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Temperature and Age Analysis of Deep-Sea Cores

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Several papers have been published recently dealing with the stratigraphy of foraminiferal lutite in deep-sea cores and its relationship to continental Pleistocene stratigraphy (*1–6*). The deep-sea record has been studied by different methods. I have used oxygen-isotopic analysis; Ericson and Wollin have used micropaleontological analysis; and Rubin and Suess and Broecker, Kulp, and Tucek have used radiocarbon analysis. The results have been interpreted somewhat differently by Suess (*6*) and me (*1, 2*) on one side and by the group at the Lamont Geological Observatory on the other side (*3, 5, 7*). The purpose of this article is to analyze these differences and to draw the possible conclusions from the published evidence.

Stratigraphy and Micropaleontology

Ericson and Wollin (*3*) have recently determined the temperature variations in three deep-sea cores from the Caribbean and the equatorial Atlantic Ocean by the following methods: (i) the relative abundances of the pelagic foraminifer *Globorotalia menardii* and other warm-water, pelagic foraminifera in the fossil fauna and (ii) the number of specimens of *Globorotalia menardii* per milligram of the sediment fraction that is larger than 74 microns. The results were compared with the paleotemperatures determined by means of oxygen-isotopic analysis.

The first method fails to reveal clearly cold stages 6, 8, and 10 in core A172-6 and cold stages 8 and 10 in core A179-4 (*8*). The second method, on the other hand, yields good correlation with the isotopic temperatures for all stages down to stage 11. *Globorotalia menardii* is rare or absent in stage 12, which was shown to have been cool by isotopic data, and in stage 13, which was shown to have been as warm as any other warm stage. Ericson and Wollin concluded that stages 12 and 13 correspond to one glacial age, and they suggest postdepositional oxygen isotopic exchange between shell material and water as a possible explanation for the isotopic values that have been measured in stages 12 and 13.

Bottom water is colder than superficial water, however, and exchange could have resulted only in the displacement of isotopic temperatures below the actual temperatures. Consequently, if isotopic exchange occurred, the true temperatures of stages 12 and 13 would be even higher than those shown by the isotopic analyses. Paleotemperature analysis of Tertiary cores from the Atlantic Ocean (*9*) indicates that no appreciable isotopic exchange has occurred in 20 to 30 million years. The presumption that isotopic exchange took place in a few hundred thousand years is not acceptable (*10*) and the fully interglacial character of stage 13 must be maintained.

This conclusion is supported not only by the isotopic results, but also by the sedimentological, chemical, and micropaleontological data presented by Ericson and Wollin (*4*).

The weight percentage of the sediment fraction larger than 62 or 74 microns shows good correlation with isotopic temperatures in all cores for which data are available, unless postdepositional solution has interfered (*1, 4*). This correlation indicates that the average weight of pelagic foraminifera is a direct function of temperature. The value of this parameter for stage 13 of core A179-4 is typical of warm stages, and this is also true for core A172-6 if levels of postdepositional solution are excluded.

Twelve chemical analyses for various levels of core A179-4 (*4*) show carbonate values ranging from 48.8 to 77.0 percent in stages which isotopic results show to have been warm, and carbonate values ranging from 43.7 to 50.7 percent in cold stages. Two analyses (at 640 and 690 centimeters below the top of the core) correspond to stage 13, and the results (59.7 and 55.0 percent, respectively) are within the range of values for the warm stages and agree with the isotopic evidence.

Globorotalia menardii seems to offer an often reliable method for estimating temperature variations, especially if Ericson and Wollin's method, which consists of expressing abundance by the number of specimens per milligram of the sediment fraction larger than 74 microns, is used. However, negative results owing to absence of this species or any other warm-water species may not necessarily indicate low temperature. Such species, in fact, may be replaced by other warm-water species of similar depth habitats.

