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*Concentrations of Particulate Iron in Atlantic Open-ocean Water*¹

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ABSTRACT

Measurements of particulate iron concentrations have been carried out on samples from the western Atlantic Ocean and the Caribbean Sea. Water samples were collected in 30-l Niskin bottles; iron analyses were done by atomic absorption spectroscopy. The average of 184 iron determinations on shallow open-ocean water (0-300 m) was 0.177 $\mu\text{g/l}$; the average of 112 determinations on deep water (500-7535 m) was 0.255 $\mu\text{g/l}$. These averages are lower than previous estimates by an order of magnitude or more. Spectrophotometric and atomic-absorption analyses carried out on a set of duplicate samples from the surface water of the Puerto Rican Trench indicate that the method of analysis is not the reason for the large discrepancy observed in the concentrations of particulate iron.

Introduction. The most conveniently distinguishable forms of iron in water are particulate iron and soluble iron. The amount of particulate iron and its quantitative variations from place to place are important for any appraisal of the geochemistry of iron in the oceans, of the way it reaches the sediments, and of the rates of biological and geochemical turnover. Harvey (1937) and Goldberg (1952) have concluded that diatoms preferentially use particulate iron instead of soluble iron and that these organisms may be able to use only particulate iron to satisfy their biological needs. Further, Ryther and Guillard (1959) and Menzel and Ryther (1961) have suggested that iron may be limiting in the photosynthetic process and that this may account, in part at least, for the low quantity of phytoplankton in the Sargasso Sea; however, Menzel et al. (1963) have reported conflicting results.

The purpose of this paper is to present and discuss data that were derived from samples taken in the western North Atlantic Ocean and Caribbean Sea at depths above 300 m and below 500 m. The works of some previous investigators are reviewed and compared, and our own work is discussed in the light of earlier results.

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Previous Investigations. The first quantitative determinations of particulate iron in seawater were made by Braarud and Klem (1931). Since that time a number of studies on this element in seawater have been published, and this literature reports that the concentration of particulate iron in the open ocean spans a range that is greater than 1000-fold (0.1 to 100 $\mu\text{g/l}$). In river water and other near-shore waters, where terrigenous influences are significant, the concentration may exceed 1000 $\mu\text{g/l}$ (Williams and Chan 1966, Ryther et al. 1967). Table I, presenting data from 14 previous papers and including data from this study, summarizes pertinent information on 1131 samples from the Atlantic, Pacific, Indian, and Antarctic oceans and smaller adjacent bodies of water. For the most part, Table I lists data related to the open ocean and excludes data for fjords, inlets, areas clearly influenced by river drainage, and areas within 100 km of land. Exceptions are the work of Cooper (1935, 1948), which is included because of its historical significance, the work of Corcoran and Alexander (1964), which was done near calcareous islands, and the work of Zeitlin and Lei (1965), which provided no basis for exclusion because the sampling localities were not given.

Table I clearly indicates the wide range of variation in the average values for particulate iron obtained by these investigators. If the present study is excluded from consideration, it is seen that only two investigations (by Menzel and Spaeth 1962, Joyner 1964) show average values for particulate iron that were lower than the 3.1 $\mu\text{g/l}$ value reported by Braarud and Klem (1931) for Atlantic samples taken at a depth of less than 300 m. Five investigations (by Thompson and Bremner 1935, Cooper 1935, Schaefer and Bishop 1958, Zeitlin and Lei 1965, Toyota and Okabe 1967) show average values above 10 $\mu\text{g/l}$; four of these five investigations pertain to the Pacific.

Concerning investigations of the Pacific, it is of interest to note that studies in the slope waters of the northeastern Pacific by Joyner (1964) and Williams and Chan (1966), the only investigators who have reported the use of stainless-steel wire, yielded average values (2.3 and 3.4 $\mu\text{g/l}$) that were much lower than the values (8.1 and 11.8 $\mu\text{g/l}$) reported for the open Pacific by Lewis and Goldberg (1954) and Toyota and Okabe (1967). These differences are of particular interest since greater concentrations of particulate iron might reasonably be expected in the region sampled by Joyner and by Williams and Chan as a result of terrigenous material being delivered to the coastal area by the Columbia and Fraser rivers. The results of Joyner and of Williams and Chan are also much lower than those of Thompson and Bremner (1935), although two of the Thompson and Bremner stations were only 100 km from several of Joyner's stations, and in both investigations the water at 1000 m was sampled. For open waters at 1000 m in the northern Pacific, Lewis and Goldberg (1954) reported values of 5 and 18 $\mu\text{g/l}$ for two stations that were separated by a few hundred kilometers. We find it difficult to imagine any realistic

mechanism that would cause the water at 1000 m in the northern Pacific to contain such variable concentrations of particulate iron.

