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Notes on the Strontium Content of Séa Water, Celestite Radiolaria, and Strontianite Snail Shells[1]

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I. The strontium value of sea water has been in doubt because of the wide range in reported values. The values of strontium in mg/l for a salinity of 35 parts/mille as reported by different workers with different methods are as follows: Desgrez and Meunier (*1*), 8.7; Thomas and Thompson (*2*), 13.2; Ramage (*3*), 40.–50.; Noll (*4*), 7.0–7.9; Miyake (*5*), 14.4; Vinogradov (*6*), 8.0; and Vinogradov (*7*), 10.0.

In the present study 235 determinations of Sr/Ca ratio have been made on 160 samples from diverse parts of the Atlantic, including samples in all seasons from Long Island Sound, deep samples from the middle Atlantic and opposite Gibraltar, and samples from the Gulf Stream.[2] Arc and flame spectrophotometric methods were used on single and double oxalate precipitations. The preferred value of atomic Sr/Ca ratio from these analyses is 9.23 atoms/1,000 atoms Ca, which corresponds to 8.10 mg/l strontium in salinity of 35 parts/mille.

TABLE 1

ANALYSIS OF *Acanthometra*
(Percentage of ash)

	Ca and Sr	SO_4	R_2O_3	SiO_2	Sr*	Ca*	Loss
	17.3	—	1.3	6.0	—	—	—
	18.5	—	—	6.4†	—	—	—
	16.5	—	.5	27.8†	—	—	—
	25.1	—	1.5	13.6	—	—	—
	—	38.7	—	5.8	—	—	—
	—	41.2	—	.4	—	—	—
	—	> 31.	—	1.2	—	—	—
	—	—	—	—	28.1	.8	—
Mean:	19.4	36.9	1.1	8.7	—	—	33.9
Gravimetric analyses by Scheviakov (*17*):							
	22.5	—	17.6	21.6	—	—	29.6

* Spectrophotometric analysis.
† Silica determined with HF.

These analyses, when treated by analysis of variance, indicate that strontium is a conservative element varying with salinity. The total variation of the Sr/Ca ratio after analytical error has been removed is less than 8.4% for 95% of a group of analyses. The means of Ca/Cl and Mg/Cl ratios quoted by Thomson and Wright (*8*) have about the same variation, with 4.15% and 6.9% deviation at the 5% probability level. Thus a trace element such as strontium is not necessarily nonconservative in the ocean.

The analyses of this study roughly confirm the strontium values reported by Desgrez and Meunier, Noll, and Vinogradov as being close to the correct value. Since Miyake's method was a gravimetric separation method and therefore less reliable (*9*), and since Thomas and Thompson have never published any details or data, the overwhelming weight of all evidence places the strontium content of sea water at about 8.1 mg/l. This is considerably lower than the value of 13 mg/l being used in some reference books (*10–12*).

II. Although celestite was suggested by Müller (*13*) in 1858 as the substance of crystals found in *Collosphaera*, a radiolarian, Bütschli's (*14*) investigations in 1906 first demonstrated the celestite nature of the skeletons of radiolaria in the suborder Acantharia. Although this finding was supported by further evidence (Popofsky [*15*], Schmidt [*16*]), that the skeleton was celestite was never completely certain because the chemical analyses made of *Acanthometra pellucidum* by Scheviakov (*17*) were held to indicate that the skeleton was composed of calcium aluminum silicate. The issue is clearly stated by Hutchinson (*18*).

In the present study a plankton sample of *A. pellucidum* (sp. ?) from the Atlantic[3] was analyzed gravimetrically, spectrophotometrically, and with x-ray powder pattern methods.[4] The diffraction pattern was identical with that of celestite. The results of the chemical analyses are shown in Table 1, with the analyses reported by Scheviakov (*17*). The results are very rough because of the small amounts of material that were available for manipulations. They support the conclusion from the x-ray patterns that the main mineralogical crystal form present is celestite. What Scheviakov's figures mean is still uncertain. Also obscure is the physiology of the deposition of celestite.

Incidentally, a curious error has crept into some standard references (*10–12*). The radiolaria were described as having a skeleton of strontium *carbonate*, although apparently no original worker has really maintained this.

III. In the course of experiments in which snails (*Physa*) were raised in culture bottles with varying strontium concentrations, snails were raised with shells of more than half strontianite. The Sr/Ca ratio in the shells was about one third the Sr/Ca ratio in the aquatic culture medium. The visible appearance was similar to that of normal aragonite shells.

[1] From a dissertation on The Biogeochemistry of Strontium, presented to the faculty of Yale University in partial fulfillment of requirements for the Ph.D. degree. The stimulating direction of G. E. Hutchinson is gratefully acknowledged.

[2] Collected by Bingham Oceanographic Laboratory and Woods Hole Oceanographic Laboratory and made available by G. A. Riley, E. F. Thompson, and Dean Bumpus.

[3] Collected by the Bingham Oceanographic Laboratory. Species identification is not completely certain.

[4] Grateful appreciation is expressed to Horace Winchell, of the Brush Mineralogical Laboratory, Yale University, for use of x-ray facilities, and to James Clark for the first determination.

X-ray diffraction demonstrated that the shells with high strontium contained tiny crystals of both aragonite and strontianite, instead of an isomorphous intermediate of a substitution series. A diffraction pattern of an artificially mixed powder of strontianite and aragonite was nearly identical with the diffraction pattern of the shells. There were lines of both crystal species present.

The inducement of high strontium in the calcareous skeletons of organisms described above is not without precedent. Papillon (*19*), König (*20*), Stoeltzner (*21*), and Kinney and McCollum (*22*) produced up to 10% strontium content in bones of rats fed on high strontium. Wheeler (*23*) produced eggshells high in strontium by feeding chickens high strontium food. Robison and Rosenheim (*24*) produced deposition of bone salts in bone tissue culture experiments by introducing a medium high in strontium.

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