Absolute estimates of the abundance of pelagic Foraminifera in cores A179-4 and A172-6 were published by Ericson and Wollin (*4*) using six symbols. Their data for various species in the two cores are shown as graphs in Figs. 1 and 2. The estimates of abundance were limited to the level of 100 specimens per tray spreading—that is, variations in abundance were considered only when numbers smaller than 100 were involved. Some species generally are present in greater abundance throughout the cores (*Globigerinoides rubra* and *G. sacculifera*), and their variations were not determined. Graphic representation of the data would be a straight line. Other species occur in greater abundance through long sections of the cores, where they form broad, flat peaks in the graphs (for example, the *Globorotalia menardii* group). The abundances of still other species vary between zero and 100 specimens per tray spreading, and their variations may be compared with the variations of the isotopic temperature. In making such comparisons, one should keep in mind that, as pointed out by the authors, the abundance estimates are very crude, and correlations should be viewed with considerable optimism. More accurate abundance determina-

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Table 1. Correlation between core stages and continental events according to my method (*1*) and the method of Ericson and Wollin (*3*).

Core stage	Emiliani	Ericson and Wollin	
		Core A172-6	Core A179-4
1	Present interglacial	Present interglacial	Present interglacial
2 3 4	Würm	Last glaciation	Last glaciation
5	Riss-Würm		
6	Riss		
7 8 9	Mindel-Riss	Last interglacial	Last interglacial
10	Mindel		
11 12 13	Günz-Mindel	Penultimate glacial	Penultimate glacial
14	Günz		

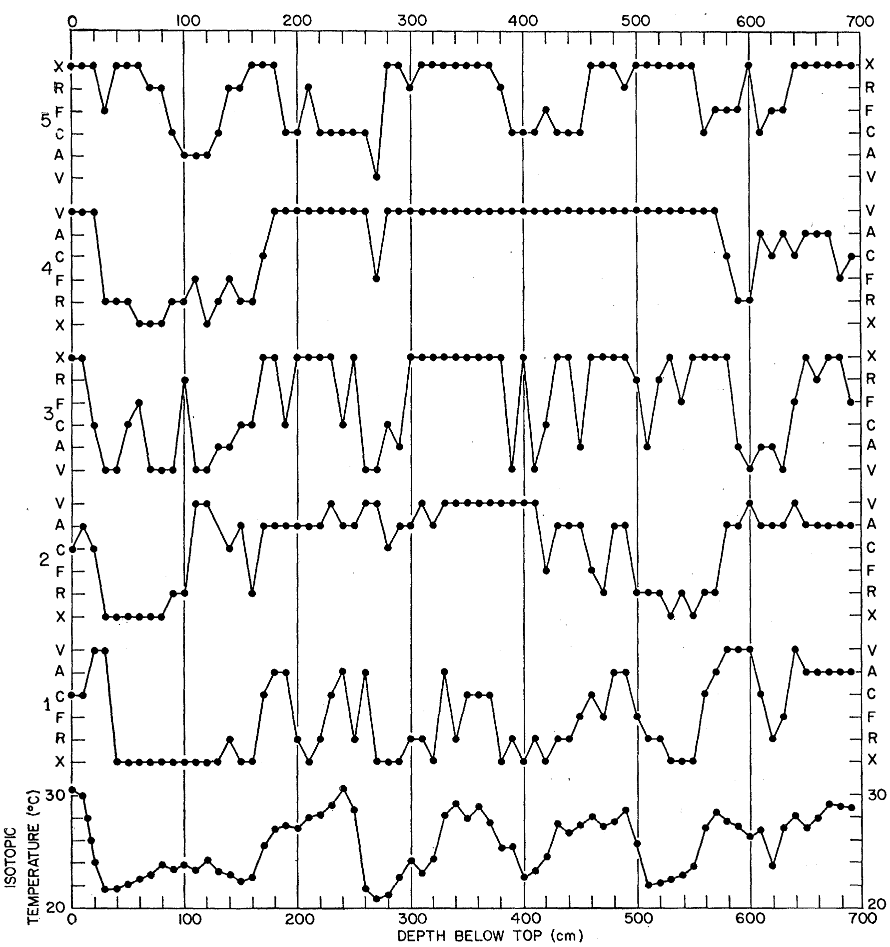

Fig. 1. Isotopic temperatures (from *Globigerinoides rubra*) and foraminiferal abundances of core A179-4: 1, *Sphaeroidina dehiscens*; 2, *Pulleniatina obliquiloculata*; 3, *Globigerina inflata*; 4, *Globorotalia menardii* group; 5, *Globigerina bulloides*. *V*, very abundant; *A*, abundant; *C*, common; *F*, frequent; *R*, rare; *X*, absent (see Ericson and Wollin, *4*, p. 116).