The results for the Atlantic show smaller differences than those for the Pacific. The average concentrations of particulate iron reported by Braarud and Klem (1931), Menzel and Spaeth (1962), Ketchum and Ryther (1966), and Ryther et al. (1967) range from 1.8 to 4.4 $\mu\text{g/l}$. Even the results of Corcoran and Alexander (1964) for the near-shore waters in the Straits of Florida average only about 6.4 $\mu\text{g/l}$; the coralline islands of the Bahamas are adjacent to the Straits, but there is little reason to believe that coral releases much iron to these waters as they flow by. Cooper's (1935) relatively high value of 12 $\mu\text{g/l}$ seems reasonable because of the discharge of clay and other eroded materials into the English Channel.

There is a distinct difference, then, between the values reported for the Atlantic and Pacific oceans. The mean value for the Pacific is about 9.7 $\mu\text{g/l}$, while that for the Atlantic is about 2.5 $\mu\text{g/l}$, a difference that holds whether one considers only surface or deep-water values.

Our first attempts at particulate iron measurements in the Atlantic, using 30-l Niskin bottles, aluminized hydrographic wire, and a closed filtering system, gave results similar to those of other investigators. When, however, we discovered and painted over the rusty washers and bolts on the inside of the Niskin bottles, we found concentrations that were generally about one-tenth as great as those from the original determinations.

Materials and Methods. All water samples were collected with 30-l Niskin bottles during TRIDENT cruises 049 (May 19–June 10, 1968), 050 (June 13–June 18, 1968), and 055 (September 12–October 11, 1968) (see Fig. 1). A total of 296 samples was collected at 50 stations in the open Atlantic and Caribbean where river drainage has little, if any, influence on the water. At all but a few stations, six Niskin bottles were used per hydrocast, and their order on each cast was determined, prior to the cruise, by using a random-number table. Only aluminized hydrographic wire was used during these collections; the wire was new, or nearly new, at the beginning of each cruise, and there was no evidence of rust flakes being released to the water.

Although the Niskin bottles were made of polyvinylchloride, machine screws and galvanized washers had been used to secure the tripping mechanisms from within. An effort had been made by the manufacturer to cover the metal surfaces inside the Niskin bottle with PVC glue, but each bottle had several washers that remained partially exposed. To minimize sample contamination, we applied two coats of epoxy paint to these metal surfaces where they would have come in contact with salt water.

A silicone rubber tube carried the water from the plastic valve of each Niskin bottle to a polypropylene filtering head (made to order by Millipore Filter Corporation). Each filtering head consisted of two polypropylene plates

Table I. Concentrations of particulate iron in open-ocean water.

	Region sampled	Sampling depth (m)	No. of samples	Concentration ($\mu\text{g/l}$) Av. Range		Filter	Kind of hydrowire	Sampler type	Vol. coll. (l)	Anal. method††
ATLANTIC OCEAN										
Braarud and Klem (1931)	Northeast Atlantic	0-150	2	3.1	2.8-3.5	Gooch	-	-	-	C
Cooper (1935)	English Channel	Surface	6	12.0	4-25	Membrane	-	Wooden bucket (surface) Nansen	14.0 1.0	C
Cooper (1948)	English Channel	0-65	6	5.66	0-10	Membrane	-	Nansen	1.0	C
Menzel and Spaeth (1962)	Sargasso Sea	1-1400	314	1.8	0-8.8	Millipore 0.45 μ	-	Teflon-coated Nansen	1.1	S
Corcoran and Alexander (1964)	Florida Current	0-600	-	6.4	4.5-8.9	Glass fiber	-	Niskin	5.0	S
Ketchum and Ryther (1966)	Equatorial Atlantic (Sts. 431-436) ATLANTIS Cruise 14	1-400	58	3.86	0.26-20.1	Membrane 0.8 μ	-	Nansen	1.1	S
Ryther et al. (1967)	Equatorial Atlantic	Surface	1	4.42	None	Membrane 0.8 μ	-	Nansen	1.1	S
Betzer and Pilson (1970)	Western Atlantic and Caribbean	0-7535	296	0.177† 0.255*	0.027-2.56	Millipore 0.45 μ	Aluminized steel	Niskin	28	A

