Strontium-90 Fallout: Comparison of Rates over Ocean and Land

Abstract. *Measurements of strontium-90 in waters residing on the Bahama Banks for periods between 12 and 180 days suggest that fallout rates onto these waters are substantially the same as the average rates at all fallout collection stations between 20° and 30° north latitude. If the amount of preciptation on the Bahama Banks is reasonably representative of the oceanic areas in this latitude band, our results support the conclusion that the amount of strontium-90 deposited per unit area of ocean surface is within a factor of 2 of that on land.*

Bowen and Sugihara have suggested that the rate of fallout of Cs^{137} and Sr^{90} upon the oceans is several times greater than upon adjacent land masses (*1*). They based this conclusion on comparisons between integrated fallout for land stations (rain or soil sampling, or both) with that for oceanic areas (vertical profiles for sea water). Whereas the estimates for land have been independently verified in several ways (*2*), those for sea water are subject to considerable controversy (*3*). The problem is as follows: the amount of Sr^{90} and Cs^{137} contained within the first 300 meters of sea water broadly agrees with the amount on land. The results of Bowen and Sugihara (*1*) generally show concentrations averaging on the order of 15 to 30 percent of the surface value for the next 2000 meters. When added to the contribution of the upper 300 meters, total inventories two to four times the land values are obtained. Rocco and Broecker (*3*), on the other hand, while in agreement regarding the upper 200 meters, claim that negligible fallout has penetrated below this level. Thus integrations of their data agree satisfactorily with land fallout data. Knowledge of the true amount of ocean fallout is necessary for accurate computations of worldwide inventories of Sr^{90} disseminated by atmospheric nuclear weapon tests. Global deposition of this nuclide on the earth's surface has been inferred from data from networks of sampling stations on land. Generally these data, either corrected (*4*) or uncorrected (*2*) for theoretical mean precipitation values within 10° latitude bands, are extrapolated by area over the oceanic bodies. Because about two-thirds of the earth's surface is water, the accuracy of the assumption that fallout onto the oceans is the same per unit area as on land is of great importance.

Volchok (*5*) has recently computed the total oceanic fallout by substracting the increment of land fallout from the total stratospheric release (as estimated from direct stratospheric measurements); he concludes that oceanic fallout per unit area averages 50 percent higher than land fallout.

This paper summarizes an attempt to make a direct comparison of the Sr^{90} increment to an oceanic area with that for land stations in a manner free from the uncertainties introduced by vertical integrations over the entire water column and of corrections for horizontal transport. The large shallow water banks of the Bahamas present a unique situation. They are large enough (about 100 miles or 160 km across) to be nearly free from the influence of the fringing islands, they are uniformly shallow (about 4 m) so that vertical summation presents no problem, and their waters mix with the open ocean so infrequently that they integrate fallout for periods up to 6 months.

A series of samples were collected from different locations on one of these banks (Great Bahama) in June 1963. The locations are shown in Fig. 1. As shown in a separate publication (*6*) the mean residence times on the bank for the water molecules making up each of these samples was estimated

Table 1. Strontium-90 fallout on the Great Bahama Banks compared with the average for the latitude band 20° to 30°N.

Sample No.	Residence time * (days)	Sr^{90} (dpm/100 liter)		Sr^{90} (mc/mi^2)	
		Observed	Corrected	Bahama Banks	Av. of all sites
63-12	12	53	21	1.0	1.0
63-5	48	98	66	3.1	4.6
63-20	73	114	82	3.9	7.0
63-19	96	212	180	8.5	8.8
63-16	133	182	150	7.1	10.8
63-17	142	309	277	13.1	11.2
63-18	180	215	183	8.7	12.3

* Collections were made between 4 and 9 June 1963.