tions, in fact, probably would have resulted in better correlations.

The last temperature rise is clearly shown by all species except *Globigerina bulloides* (Fig. 1). This species is too rare in core A172-6 and is not shown in Fig. 2. *Globigerina bulloides* does not seem to correlate with temperature except occasionally. The ordinate for this species and for *Globigerina inflata* has been inverted to facilitate comparison.

The *Globorotalia menardii* group shows a good correlation with temperature for stages 1 to 5 and also for stage 13 in core A179-4 only. No abundance variations are shown by the graphs in the mid-portion of the cores because of the afore-mentioned artificial boundary condition. Actually, the absolute abundance of this species varies considerably over this interval, as may be calculated from the data of Tables 2 and 3 in one of the papers by Ericson and Wollin (*3*) and from the top graphs of Figs. 2 and 3 in one of my papers (*1*). The absolute abundances correlate with isotopic temperature in a way similar to that of the number of specimens per milligram of sediment fraction larger than 74 microns.

Globigerina inflata shows a fairly good correlation with temperature, although many irregularities occur. In particular, abundance values characteristic of warm stages may be noticed in stage 13 of core A179-4. The evidence is inconclusive for stages 11 to 13 of core A172-6 because peaks and valleys cross stage boundaries.

Pulleniatina obliquiloculata shows good correlation with isotopic temperatures throughout most of the two cores. Stage 6, however, is very poorly represented, and the evidence for stage 11 is inconclusive. Stage 13, on the other hand, is represented in both cores by abundance values that are typical of warm stages.

Sphaeroidina dehiscens shows in both cores a correlation with isotopic temperatures which is considered excellent. All stages except stage 3 of core A179-4 are well represented. Values typical of warm stages occur at stage 13 in both cores.

In conclusion, the species for which significant variations in abundance can be derived from Ericson and Wollin's tables clearly indicate that stage 13 was warm. The exceptions, which occur only in core A172-6, are *Globorotalia menardii* and, to a smaller degree, *Globigerina inflata*. The interglacial character of stage 13, therefore, seems to be well established also on micropaleontological grounds.

Correlations with Continental Events

Ericson and Wollin (*3*) correlated temperature variations of the cores with glacial and interglacial events of the continents in a way entirely different from that suggested by me (Table 1). The foregoing evidence for a warm stage 13, however, seems sufficiently strong to require that the correlation proposed by these authors should be abandoned.

Ericson and Wollin (*3*, text Fig. 4) correlated stage 3 of core A172-6 with stage 5 of core A179-4 (Table 1), on the basis of the *Globorotalia menardii* abundances alone (Figs. 1 and 2, curves 4). This correlation, however, is contradicted by (i) the abundances of such other species as *Pulleniatina obliquiloculata* and *Globigerina inflata* (Figs. 1 and 2, curves 2 and 3), (ii) the percentages of the sediment fraction larger than 74 microns (*1*, Figs. 2 and 3, upper curves), and (iii) the isotopic temperatures (*1*, Figs. 2 and 3, lower curves). Furthermore, not only is the maximum istotopic temperature of stage 3 in core A172-6 much lower than the maximum of stage 5 in core A179-4, but also core A172-6 shows a rate of sedimentation higher than the other core, so that it is difficult to see how stage 3 of core A172-6 (maximum at 170 centimeters below the top) could correspond to stage 5 of core A179-4 (maximum at 240 centimeters below the top) unless considerable changes in the rates of sedimentation are assumed to have occurred within each core. Rates of sedimentation, however, appear to have remained remarkably constant within each core (*1*).