PACIFIC OCEAN

Thompson and Bremner (1935)	Northeast Pacific	0-2000	32	16.0	0-42	Whatman # 42	-	-	-	C
Lewis and Goldberg (1954)	North Pacific	10-3500	268	11.7† 4.5*	0-36	Millipore 0.45 μ	-	Nansen	1.2	S
Schaefer and Bishop (1958)	Bight of Panama (Pacific)	10 and 65	36	11.2	0-82	Millipore 0.45 μ	-	-	1.0	S
Joyner (1964)	Northeast Pacific	0-1800	21	2.3	0-6.2	Millipore 0.45 μ	Stainless steel	VanDorn	2.0	S
Zeitlin and Lei (1965)	Near Hawaii	Surface	-	-	27.9-192	-	-	-	-	-
Williams and Chan (1966)	Northeast Pacific (PAC 1-4)	0-120	8	3.4	1-14	Millipore 0.45 μ	Stainless steel	VanDorn	3.0	S

PACIFIC, INDIAN, AND ANTARCTIC OCEANS

Toyota and Okabe (1967)	-	0-2383	70	11.8	1.7-85	Millipore 0.45 μ	-	VanDorn	2-5	S
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† above 300 m; * below 300 m; †† C, Colorimetric; S, Spectrophotometric; A, Atomic absorption.

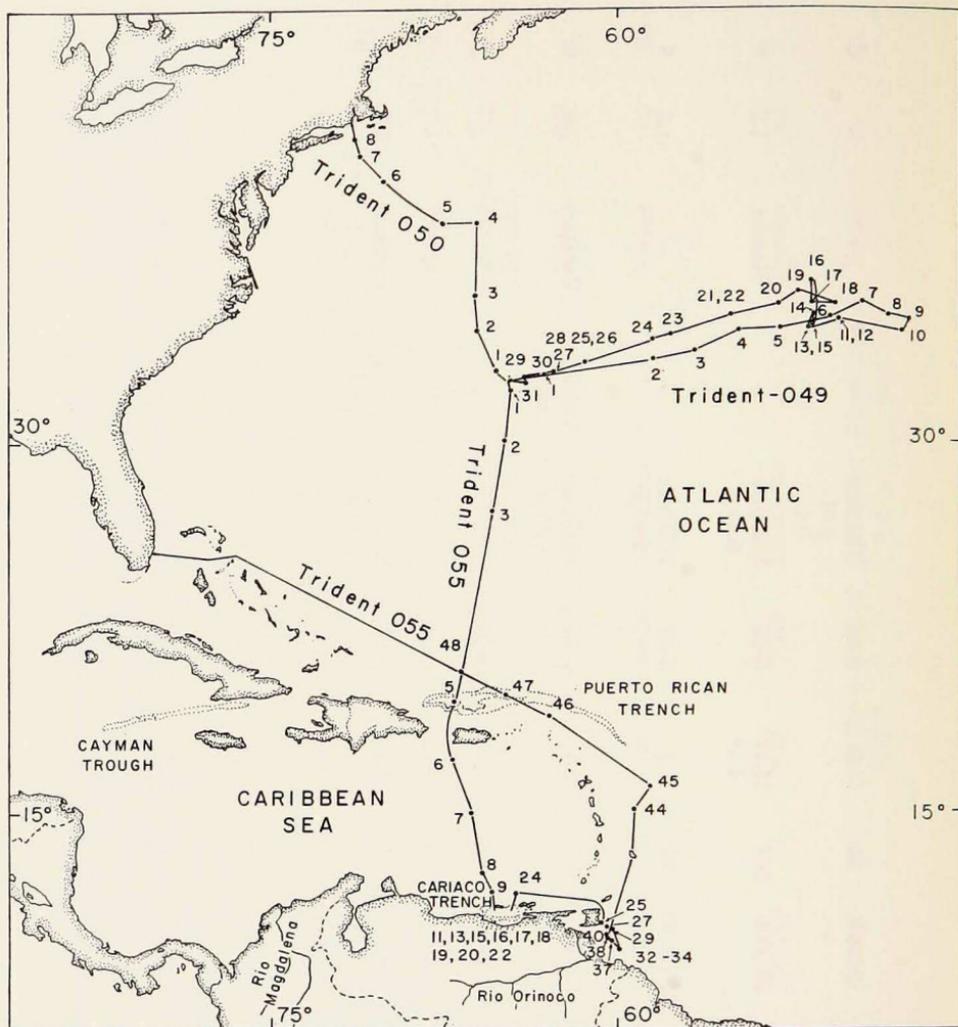


Figure 1. Cruise tracks of the R/V TRIDENT. Particulate-iron determinations on samples from all numbered stations.

with 0.63-cm-diameter inlet and outlet tubulations to which the silicone rubber tubes were attached. When the plates were tightened against each other by means of three nylon bolts along the rim of each plate, the interior of the head, which contained a filter pad (90 mm) and a space about 10 ml in volume, was airtight. Thus the entire filtering equipment constituted a closed system.

