Shallow-water Strontium-90 Anomaly about the Antilles Arc–1970[1]

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ABSTRACT

Vertical profiles about the southeastern approaches to the Caribbean in early 1970 have shown a consistent Sr-90 inversion, with the maximum concentrations at depths of about 100 m. It appears that four water masses may be involved, in this area, in a very complicated mixing and overlayering phenomenon.

Introduction. During February, March, and April 1970, RV ATLANTIS II of the Woods Hole Oceanographic Institution was engaged in a detailed study of the hydrography of the southeastern approaches to the Caribbean Sea; the hydrographic data and station locations used in this study have been reported (Metcalf et al. 1971). At a number of these stations, vertical series of large-volume water samples were collected (Bodman et al. 1961) to be analyzed for longer-lived radionuclides delivered as fallout. The oceanographic interpretation of such data has been extensively described (Bowen and Sugihara 1965, Bowen et al. 1968, 1969, Volchok et al. 1971).

Although the radionuclide analyses of many samples are uncompleted, enough data are now available to show that the strontium-90 concentrations at these stations cast some unexpected light on the shallow-water circulation in this area. We believe that the distributions observed are interesting enough to justify this interim report; we cannot hope that analyses of all the samples will be completed before the end of 1972.

Sampling and Analysis. Two types of stations are reported here: "Standard stations" and "Near-surface stations". At the standard stations, samples were collected essentially as described by Bodman et al. (1961); the ten such stations

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discussed were located as follows: two north of the Antilles Arc, three west of the islands, and five in the major southeastern passages between the islands. Samples were collected at nominal depths of 0, 50, 100, 200, 300, 400, 500, 600, and 700 m, but not each of these depths was sampled at every station; deeper samples were taken, but they will not be discussed here.

The near-surface stations were prompted by a report on statistically significant variations in stable strontium concentration in the upper 50 cm of the oceanic water column (Burrell and Goering 1968). Here we present analyses of samples taken at intervals between the surface and 49 cm at three such stations on this cruise. These samples were collected by means of a series of orifices (mounted on a float) connected by 1.2-cm ID polyvinyl hoses to a manifold system (on deck) so that two high-capacity pumps (Jabsco B6–M6) could pump in parallel; about 20 minutes of pumping per 60-l sample were required. Observation indicated that the orifice depths varied by less than about $\pm$ 3 cm, even under fairly rough sea conditions. A full description of this device is being prepared for publication.

The analyses reported here were done, under contract, by three different commercial radiochemical firms; the quality control will be discussed in the complete report. Volchok (1968) and Bowen (1970) have presented Sr-90 intercomparison data showing the good performance of several radiochemical firms, including those firms that did analyses for the present study.

Table I presents the data now at hand showing the Sr-90 concentrations at the two sets of stations. Complete tabulations of the hydrographic data for each of the standard stations have been presented by Metcalf et al. (1971). The salinity data for the large-volume samples and for the near-surface stations are presented in Table II; in Table III are presented the oxygen data for the large-volume sample depths, from Metcalf et al. (1971). In Table III, the values shown in parentheses were obtained by interpolation from adjacent depths, where the large-volume depths were not represented in the hydrographic casts. Comparison of the data in Table II with the salinities of the complete hydrographic casts confirms that the Bodman et al. samplers performed well at each of these stations.

Discussion. At the standard stations, whenever the necessary data were available, we observed a distinct maximum of Sr-90 concentration at about 100 m below the surface. Only at St. 1714, far north of the Caribbean, did the subequal concentrations of Sr-90 at 2, 50, and 300 m appear to be inconsistent with that pattern.

Reference to earlier reports on Sr-90 distributions shows how unusual this pattern is: it is usual to observe the maximum concentration of Sr-90 at the surface, extending without change through a "mixed-layer" and then diminishing below that; Broecker (1966) and Volchok et al. (1971) have suggested that the "mixed-layer" depth varies in different oceans and in different lati-

Table I. Strontium-90 concentrations about the approaches to the Caribbean, 1970. dpm per 100 l (dpm = disintegrations per minute).

