

become deeper basin water circulates cyclonically, requiring a travel time of more than 2 years to reach the sampling location. Actually, the pattern of circulation of the deeper waters has not been definitely established. If the water was formed near Jan Mayen Island (a distinct possibility) and traveled the most direct route to the sampling location in 8 months to 1 year, its rate would be only 2 to 3 mi per day, and it would arrive with a tritium content approximately that of average Atlantic water.

2) The measurements, on which the value of 1.0 TU for the average Atlantic water prior to the spring of 1954 are based, vary from 0.62 to 1.5 ± 0.4 TU (3). Let us suppose that the 400-m sample had an original value at the surface of nearer 1.5 than 1.0 TU. Then this sample would have had several years in which to traverse whatever portion of the polar basin lay between and still arrive with a tritium content of 0.9 ± 0.1 TU. In other words, the results of the tritium sampling as reported are too sketchy to serve as the basis of any real conclusions concerning the water circulation of the area.

C. A. BARNES

L. K. COACHMAN

Department of Oceanography,
University of Washington, Seattle

References and Notes

1. M. J. Dunbar, *Bull. Fisheries Research Board Can.* 88 (1951).
2. H. U. Sverdrup, M. W. Johnson, R. H. Fleming, *The Oceans* (Prentice-Hall, New York, 1942); *Recent Soviet Scientific Investigations in the North Polar Regions* [a translation by K. R. Whiting of A. F. Laktionov, *Severnnyy Polyus* (Sea Transport Publishing, Moscow, 1955), pp. 347-426] (Documentary Research Division, Research Studies Institute, Air University, 1956).
3. B. J. Giletti, F. Bazan, J. L. Kulp, *Trans. Am. Geophys. Union* 39, 807 (1958).

30 April 1959

The careful study by Barnes and Coachman of our paper, which attempted to show the potential application of tritium as a natural tracer in arctic problems, is appreciated. They correctly suggest that the heading over the column giving the salinity data should read "per mill" rather than "percent."

We agree that interpretation cannot be carried too far on the basis of such a limited number of measurements; nevertheless, these data are pertinent to the problem discussed and help to limit speculation. Moreover, a sufficient number of tracer data could, alone, lead to solution of this problem, contrary to the statement of Barnes and Coachman that these can only supply "supporting information." The practical difficulties are many, however, and obtaining these reconnaissance samples was a considerable achievement on the part of Cray and Goldstein.

It was not suggested in our paper that the earlier interpretation of most oceanographers—that Atlantic-derived water occupies the Arctic Ocean at depths greater than 200 m,—be discarded. From the tritium data, however, it appeared that another source might contribute to the total influx. To quote from our article (page 903): "In this case the amount of water is small and affects only the bottom 100 m. This sinking water mixes with the normal Atlantic-derived water. . . ." Since Barnes and Coachman agree that it is possible to have a mixture of 80 percent Atlantic water and 20 percent surface water at the station in question, there would appear to be no real disagreement on this point.

The two explanations which Barnes and Coachman suggest from comparison of the tritium concentrations of the 400-m sample in the arctic and of average North Atlantic surface water do not appear to be substantially better than that suggested by us. Our suggestion is that the high tritium content resulted from the sinking of surface water during times of freezing and the mixing of this water of higher tritium content with the Atlantic-derived water.

Their first hypothesis requires the assumption that the water at 400-m depth north of Ellesmere Island comes from the vicinity of Jan Mayen Island by a direct route at the rate of 2 to 3 mi per day. This would indeed account for the tritium content, within the range of experimental error, but such westward movement around the north coast of Greenland and the Canadian archipelago would be in conflict with the pattern of flow proposed by Worthington (1). It will be recalled that the area studied by him included the Chuckchi Sea and Beaufort Sea and the area of collection of the sample in question.

For their second hypothesis, based on the data of Giletti, Bazan, and Kulp (2) for North Atlantic surface water, they base their arguments on the sample with the largest error. Owing to the small size of this sample, the counting statistics gave a standard deviation of ± 27 percent, which essentially overlaps the mean of all values. This large error must be compared with the standard deviation of ± 10 percent obtained for each of the remaining eight analyses. Of the better measurements, the highest value is 1.34 ± 0.1 TU. If this value is used, the time allowed for the cyclonic gyre of 3500 mi is 7 years. This is based on comparison with the value observed at the station in question (0.9 TU) and implies a mean flow rate of 1.3 mi/day. This rate is probably less than the true rate, which should be inferred from the average North Atlantic value; calculation on this basis gives 4.8 mi/day.