Before the water samples were filtered, aliquots were drawn from each 30-l Niskin bottle for salinity and oxygen determinations, and the silicone

rubber tube connecting each sample bottle with a filtering head was flushed with 400 ml of the sample (five times the internal volume of the tubing). Each tube was then connected to its filtering head and the water was fed by gravity through a $0.45\text{-}\mu$ 90-mm-diameter Millipore® HA filter. All six samples were filtered simultaneously. Usually, about 26 l of water were passed through each pad, and the actual volume was monitored by collecting the effluent in calibrated bottles. On cruises 049 and 050, the filtering time was about six hours. On cruise 055, due to a modification in the apparatus, the filtering time was about two hours. The difference in filtering time did not affect the iron concentrations observed in the deep and shallow samples gathered in the Sargasso Sea. After filtration, the ends of each of the silicone rubber tubes were sealed with polyethylene bags to minimize airborne contamination. These bags were kept in place until the next water samples were ready to be processed.

The filter pads were handled only with Teflon-coated tweezers. After a water sample had been filtered, the excess moisture was removed by placing a wet pad (sample side up) in a freshly drawn large Kimwipe®. The filter pad was folded and placed in a screw-cap test tube for storage until the analyses could be carried out on land.

Prior to analysis, the filter pads were placed in 250-ml Vycor beakers, concentrated nitric acid (10 ml) was pipetted into each beaker, a Teflon® watch glass was put in place, and the acid was boiled until about 1 ml of the solution remained. This solution was then transferred from the beaker to a 25-ml volumetric flask and brought to volume with deionized water. Iron analyses were carried out by atomic absorption spectroscopy, using a Perkin-Elmer model 303 with a Boling-head laminar-flow burner and an air-acetylene flame. The aqueous samples were aspirated into the flame and their signals were compared with those of iron standards (0.1, 0.25, 0.50, 1.0, and 2.0 $\mu\text{g/ml}$). The iron standards were prepared from 1.443 g of reagent-grade Fe_2O_3 that had been dissolved in concentrated HCl and diluted to one liter. All dilutions of this 1000 $\mu\text{g/ml}$ standard were carried out in 1-l volumetric flasks that had been cleaned with 6N HCl and rinsed with deionized water. Triplicate iron analyses of each set of samples (10 samples/set) and of the five standards were carried out at 5X scale expansion. Reagent blanks were determined on fresh filter pads that were prepared in the same manner as cruise samples (Table II). The average analytical uncertainty (at the 95% confidence limits) for triplicate determinations was 6% of the determined values.

To ascertain whether the digestion method used would release all the iron in strong organic combination, we added varying amounts of a hemoglobin standard (derived from doubly recrystallized bovine hemoglobin) to the Vycor beakers containing single 90-mm $0.45\text{-}\mu$ Millipore® HA filter pads. The amounts added were comparable to the amounts of iron in the samples. The nitric acid digestion and the subsequent analysis followed the same procedure

Table II. Reagent and filter-pad blanks for particulate-iron analyses.

Filter pad no.†	Iron content (μg)	Blank per liter of water filtered ($\mu\text{g/l}$)*
1	2.050	0.079
2	1.925	0.074
3	1.875	0.072
4	1.775	0.068
5	1.825	0.070
6	1.950	0.075
7	2.000	0.077
8	1.900	0.073
9	1.975	0.076

Average contribution 0.074

For comparison:

Av. shallow-water concentration of particulate iron = $0.177 \mu\text{g/l}$ Av. deep-water concentration of particulate iron = $0.255 \mu\text{g/l}$ † 90-mm-diameter 0.45- μ Millipore® HA filter pad.

* Contribution based on an average filtered volume of 26 l per sample.

as that for the samples. The average recovery was 102%; the calculated iron recoveries for five different hemoglobin concentrations were 104, 102, 102, 100, and 100%.