Standard Stations	1714	1559	1713	1652	1696	1691	1683	1588	1589	1673
Lat. N.	27°00′	20°00′	16°59′	15°51′	15°14′	14°17′	13°25′	12°74′	12°37′	11°31′
Long. W.	73°00′	64°22′	64°00′	61°00′	61°06.5′	60°55′	61°01′	62°29′	64°22′	61°57′
Date, 1970	26-IV	9-II	20-IV	26-II	6/7-II	4-IV	22-III	18-II	19-II	18-III
Location	N. of Haiti	N. of Puerto Rico	Off. St. Croix	E. of Marie Galante Channel	Dominica Channel	St. Lucia Channel	St. Vincent Channel	W. of Antilles	W. of Antilles	Grenada-Trinidad Passage
Depths (m)										
2	27 ± 1	20 ± 1	16 ± 1.5	12 ± 0.5	13 ± 0.5	11 ± 0.	15 ± 1		13 ± 1.7	12 ± 0.5
50	31 ± 3	21 ± 1.5				11 ± 1.7		18.5 ± 1.5		22.5 ± 0.8
100		26 ± 1.5	25 ± 2	17 ± 1	21 ± 1		21 ± 1		21 ± 0.5	26 ± 0.8
200										
300	29 ± 1.5	25 ± 1				6 ± 0.5		6 ± 0.5		
400				2 ± 0.5						
500		7.5 ± 0.5		< 0.5			2 ± 0.5			
600										
700					< 0.5	< 0.6				

Near-surface Stations	1	2	3
Lat. N.	14°27′	13°43.3′	17°44′
Long. W.	60°55.5′	60°59′	64°56.7′
Date, 1970	2-III	11-IV	21-IV
Location	Havre de la Trinité-Martinique	St. Vincent Channel	S. of St. Thomas
Depths (cm)			
3		9 ± 0.5	20 ± 2.
12.5		9 ± 0.5	
14	11.5 ± 1	10.5 ± 1	15 ± 0.5
20			16 ± 0.5
29.5		12 ± 1	18.5 ± 1.5
49		15 ± 1.5	

Table II. Salinity data for the samples referred to in Table I.

Standard Stations	1714	1559	1713	1652	1696	1691	1683	1588	1589	1673
Lat. N.	27°00′	20°00′	16°59′	15°51′	15°14′	14°17′	13°25′	12°74′	12°37′	11°31′
Long. W.	73°00′	64°22′	64°00′	61°00′	61°06.5′	60°55′	61°01′	62°29′	64°22′	61°57′
Date, 1970	26-IV	9-II	20-IV	26-II	6/7-IV	4-IV	22-III	18-II	19-II	18-III
Locations	N. of Haiti	N. of Puerto Rico	Off St. Croix	E. of Marie Galante Channel	Dominica Channel	St. Lucia Channel	St. Vincent Channel	W. of Antilles	W. of Antilles	Grenada-Trinidad Passage
Depths (m)										
2	36.634	36.178	36.162	35.973	35.019	35.554	34.390	35.986	34.886	35.617
50	36.697	36.199	36.174	36.052	36.600	35.587	35.872	36.057	36.101	36.757
100	36.709	37.083	36.869	36.539	36.978	36.819	36.096	36.760	36.758	36.689
200	36.648	36.801	36.563	36.433	36.436	36.502	36.101	36.015	35.988	35.569
300	36.561	36.434	35.894	35.734	36.008	35.460	35.265	35.196	35.579	35.457
400	36.508	36.139	—	35.396	35.442	—	35.088	34.904	35.014	34.935
500	36.411	35.822	35.069	34.969	35.153	35.078	35.003	34.781	34.879	34.810
600	36.229	35.493	—	34.766	34.884	34.772	34.770	34.723	34.775	—
700	35.881	35.180	—	34.678	34.747	34.697	34.721	34.730	34.717	—

Near-surface Stations	3
Lat. N.	17°44′Y
Long. W.	64°56.7′
Date, 1970	21-IV
Location	S. of St. Thomas
Depths (cm)	
3.	36.167
12.5	36.164
14	36.155
20	36.156
29.5	36.158
49	36.159

Table III. Oxygen data* for the samples referred to in Table I.