Core stage 3, which represents a cool, interglacial stage, is clearly shown by the isotopic temperatures in core A172-6 and in core 189 from the Mediterranean Sea. It is less evident in other cores (A179-4 and 234) and very obscure in some (A180-73 and 246) (*1, 2*). It is again very clear in core 280 (*11*).

Ewing and Donn (*7*), apparently relying more on negative evidence, stated that temperature decreased at the rate of about 1°C per 11,000 years from 90,000 to 11,000 years before the present. However, while the record contained in a natural layered medium can be easily smoothed by natural agents, it cannot be enhanced, so that positive evidence for a parameter gradient should outweigh negative evidence. The conclusion is justified, therefore, that temperature decreased from the maximum of stage 5 to the minimum, about as low as any other, of stage 4; it then rose to the minor maximum of stage 3 and decreased to the new minimum of stage 2, after which it finally rose to its modern values (stage 1).

Beginning of the Last Rise in Temperature

Dating the beginning of the last rise in temperature was the object of radiocarbon measurements performed by Rubin and Suess (*12, 13*) on deep-sea core material at my suggestion. Ericson and Wollin (*3*, text Fig. 6) and Ericson *et al.* (*5*) presented several radiocarbon dates determined by Broecker, Kulp, and Tucek (*14*) for five Atlantic Ocean cores that have not been analyzed isotopically for temperature. The core levels corresponding to the beginning of the last temperature rise were determined micropaleontologically in these five cores. This method seems reliable in view of the excellent correlation between isotopically and micropaleontologically determined

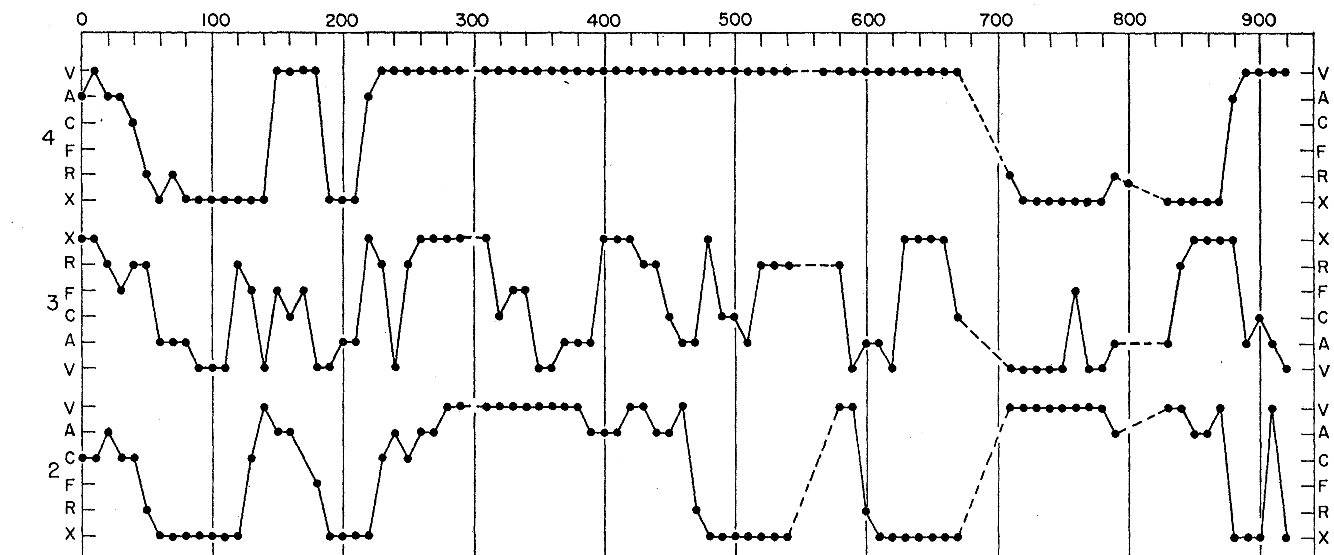

Fig. 2. Isotopic temperatures (from *Globigerinoides rubra*) and foraminferal abundances of core A172-6: 1, *Sphaeroidina dehiscens*; 2, *Pulleniatina obliquiloculata*; 3, *Globigerina inflata*; 4, *Globorotalia menardii* group. *V*, very abundant; *A*, abundant; *C*, common; *F*, frequent; *R*, rare; *X*, absent (see Ericson and Wollin, *4*, p. 116).