Cooper (1935) and Thompson and Bremner (1935) first pointed out that the results of replicate determinations of total iron were often very different; they attributed this difference to an erratic distribution of large particles of iron. Later, Lewis and Goldberg (1954) found that the concentrations of particulate iron in replicate 1-l water samples sometimes differed by as much as a factor of 14. We attempted to define the variability in particulate-iron concentrations associated with closely spaced (1-2-m intervals) 30-l samples. At Sts. 2, 5, 10, 12, 16, 20, and 26 on cruise 049 and at St. 3 on cruise 050, duplicate water samples from above 300 m were gathered; at Sts. 9, 11, 24, 25, and 27 on cruise 049 (Fig. 1), duplicate water samples from below 300 m were obtained. Both sets were analyzed as above. The data on the duplicate water samples from above and below 300 m are presented in Table III. The average difference in duplicate samples is greater for shallow-water samples than it is for deep-water samples: $0.048 \mu\text{g/l}$ and $0.021 \mu\text{g/l}$, respectively. Lewis and Goldberg's shallow-water samples were also slightly more variable than their deep-water samples.

Results. A summary of our data is presented in Fig. 2, and all data are tabulated in the Appendix. Based on the 296 determinations, the median concentration is $0.13 \mu\text{g/l}$. Of the 296 determinations, 207 yielded concentrations of less than $0.2 \mu\text{g/l}$; there is, however, a long tail at the high end of the distribution, so the overall average is $0.206 \mu\text{g/l}$.

Table III. Particulate-iron concentrations in duplicate water samples.

Cruise	Station	Mean depth (m)	Sample 1 ($\mu\text{g/l}$)	Sample 2 ($\mu\text{g/l}$)
SHALLOW WATER				
TR-049	2	99	0.058	0.044
"	5	26	0.086	0.027
"	10	0	0.142	0.254
"	10	50	0.093	0.075
"	10	100	0.097	0.097
"	12	1	0.213	0.138
"	16	49	0.080	0.041
"	20	24	0.162	0.071
"	26	100	0.208	0.167
TR-050	3	50	0.253	0.288
Average difference = 0.048 $\mu\text{g/l}$				
DEEP WATER				
TR-049	9	3001	0.068	0.085
"	11	999	0.092	0.069
"	24	3999	0.504	0.479
"	25	601	0.137	0.130
"	27	2001	0.254	0.221
Average difference = 0.021 $\mu\text{g/l}$				

We obtained an average of 0.177 $\mu\text{g/l}$ for 184 samples from 29 shallow stations (0-300 m) and an average of 0.255 $\mu\text{g/l}$ for 112 samples from below 300 m. Seven samples from a depth of 4000 to 5000 m in the Atlantic could be identified on the basis of salinity (Table IV) as containing a significant proportion of Antarctic Bottom Water (Worthington and Metcalf 1961). If we eliminate these seven samples from consideration, then the deep-water average is 0.206 $\mu\text{g/l}$.

Aside from the possible difference in the concentration of particulate iron in Antarctic Bottom Water, there is no noticeable difference between the various areas sampled in the Atlantic and Caribbean. This is true for both shallow-water and deep-water samples. No relationship of concentration to depth in the upper 300 m was noted, except that the bottle at the surface often gave a concentration that was higher than the rest of the samples.

The results of the particulate-iron determinations from cruises 049 and 050 were much lower than the determinations of other investigators. At first it seemed possible that in some way the method of analysis did not recover the iron. Accordingly, on TRIDENT cruise 055 we attempted a comparison of the spectrophotometric method of Lewis and Goldberg (1954) with our atomic-absorption method. Samples were gathered from 10, 25, 50, 75, 100, and 300 m in the surface waters of the Puerto Rican Trench (St. 48). Five hours later a duplicate set of samples was gathered from the same depths at the same station. The first set of samples was analyzed according to our method,