Standard Stations	1714	1559	1713	1652	1696	1691	1683	1588	1589	1673
Lat. N.	27°00′	22°00′	16°59′	15°51′	15°14′	14°17′	13°25′	12°74′	12°37′	11°31′
Long. W.	73°00′	64°22′	64°00′	61°00′	61°06.5′	61°55′	61°01′	62°29′	64°22′	61°57′
Date, 1970	26-IV	9-II	20-IV	26-II	6/7-IV	4-IV	22-III	18-II	19:II	18-III
Locations	N. of Haiti	N. of Puerto Rico	Off St. Croix	E. of Marie Galante Channel	Dominica Channel	St. Lucia Channel	St. Vincent Channel	W. of Antilles	W. of Antilles	Grenada-Trinidad Passage
Depths (m)										
2	5.02	4.90	5.32	4.56	4.74	4.76	4.54	4.70	4.68	5.09
50	5.45	4.84	5.02	(4.50)	4.68	4.66	4.84	4.75	4.53	(4.30)
100	5.10	4.48	4.19	4.11	4.17	(4.25)	4.46	3.39	3.59	3.63
200	4.86	4.33	3.50	3.34	3.75	3.83	3.41	3.34	3.32	3.27
300	4.81	4.55	—	2.84	3.68	(3.30)	3.70	3.00	2.96	3.02
400	4.77	4.06	—	2.67	3.08	(2.98)	3.43	2.88	3.04	2.93
500	(4.52)	3.91	—	2.76	2.85	(2.85)	3.08	2.89	2.82	3.08
600	4.28	3.48	—	2.91	2.81	(2.83)	3.30	2.95	2.87	—
700	(3.97)	3.04	—	2.99	3.39	(2.90)	3.32	3.22	3.07	—

* From hydrocasts; values in parentheses are interpolated from adjacent depths.

tudinal bands—certainly seasonally as well, as would be expected from hydrographic considerations.

Even more unexpected is the concentration profile shown at near-surface St. 2: a systematic increase in Sr-90 from 12.5 cm to 49 cm, with a "mixed-layer" of uniform Sr-90 concentration that was no more than 14 cm thick! Also note the excellent agreement between the 49-cm concentration at St. 2 and the 2-m concentration at St. 1683, both in the St. Vincent Passage (15 ± 1.5 dpm versus 15 ± 1 dpm Sr-90/100 l, respectively); this agreement lends confidence to the conclusion that the Sr-90 observed in the 49-cm to 2-m samples characterizes an extensive layer. Clearly, the data now available from near-surface St. 3, only a little south of St. Thomas, indicate that a different water mass was represented there at 49 cm: in fact, this could easily have been the same surface water as that sampled at St. 1559, north of the Antilles. In respect to the Sr-90 concentrations, only St. 1714 appears not to be obviously related to any of the other stations in Table I.

Thus, it appears that at least four shallow-water layers of different Sr-90 concentration are represented at these stations (disregarding St. 1714). Giving each a letter designation, for convenience in further discussion, they may be described as follows:

(Layer A) A very shallow mass, at the surface, characterized by an Sr-90 of 9 to 10 dpm/100 l.

(Layer B) At depths of 0.5 m to 50 m at most, a shallow near-surface Sr-90 layer of 12 to 15 dpm/100 l.

(Layer C) In the southeastern passages, at about 100 m, a layer of high salinity (36.75–36.98‰), low oxygen (< 4.2 ml O_2/l), and very uniform Sr-90 (21 dpm/100 l); St. 1652 shows that this layer may tend to lie deeper west of the Antilles.

(Layer D) Both north and south of St. Thomas (Sts. 1559, 1713), at about 100 m, a layer very similar to layer C with respect to salinity and oxygen but with an Sr-90 of 25 to 26 dpm/100 l.

Confirming the exclusion of St. 1714 from this discussion, we note that no water with as high salinity or as low oxygen as layers C or D was represented at St. 1714; nor, so far as we know, was there any water with as low Sr-90 as layers A or B at St. 1714.