Not only is this a rather high rate but

it requires a high tritium concentration throughout the Arctic Sea. It would be reasonable to expect this layer of higher tritium content to be at least 300 m thick. The cosmic-ray tritium production required to maintain this level in a steady state would be at least equal to that required for the entire North Atlantic surface water. If this arctic water all came from the Atlantic, the natural tritium production would have to be almost double the presently assigned value. If anything, the production rates calculated from observations on tritium reservoirs are already too high (when compared with calculations of production based on cosmic-ray reaction rates), and this makes the hypothesis of doubtful validity.

Further study of tritium in selected localities could easily support or disprove either of the suggestions by Barnes and Coachman. Far more sampling would be needed to "prove" any of the hypotheses discussed.

It is concluded that although more information is required to settle the matter, the natural tritium tracer may provide the means for doing so. Indeed, it has already focused attention on the areas where the critical data are likely to be obtained.

B. J. GILETTI

J. L. KULP

Department of Geology and Mineralogy,
University Museum, Oxford, England,
and Lamont Geological Observatory,
Palisades, New York

References and Notes

1. L. V. Worthington, *Woods Hole Oceanog. Inst. Tech. Rept.* 53-92 (1953); *Trans. Am. Geophys. Union* 34, 543 (1953).
2. B. J. Giletti, F. Bazan, J. L. Kulp, *ibid.* 39, 807 (1958).

20 May 1959

Absorption of Iron from Iron Chelate by Sunflower Roots

Abstract. Roots of decapitated sunflower plants absorbed iron from the ferric chelate of ethylenediamine di(*o*-hydroxyphenylacetic acid), leaving most of the acid in the nutrient solution. The chelating capacity of the nutrient solution increased as iron was absorbed by the plants. Most of the absorbed iron was found in the plant exudate.

Early investigators (1) suggested that synthetic chelating agents delivered iron to roots but were not themselves absorbed. Later research (2) led to the view that both components of the metal chelate were absorbed. Some emphasis has been placed on equivalent uptake of metal chelate components by plants (3), but later reports (4) suggest a non-equivalent uptake. The experiments reported here show that sunflower plants

Table 1. Changes in iron (FeEDDHA), total iron, and chelating capacity* of a nutrient solution containing sunflower plants and the concurrent changes in total iron and chelating capacity of the plant exudate.

Time of sampling of nutrient and exudate (hr):	Nutrient Solution			Exudate	
	Fe (FeEDDHA) (ppm)	Fe (total) (ppm)	Fe* chelating capacity (ppm)	Fe (total) (ppm)	Fe* chelating capacity (ppm)
0	5.4	5.5	0.043		
5		5.4	0.177	3	0.003
10.5	4.5	4.5	0.227	25	0.004
16.5		3.5	0.282	69	0.006
23.0	3.6	3.2	0.289	54	0.005
31.5		3.3	0.315	24	0.003
42.5	3.6	3.2	0.302	6	0.012

* In terms of Fe⁵⁵, ⁵⁹ chelated.

absorb iron from the iron chelate but, for the most part, leave the chelating agent in the nutrient solution. The chelating agent was ethylenediamine di(*o*-hydroxyphenylacetic acid), designated EDDHA (5). This compound gives a deep red color when combined with ferric iron.

The basic nutrient medium used was an iron-free, modified Steinberg solution (6) adjusted to pH 6.8. Spectrophotometric determinations show that the nutrient solution, alone, does not absorb at 480 mμ. Neither does nutrient containing EDDHA absorb at this wavelength. However, nutrient solutions containing the ferric chelate of EDDHA (FeEDDHA) show a specific absorbance at 480 mμ and the characteristic red color. The absorbance varies with concentration according to the Beer-Lam-

bert law. Consequently, the loss of iron from a FeEDDHA nutrient solution by root uptake is reflected in decreased absorbance and color, whereas the addition of iron to an iron-depleted nutrient (containing EDDHA) results in increased absorbance and color. This report outlines the method by which the difference in uptake of metal chelate components was determined.

Seeds of sunflower (Greystripe), germinated 3 days on moist muslin, were transferred to basic nutrient solution for 15 days' growth. Basic nutrient solution containing 5.5 mg of iron (as FeEDDHA) per liter was prepared, and a 10-ml sample (hereafter designated "prenutrient") was set aside. Thirty sunflower plants, grouped for exudate collection, were placed in the solution. The stems were cut off and fastened in an

inclined position. After the prenutrient sample had been set aside (zero time), a 5-ml sample each of nutrient and exudate was collected, at 5, 10.5, 16.5, 23, 31.5, and 42.5 hours, respectively. The nutrient and exudate samples were analyzed by three methods: (i) Iron was determined after ashing at 500°C by *o*-phenanthroline (7) and reported as total iron. (ii) Iron as FeEDDHA was determined spectrophotometrically at 480 mμ. (iii) The chelating capacity of nutrient and exudate was determined by the addition of 2.9 μg of Fe^{55,59} (specific activity, 937 count/sec μg) to each 1-ml sample, followed by adjustment to pH 6, heating to 90°C, and equilibration for 12 hours. Samples were then adjusted to pH 8, heated, filtered (No. 42 Whatman) into planchets, slowly dried, and counted in a proportional counter. The amounts of radioiron chelated were taken as an index of the chelating capacity of the samples.

