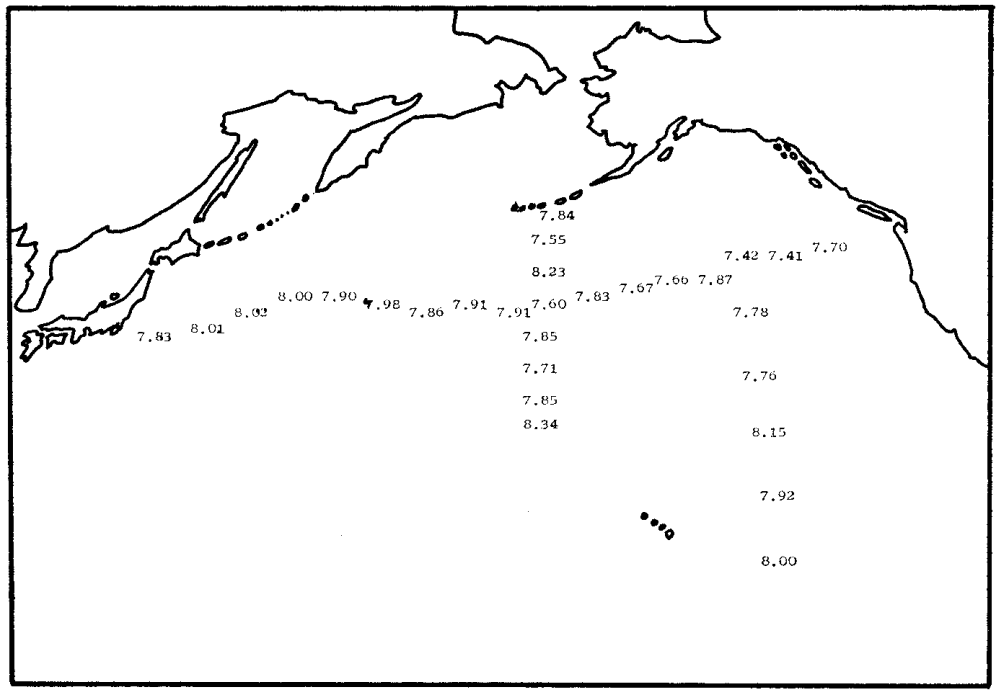

Fig. 2. Sr concentrations in surface water of the North Pacific.

Table 5. Vertical means of Sr concentrations and Sr/Cl ratios.

Region	Sample Nos.	Maximum depth (m)	Sr (mg/kg) Means ± 95 % C.L.*	Sr/Cl (mg/kg/‰) Means ± 95 % C.L.*
Adjacent seas of Japan				
Sagami Bay	9	1,100	8.23 ± 0.15	0.432 ± 0.012
off Sanriku	10	3,000	8.31 ± 0.14	0.437 ± 0.008
Kashimanada	7	1,500	8.49 ± 0.36	0.446 ± 0.020
	8	1,000	8.40 ± 0.22	0.441 ± 0.009
	16	1,500	8.34 ± 0.12	0.442 ± 0.005
	6	1,200	8.21 ± 0.18	0.429 ± 0.012
Means	37		8.36 ± 0.03	0.440 ± 0.002
Northern Japan Sea	11	2,500	8.16 ± 0.08	0.433 ± 0.007
	5	3,000	8.20 ± 0.22	0.435 ± 0.014
Means	16		8.17 ± 0.01	0.434 ± 0.001
Regional means	72		8.30 ± 0.02	0.437 ± 0.001
North Pacific	13	6,070	7.88 ± 0.11	0.417 ± 0.005
	10	4,070	7.90 ± 0.09	0.417 ± 0.003
	13	5,780	7.88 ± 0.08	0.413 ± 0.004
	8	1,500	7.89 ± 0.09	0.415 ± 0.005
	13	4,900	7.99 ± 0.10	0.418 ± 0.005
	10	3,030	8.06 ± 0.11	0.421 ± 0.006
	10	3,300	8.00 ± 0.10	0.418 ± 0.005
	9	3,080	7.97 ± 0.15	0.416 ± 0.007
	10	3,020	8.04 ± 0.20	0.424 ± 0.010
	10	2,900	7.86 ± 0.24	0.416 ± 0.010
	10	2,850	7.89 ± 0.19	0.419 ± 0.006
Regional means	116		7.94 ± 0.07	0.418 ± 0.001
Total means	188		8.08 ± 0.02	0.425 ± 0.001

* 95 % confidence limit, without consideration of analytical errors.

Table 6. Comparisons of Sr concentrations and Sr/Cl ratios of original and filtered sea water.