The shallow water in the area sampled consists of a mixture of North Equatorial Current and South Equatorial Current waters. The North Equatorial Current is routinely sampled by local fishing vessels off the Cape Verde Islands as part of our program of study of Atlantic Ocean surface-water fallout concentrations (Bowen et al. 1968); the Sr-90 in five samples taken in 1969 and in the first quarter of 1970 ranged from 12.3 to 17 dpm/100 l, the mean being 14 dpm. The South Equatorial Current is frequently sampled (as a part of the

same program) by Farrell Lines freighters as they cross the equator; in May 1970, the Sr-90 content was 10.5 ± 0.7 dpm/100 l. These Sr-90 concentrations, then, are consistent with the hypothesis that layer A is water of the South Equatorial Current, lying as a very thin lamina over the thicker layer B that consists of water of the North Equatorial Current.

Unfortunately, we do not have such useful comparative information about Sr-90 in layers C or D (at 100-m depths). In June 1969 we observed salinities of 36.75 to 36.98‰ (the range that characterizes both C and D) at the surface at both 31°38'N, 15°28'W and 34°51'N, 20°42'W; in each case, however, the Sr-90 concentration was much higher than that of either C or D: 33 to 34 dpm/100 l. We also observed this Sr-90 concentration in surface and subsurface water having a salinity greater than 36.7‰ in November-December 1969 in the Sargasso Sea between 25°14'N, 67°38'W and 27°47'N, 67°35'W. In January 1968, at 13°44'N, 50°53'W, at 100 m, water with a salinity of 36.932‰ showed an Sr-90 content of 26 ± 1.7 dpm/100 l, but it is difficult to relate this observation to the 1970 Antillean concentrations because of the large gap in space and time.

Going even further back in time, an interesting example of the dynamic state of the high-salinity water in this area of the western Atlantic was observed at about 16°N, 59°W: in April 1967, at 100 m, we sampled water having a salinity of 36.045‰ and an Sr-90 of 16 ± 0.6 dpm/100 l; the water with a salinity of 36.8‰ at this time lay deeper than 150 m. By contrast, in January 1966, at about 55 m, we sampled water with a salinity of 36.380‰ and an Sr-90 of 29 ± 1 dpm/100 l; the hydrostation showed that the water of salinity 36.8‰ lay, then, at about 70 m. At both of these stations there was good agreement between the temperatures and salinities at the various depths sampled for the hydrostation and at the same depths when sampled, often some hours later, for the large-volume samples (Bodman et al. 1961); this we take to show that the water columns were reasonably constant in vertical structure and that neither set of observations was the result of internal waves.

Our most recent sampling within the Caribbean was in May–June 1966; at 15°58'N, 64°34'W, at 100 m, we found water with a salinity of 36.974‰ and an Sr-90 of 26 ± 1 dpm/100 l; at 18°50'N, 81°55'W, at 100 m, we found water with a salinity of 36.401‰ and an Sr-90 of 23 ± 1 dpm/100 l (at this station no water with a salinity higher than 36.75‰ was observed). Comparison of these stations with those of the IGY cruises (Fuglister 1960) seems to indicate that the area around the Antilles Arc is a zone of very active mixing in the depth range of 100 m; it is at least reasonable to argue that our layer C represents a dilution (at or close to the areas where it was sampled) of layer D with water having similar physical and chemical properties but a lower Sr-90 content. The IGY Atlas (Fuglister 1960) shows that water of salinity 36.75‰ extended as far south as 8°30'N along the 50°W N–S section; such salinity was not observed at 50°W on the 8°N E–W section but only as a narrow

tongue at about 55°W. We have not sampled this southern extension of high-salinity water for Sr-90, but the situation would favor a relatively low Sr-90 in this area. The irregularity in the occurrence of high-salinity water at about 8°N and of the depths it occupies at 16°N, 59°W could indicate that the southern tongue (hypothetically, of low Sr-90) may periodically retreat northward, to mix with our layer D in the area of the southeastern approaches to the Caribbean.

We expect that, when all the samples now at hand have been analyzed, the data will provide further illumination for this interesting situation.

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