The absorption of iron by sunflower roots is reflected in the decrease in iron in the nutrient and the increase in iron in the exudate (Table 1). With the loss of iron from the nutrient, the chelating capacity of the nutrient increased sevenfold. This suggested that iron-free EDDHA was remaining in the nutrient. To test this possibility, excess iron was added to samples of pre- and postnutrient. The resulting increase in absorbance values (Fig. 1) shows that the iron added to the postnutrient was chelated by EDDHA. Addition of iron to the prenutrient caused very little change.

From these experiments it is concluded that iron and EDDHA are not absorbed by sunflower plants in equivalent quantities but that iron is released to the roots and most of the EDDHA remains in the nutrient solution (8).

LEE O. TIFFIN
JOHN C. BROWN

Mineral Nutrition Laboratory,
U.S. Department of Agriculture,
Beltsville, Maryland

References and Notes

1. I. Stewart and C. D. Leonard, *Science* 116, 564 (1952).
2. C. D. Leonard and I. Stewart, *Proc. Am. Soc. Hort. Sci.* 62, 103 (1953); I. Stewart and C. D. Leonard, in *Mineral Nutrition of Fruit Crops*, N. F. Childers, Ed. (Horticulture Publications, New Brunswick, N.J., 1954), pp. 775-809; A. Wallace and C. P. North, *Calif. Agr.* 7, 8 (1953).
3. A. Wallace, C. P. North, R. T. Mueller, L. M. Shannon, N. Hemaidan, *Proc. Am. Soc. Hort. Sci.* 65, 9 (1955).
4. A. Wallace, L. M. Shannon, O. R. Lunt, R. L. Impey, *Soil Sci.* 84, 27 (1957).
5. H. Kroll, M. Knell, J. Powers, J. Simonian, *J. Am. Chem. Soc.* 79, 2024 (1957).
6. R. A. Steinberg, *Plant Physiol.* 28, 319 (1953).
7. L. G. Saywell and B. B. Cunningham, *Ind. Eng. Chem. Anal. Ed.* 9, 67 (1937).
8. Experiments with other plant species lead to the same conclusion. This work is being done in cooperation with the University of Maryland.

5 March 1959

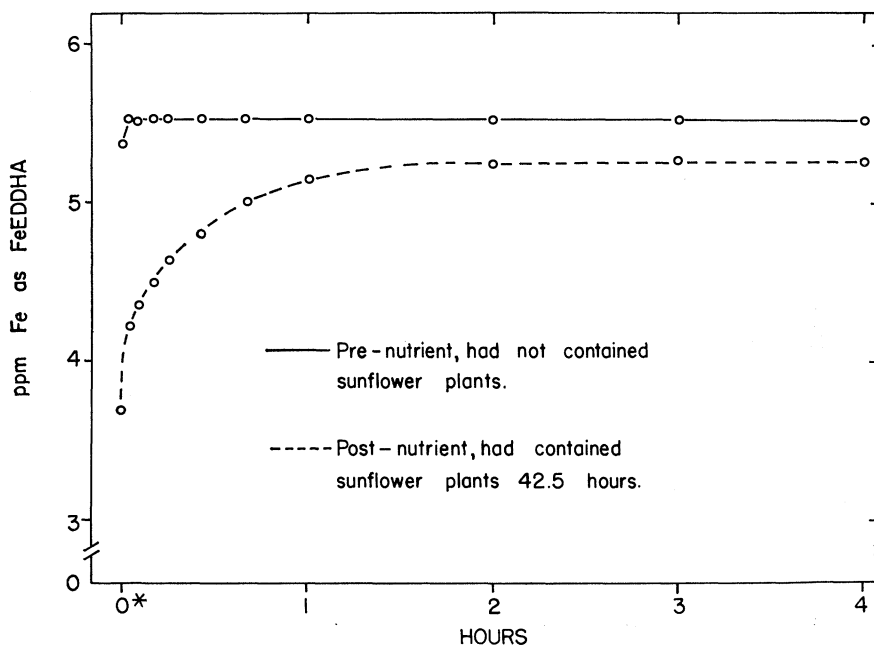


Fig. 1. Rate and extent of chelation of iron as FeEDDHA at 480 mμ by a nutrient solution before and after it contained sunflower plants. Excess Fe⁺⁺⁺ was added to pre- and postnutrient samples at zero time (*).