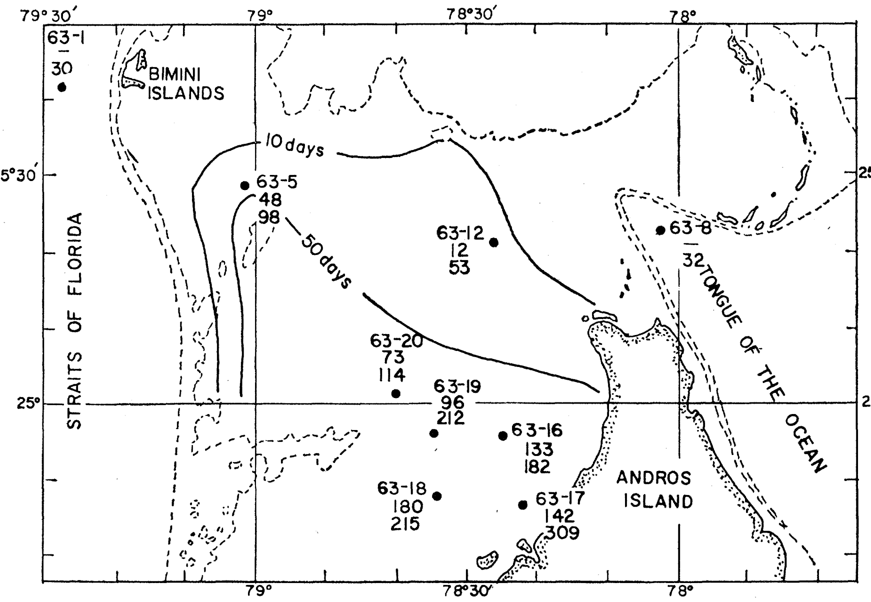

Fig. 1. Map of Great Bahama Bank (northwestern part) showing location of samples, residence times (in days), and observed Sr^{90} concentrations (in disintegrations per minute per 100 liters).

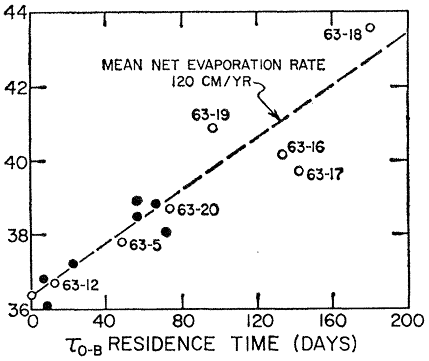

Fig. 2. Salinity versus residence time based on the results of Broecker and Takahashi (*6*). The samples marked with open circles are those for which Sr^{90} measurements were made.

from their bomb C^{14} content. The method is briefly summarized as follows: Waters flowing onto the bank from the adjacent open ocean contain only 10 percent as much bomb C^{14} as the atmosphere over the bank. Once the water is isolated on the shallow bank and hence is not subject to the rapid depletion of newly added bomb C^{14} through deep mixing, the C^{14}/C^{12} ratio grows toward equilibrium with that in the atmosphere. The rate of growth depends on: (i) the water depth (uniformly 4 m), (ii) the total dissolved inorganic carbon content of the water (uniformly 2.0 ± 0.2 mole/m^3), and (iii) the exchange rate of CO_2 between the atmosphere and ocean surface (8 ± 4 mole/m^2 yr) (*6*). Estimates of residence time made in this manner are summarized in the second column of Table 1. The uncertainty of 50 percent is due entirely to the permissible range of exchange rates. The range of residence times for the samples in this study was found to be 12 to 180 days.