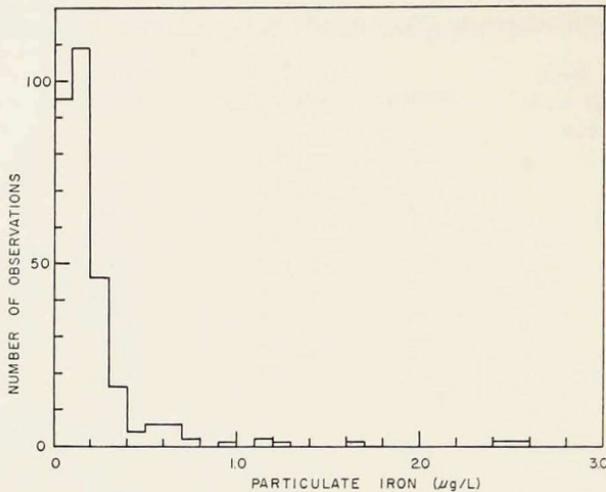


Figure 2. Frequency histogram of all particulate-iron concentrations determined on samples from the stations shown in Fig. 1.

while the second set was analyzed by the spectrophotometric method of Lewis and Goldberg (1954). Results of the atomic-absorption determinations gave an average particulate-iron concentration of $0.138 \mu\text{g/l}$; the average of the six spectrophotometric determinations was $0.129 \mu\text{g/l}$.

Note that both sets of samples used in the comparison of the spectrophotometric and atomic-absorption methods were collected at St. 48 according to our methods. We thought it was possible that the low particulate-iron concentrations found by both methods might have resulted from the attachment of iron particles to the silicone rubber tubes that conducted the water samples from the Niskin bottles to the polypropylene filtering heads. This possibility was examined by passing 100 ml of 6N HCl through each tube and then determining the iron concentration in the effluent. This procedure leached a small amount of iron from the tubing; however, the amount recovered, an average of $0.008 \mu\text{g Fe/l}$ of seawater that had been run through each tube during the entire cruise, was less than 5% of the total amount of particulate iron in seawater.

Discussion. In general, our results give mean concentrations of less than 0.1 of the mean concentration reported by anyone else and less than 0.01 of the mean concentrations reported by some investigators. No two previous investigators have published reports on the concentration of particulate iron for the same area in the Atlantic, and this has made comparisons impossible. On two occasions, however, we sampled in the same areas and over the same depth range as others. Our data for St. 1 (cruise TR-055), 30 km southeast of Bermuda, can be compared with data gathered over the course of one year by

Table IV. Particulate-iron concentration in Antarctic Bottom Water collected on cruise TR-049 (May-June 1968).

Station no.	Depth (m)	Salinity (‰)	Particulate iron ($\mu\text{g/l}$)
1	4000	34.896	0.615
7	5000	34.885	1.1
17	5000	34.896	1.16
18	5000	34.897	2.56
19	5000	34.890	1.27
23	4000	34.898	0.607
29	4000	34.899	2.41

Menzel and Spaeth at a station 24 km southeast of Bermuda. Their average shallow-water (300 m and above) particulate-iron concentration was $2.1 \mu\text{g/l}$; this is 15 times greater than our average of $0.137 \mu\text{g/l}$ for six samples from a single hydrocast at the same location. Their average of $1.4 \mu\text{g/l}$ for samples taken at 1000 m is 13 times higher than our average of $0.106 \mu\text{g/l}$ for the three samples taken between 1000 and 3000 m.

Our data for St. 44 (Fig. 1) may be compared with the data of Ketchum and Ryther (1966) for St. 435 (ATLANTIS cruise 14). Both stations were north of the island of Barbados, were occupied in October, and were only 65 km apart. Their average for nine samples taken in the upper 400 m is $2.05 \mu\text{g/l}$ while our average for six samples taken in the upper 300 m is $0.188 \mu\text{g/l}$.

We think that the difference between our results and those of other investigators could be due to one or more of the following factors: (i) the use of metal sampling bottles equipped with metal fittings; for example, Betzer and Pilson (1970) have shown that the use of even Teflon-coated Nansen bottles may result in significant iron contamination; (ii) the use of uncoated or corroded hydrowire during sampling; and (iii) contamination during the processing of samples on shipboard.

Of the previous investigators listed in Table I, only two reported the type of hydrowire used in collecting their samples. They used stainless steel hydrowire and reported the lowest average concentrations of particulate iron found in the Pacific. Further, the published descriptions of most methods used for handling water samples aboard ship do not specify whether the water samples were filtered in open or closed systems.