Region	Sample Nos.	Maximum depth (m)	Sr (mg/kg) Means ± 90 % C.L.*		Sr/Cl (mg/kg/‰) Means ± 95% C.L.*	
			Original	Filtered	Original	Filtered
Kashimanada	6	1,200	8.21 ± 0.18	8.03 ± 0.29	0.429 ± 0.012	0.421 ± 0.016
	5	400	7.96 ± 0.34	8.04 ± 0.29	0.417 ± 0.019	0.422 ± 0.012
Kashimanada coast	11	0	7.81 ± 0.27	7.90 ± 0.25	0.423 ± 0.014	0.428 ± 0.011
North Pacific	29	0	7.84 ± 0.08	7.84 ± 0.09	0.418 ± 0.004	0.418 ± 0.003
	13	6,070	7.88 ± 0.11	7.91 ± 0.14	0.417 ± 0.005	0.418 ± 0.007
	4	200	7.54 ± 0.68	7.54 ± 0.37	0.410 ± 0.040	0.410 ± 0.030
	10	4,070	7.90 ± 0.09	7.90 ± 0.16	0.417 ± 0.003	0.417 ± 0.006
	4	300	7.82 ± 0.08	7.85 ± 0.13	0.413 ± 0.005	0.413 ± 0.010
	13	5,780	7.88 ± 0.08	7.92 ± 0.11	0.413 ± 0.004	0.415 ± 0.005
	8	1,500	7.89 ± 0.09	7.91 ± 0.16	0.415 ± 0.005	0.416 ± 0.007
	13	4,900	7.99 ± 0.10	8.00 ± 0.08	0.418 ± 0.005	0.416 ± 0.005
	10	3,030	8.06 ± 0.11	8.01 ± 0.06	0.421 ± 0.006	0.419 ± 0.003
	10	3,300	8.00 ± 0.10	8.02 ± 0.10	0.418 ± 0.005	0.419 ± 0.006
	9	3,080	7.97 ± 0.12	7.98 ± 0.07	0.416 ± 0.007	0.416 ± 0.003
	10	3,020	8.04 ± 0.20	8.03 ± 0.18	0.424 ± 0.010	0.423 ± 0.009
	10	2,900	7.86 ± 0.24	7.88 ± 0.20	0.416 ± 0.010	0.417 ± 0.007
	10	2,850	7.89 ± 0.19	7.86 ± 0.17	0.419 ± 0.006	0.418 ± 0.006

* 95 % confidence limit, without consideration of analytical errors.

gional means. Among the means of the adjacent seas of Japan, maximum difference beyond 95 % confidence limits from the regional means is approximately 2 %. Concerning the vertical mean Sr/Cl ratios, statistically significant difference between the adjacent seas of Japan and the North Pacific is less than 4 %. Among samples of the adjacent seas of Japan, only one sample of 72 showed variation beyond 95 % confidence limits from the vertical means of the station, and the variation is only 0.2 %. On the other hand, 14 out of 116 samples from 11 stations in the North Pacific showed statistically significant variations from the vertical means of the stations and the maximum value of the variation is less than 5 %.

Generally speaking, contrary to the reports by MACKENZIE (1964), ANGINO *et al.* (1966), ANDERSEN and HUME (1968) and ROBERTSON *et al.* (1968), no significant vertical variations of Sr/Cl ratio beyond analytical errors from vertical means of the stations were indicated, except 5 samples from the North Pacific. And also no regional variations of vertical mean Sr/Cl ratio are indicated.

The total mean values of Sr concentration and Sr/Cl ratio of waters collected from various regions and depths are 8.08 mg/kg and 0.425 mg/kg/‰, with 0.02 mg/kg and 0.001 mg/kg/‰ of 95 % confidence limits.

Comparisons of unfiltered and filtered sea water samples, as shown in Table 6, showed no statistically significant differences with respect to mean Sr concentrations and mean Sr/Cl ratios. 12 out of 40 surface water samples showed differences beyond 95 % confidence limits of Sr concentration and Sr/Cl ratio between original and filtered sea water, but maximum difference is less than 4 %. Also, numbers of samples collected from various regions and depths showed statistically significant differences between filtered and unfiltered sea water, but the differences beyond 95 % confidence limits are less than 4 %.

Therefore, considering the analytical errors, the significant differences of Sr concentration and Sr/Cl ratio, due to the sea water filtration seem to be not indicated.

5. Conclusion

By measurements of Sr concentrations of the sea waters collected from various depths of the adjacent seas of Japan and of the North Pacific, it was indicated that no remarkable variations, horizontal and vertical, of Sr/Cl ratio are found in these regions. The statistically significant

variations, if any, seem to be smaller than 5 %, and considering the analytical errors it could be said that the significant variations are not indicated practically. More precise determination of Sr contents of sea water is required to know the exact values of the variation.

The mean Sr concentration is 8.08 ± 0.02 mg/kg and the mean Sr/Cl ratio is 0.425 ± 0.001 mg/kg/‰.

And it was indicated that practically no particulate strontium, greater than 0.22 μ in diameter, existed in the sea water.

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北太平洋および日本近海海水中のストロンチウム濃度と Sr/Cl 比について

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要旨　北太平洋および日本近海海水中のストロンチウム濃度を原子吸光光度法によって測定し，Sr/Cl 比を算出した．

ストロンチウムの平均濃度は 8.08 mg/kg，平均 Sr/Cl 比は 0.425 mg/kg/‰ であった．

Sr/Cl 比の海域別，深度別変動は 5％ 以下であって，分析誤差を考慮すれば Sr/Cl 比はほとんど一定である．また，ミリポアフイルター（0.22 μ）によって分離される粒子状 Sr は存在しないと考えられる．

これ等の結果は大西洋についての最近の報告とは一致しない．