Measurements of Sr^{90} were made by techniques given by Rocco and Broecker (*3*). Because the results average many tens of times higher than blank, uncertainties due to contamination are negligible. The amount of Sr^{90} accumulated by the sample was obtained by subtracting the value measured in adjacent surface ocean water (32 disintegrations per minute per 100 liters) from that observed in the sample. This was in turn converted to a deposition value per unit area by correcting for the mean water depth. These results, summarized in Table 1, show generally that the samples which had resided on the bank for longer times accumulated more Sr^{90} than the more recent ones, although a completely consistent increase in Sr^{90} content with time was not found. This has been attributed to short-term geographical differences in rainfall, which is not unlikely since the sampling stations were separated by tens of kilometers. This effect of local rainfall has been qualitatively corroborated by studying the salinities of the samples. As shown in Fig. 2, salinity increases with residence time on the bank; it corresponds to about 120 cm/yr net evaporation (indicated by the dashed line). The individual sample points, however, do scatter; in most cases they are sympathetically opposed to the Sr^{90} results. That is, unusually low salinity (for example, note sample 63-17) suggests a recent rain which would also result in an unusually high fallout value.

Conversely, of course, those salinity values which fall substantially above the average (sample 63-18) indicate periods of unusually high evaporation, and probably little if any recent precipitation in the immediate area of the sample. Lower Sr^{90} accumulation would, therefore, be anticipated in these cases. This effect is also qualitatively borne out in Table 1.

To compare the results with concurrent land fallout values, the average Sr^{90} deposition from all land sites in the AEC Health and Safety Laboratory's fallout network in the 20° to 30° north latitude band (*2*) was graphically integrated for the time periods corresponding to the residence times of the Bahama Banks samples. These data, also shown in Table 1, indicate substantial agreement.

Our results indicate that the waters of the Bahama Banks accumulate Sr^{90} fallout at a rate within a factor of 2 of that for the land masses between 20° and 30° north latitude. This conclusion is not in agreement with Bowen and Sugihara's (*1*) claim that fallout over the oceans is on the average several times higher than that over the continents.

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References and Notes

1. V. T. Bowen and T. T. Sugihara, *Nature* **186**, 71 (1960).
2. H. L. Volchok, "Fallout Program Quart. Sum. Rep." *U.S. At. Energy Comm. Health Safety Lab. Rep. HASL 161* (1965).
3. G. G. Rocco and W. S. Broecker, *J. Geophys. Res.* **68**, 4501 (1963).
4. L. Machta, R. J. List, K. Telegadas, statement to the Joint Committee on Atomic Energy, U.S. Congress, 19 June 1963; R. S. Cambray, E. M. R. Fisher, G. S. Spicer, C. G. Wallace, T. J. Webber, *U.K. At. Energy Authority At. Energy, Res. Establ. Rep. AERE R4787* (1964).
5. H. L. Volchok, "Fallout Program Quart. Rep. *U.S. At. Energy Comm. Health Safety Lab. Rep. HASL 164* (1965).
6. W. S. Broecker and T. Takahashi, *J. Geophys. Res.* **71**, 1575 (1966).
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Magnesium Ions: Activity in Seawater

Abstract. *The activity of magnesium ions in seawater was determined from solubility data and found to be between the values determined by Platford and by Garrels and Thompson. Our value may result from extensive formation of magnesium sulfate ion pairs.*

We estimated the activity of magnesium ions in seawater by a simple procedure suggested by R. M. Garrels. The result may be compared with the value based on the work of Garrels and Thompson (*1*) and with the value obtained by Platford (*2*).

The activity of magnesium ions in seawater may be expressed in two ways. We used the conventional equation:

$$a_{Mg} = f_{Mg} \times (Mg^{+2}) \qquad (1)$$

where f_{Mg} is the activity coefficient and (Mg^{+2}) is the stoichiometric concentration. The activity coefficient f_{Mg} reflects nonspecific effects of ionic strength and specific interactions of magnesium with other ions or molecules present in seawater.

An alternative equation, implicit in the treatment of Garrels and Thompson, is

$$a_{Mg} = (f_{Mg})_u \times (Mg^{+2})_u \qquad (2)$$

where the subscript u refers to uncomplexed magnesium. Equation 2 is equivalent to Eq. 1 if the specific and nonspecific effects are separable. From single-salt solutions, Garrels and Thompson obtained activity coefficients that