The extreme variability in the concentrations of particulate iron reported for the same depth at one station is an outstanding feature of the particulate-iron literature (see Lewis and Goldberg 1954, Schaefer and Bishop 1958). The results of Lewis and Goldberg (1954) show that there is nearly as much variability in iron concentrations at any given depth as there is between various depths. This extreme variability has prevented investigators from relating their

particulate-iron determinations to the physical characteristics of water masses. The results of our duplicate determinations show that the average difference between duplicates is $0.039 \mu\text{g/l}$; this is about 25% of the average concentration in those samples. Corresponding ratios, calculated from a much more extensive series of duplicates published by Lewis and Goldberg (1954) and Schaefer and Bishop (1958), are 49% and 106%, respectively; these latter values were calculated by taking the differences between successive pairs in their triplicate determinations; from Schaefer and Bishop we included data only for those stations that were more than 100 km from land.

While the greater part of our data shows that large areas of the open ocean are characterized by similar particulate-iron concentrations (within the limits of our variability), we have found that Antarctic Bottom Water (classified as such by salinity) had as much as 10 times more particulate iron than average Atlantic deep water (Table IV). We do not know whether this increased concentration of particulate iron near the bottom in our sampling area is typical of Antarctic Bottom Water or is a local phenomenon due to the resuspension of particulate matter by bottom currents.

Of course we cannot say that our values for the concentration of particulate iron are the true values, for some of our samples may be contaminated also. The true concentrations of particulate iron in seawater may be even lower than the concentrations reported here.

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APPENDIX

Concentrations of Particulate Iron

<i>Cruise TR-049</i>			<i>Cruise TR-049</i>		
	Depth (m)	Fe ($\mu\text{g/l}$)		Depth (m)	Fe ($\mu\text{g/l}$)
1	300	.160	7	600	.064
32°29.5'N	600	.077	35°09'N	1000	.045
63°14.6'W	1000	.075	49°32.5'W	2000	.055
19/V/68	4000	.615	23/V/68	3000	.044
				4000	.132
				5000	1.11
2	0	.133	8	0	.157
33°03'N	25	.087	34°40'N	25	.093
58°33'W	50	.093	48°20'W	50	.058
20/V/68	75	.113	25/V/68	75	.044
	95	.058		100	.053
	103	.044		300	.073
3	300	.307	9	600	.110
33°27.5'N	600	.083	34°30'N	1000	.132
56°48'W			47°26.5'W	2000	.072
21/V/68			25/V/68	3000	.068
4	300	.046		3002	.085
34°07'N	600	.047		3500	.072
54°55'W	1000	.087	10	0	.142
22/V/68	2000	.130	34°02.9'N	0	.254
	3000	.118	47°43'W	50	.093
	4000	.068	26/V/68	50	.075
5	0	.236		100	.097
34°09'N	25	.086		100	.097
53°05.5'W	27	.032	11	600	.096
22/V/68	50	.069	34°33'N	998	.092
	75	.067	50°35'W	1000	.069
	100	.107	28/V/68	2000	.076
6	0	.094		3000	.104
34°33'N	25	.054		4000	.259
50°52.5'W	50	.064	12	0	.213
23/V/68	75	.029	34°26.8'N	2	.138
	100	.049	50°30.5'W	25	.080
	300	.043			

Cruise TR-049

	Depth (m)	Fe ($\mu\text{g/l}$)
28/V/68	50	.223
	75	.083
	100	.108
13 34° 14' N 51° 54' W	0	.118
	25	.076
	50	.099
	75	.096
28/V/68	100	.074
	300	.128
14 34° 41' N 51° 38.5' W	0	.180
	25	.087
	50	.051
	75	.060
	100	.072
29/V/68	300	.084
15 34° 17' N 51° 42' W	300	.042
	600	.067
	900	.095
	1200	.078
	1500	.115
30/V/68	1800	.189
16 35° 53.1' N 51° 46.1' W	0	.153
	25	.065
	48	.080
	50	.041
	75	.088
31/V/68	100	.174
17 35° 05' N 51° 48' W	600	.077
	1000	.242
	2000	.108
	3000	.080
	4000	.112
	5000	1.16
18 35° 07' N 50° 40' W	600	.081
	1200	.122
	2200	.098
	3200	.108
	4200	.375
1/V/68	5000	2.56
19 35° 28' N 52° 18' W	600	.100
	1000	.098
	2000	.130
	3000	.131
	4000	.155
2/V/68	5000	1.27

Cruise TR-049

	Depth (m)	Fe ($\mu\text{g/l}$)
20 35° 02' N 53° 09' W	0	.394
	24	.162
	25	.071
	50	.096
	75	.073
3/V/68	100	.148
21 34° 40.5' N 55° 12.5' W	0	.342
	10	.140
	20	.102
	30	.119
	40	.108
	50	.099
22 34° 40.5' N 55° 12.4' W	50	.102
	60	.077
	70	.089
	80	.109
	90	.064
3/V/68	100	.239
23 33° 58' N 57° 47' W	600	.117
	1000	.099
	2000	.135
	3000	.086
	3998	.607
4/V/68		
24 33° 49' N 58° 34' W	600	.345
	1000	.104
	2000	.144
	3000	.115
	3998	.504
4000	.479	
25 32° 58' N 61° 27' W	600	.137
	602	.130
	1000	.221
	2000	.087
	3000	.173
4000	.771	
26 32° 58' N 61° 27' W	0	.561
	25	.145
	50	.220
	75	.143
	99	.208
6/V/68	100	.167
27 32° 41' N 62° 46' W	600	.128
	1000	.234
	2000	.254

Cruise TR-049

	Depth (m)	Fe ($\mu\text{g/l}$)
7/VI/68	2002	.221
	3000	.188
	4000	.650
28 32° 41'N 62° 46'W 7/VI/68	0	.309
	25	.204
	50	.153
	75	.140
	100	.148
	300	.119
29 32° 26'N 64° 03'W 8/VI/68	300	.245
	600	.685
	1000	.152
	2000	.168
	3000	.171
	4000	2.41

30 32° 26'N 64° 03'W 9/VI/68	0	.213
	25	.238
	50	.220
	75	.155
	100	.151
300	.196	
31 32° 18'N 64° 00'W 10/VI/68	0	.931
	25	.143
	50	.200
	75	.144
	100	.146
300	.216	

Cruise TR-050

1 32° 39'N 65° 19.5'W 14/VI/68	0	.368
	25	.232
	50	.267
	75	.221
	100	1.607
	300	.138
2 34° 12'N 66° 05'W 14/VI/68	0	.304
	25	.513
	50	.230
	75	.343
	100	.364
300	.306	

3 35° 30'N 66° 14'W	0	.312
	25	.253
	49	.253

Cruise TR-050

	Depth (m)	Fe ($\mu\text{g/l}$)
15/VI/68	50	.288
	75	.231
	100	.556
4 37° 59.5'N 66° 00'W 15/VI/68	1000	.526
	3000	.295
	4000	.479
	4800	.620

5 37° 58'N 67° 27'W 16/VI/68	0	.242
	25	.183
	50	.184
	75	.152
	100	.197
	300	.077

Cruise TR-055

1 31° 57'N 64° 40'W 12/IX/68	a	0	.273
		25	.105
		50	.086
		75	.155
		100	.066
b	1000	.093	
	2000	.114	
	3000	.112	

2 30° 03'N 64° 58'W 13/IX/68	a	0	.209
		25	.150
		50	.128
		75	.168
		100	.783
	300	.257	

b	3000	.073
	4000	.204
	4500	.499

3 27° 22'N 65° 31'W 14/IX/68	3000	.192
	4000	.072
	5000	.149

5 19° 37'N 67° 12'W 16/IX/68	5535	.167
	6535	.257
	7535	.151

6 17° 09'N 67° 19'W	a	0	.256
		25	.066
		50	.081

Cruise TR-055

	Depth (m)	Fe ($\mu\text{g/l}$)	
18/IX/68	75	.089	
	100	.179	
	300	.130	
b	3000	.122	
	4000	.081	
	5000	.274	
7	a	0	.248
		25	.171
		50	.112
		75	.125
		100	.109
	300	.409	
b	2000	.180	
	3000	.183	
	4000	.190	
8	2000	.105	
	3000	.127	
	4000	.235	
9	0	.248	
	25	.129	
	50	.043	
	75	.100	
	100	.318	
	300	.366	
24	25	.160	
	50	.060	
	75	.109	
	100	.256	
	200	.572	
	300	.638	

Cruise TR-055

	Depth (m)	Fe ($\mu\text{g/l}$)	
44	10	.262	
	25	.339	
	50	.154	
	75	.106	
	100	.156	
	300	.110	
45	2050	.101	
	3050	.157	
	4050	.076	
	4550	.213	
	5050	.237	
	5650	.311	
46	10	.145	
	25	.124	
	50	.096	
	75	.037	
	100	.104	
	300	.104	
47	6000	.204	
	6500	.209	
	7000	.189	
48	a	10	.325
		25	.103
		50	.104
		75	.080
		100	.082
	300	.136	
b	10	.215	
	25	.161	
	50	.102	
	75	.038	
	100	.054	
	300	.205	