Table 2. Levels and radiocarbon ages of the beginning of the last temperature rise in deep-sea cores.

Core No.	Location	Depth below top of core (cm)	Radiocarbon age (yr)	Laboratory
A172-6	Caribbean	50	15,900	Washington
A179-4	Caribbean	30	13,600	Washington
A180-73	Equatorial Atlantic	30	13,600	Washington
A180-74	Equatorial Atlantic	35	13,600	Lamont
A180-48	Subtropical Atlantic	530	16,000	Lamont
189	Mediterranean	10	16,000	Washington
R10-10	North Atlantic	115	11,000	Lamont
A179-8	Subtropical Atlantic	270	13,200	Lamont
A179-15	Subtropical Atlantic	115	11,000	Lamont

temperatures in the upper portions of cores A172-6, A179-4, and A180-73 (*4*, Fig. 10).

Table 2 is a complete list of cores in which the beginning of the last temperature rise has been dated by the radiocarbon method. The Lamont dates and the Washington date for core 189 present some uncertainties because the analyses were performed on bulk core material, a method that may yield ages at some variance with those obtained from pure foraminiferal shells (*5, 6, 13*).

The depths below the tops of the cores (Table 2) refer to the levels corresponding to the beginning of the last temperature rise. The level of 30 centimeters below the top for core A180-74 has been chosen on the basis of the weight percentages of the size fraction larger than 74 microns (*4*, Fig. 6), a parameter that correlates well with temperature (*1, 4*). The corresponding radiocarbon ages have been calculated from the rates of sedimentation in the immediate neighborhood (cores A180-74, R10-10, and A179-15), in the whole core (core 189), and in the whole upper portion of the core on the basis of an assumed age of 2000 years (Table 3) for the top (cores A172-6, A179-4, and A180-73), or they have been estimated by extrapolation (core A180-48).

Cores A172-6, A179-4, A180-73, and A180-74 show particle-by-particle accumulation and an undisturbed record. Core A180-48 seems undisturbed in the section where the beginning of the last temperature rise may be placed. The top of core 189 is missing (*2*), but the level corresponding to the beginning of the last temperature rise is apparently preserved.

The rapid sedimentation of core R10-10 (average 12.6 centimeters per 1000 years) should have reduced the amount of reworking by bottom organisms. On the other hand, the mechanism of accumulation (about 50 percent by submarine solifluction, *15*) suggests that mixing may have been greater than that resulting from the action of bottom organisms alone. That this may have been the case is indicated by the remarkable age of the top of the core (Table 3) and by the fact that different levels (3.5 and 37.0 centimeters; 95.0 and 116.0 centimeters) gave identical ages (*14*). Cores A179-8 and A179-15 offer abundant evidence of submarine solifluction and turbidity currents (*3, 5*). Sedimentation rates vary greatly within cores R10-10, A179-8, and A179-15, while they are remarkably uniform within the other cores. It is apparent from this that the radiocarbon ages obtained from these three cores should be viewed with caution.

Table 2 shows a discrepancy up to about 2000 years among the radiocarbon ages from the undisturbed cores. Sample spacing of the isotopic, micropaleontological, and sediment size fraction analyses (usually 10 centimeters) introduces an uncertainty in determining the exact level corresponding to the beginning of the last temperature rise. The levels of Table 2 have been chosen, within the permitted limits, to minimize this discrepancy. Consequently, the discrepancy is at least as large as that shown. In particular, cores A179-4, A180-73, and A180-74 indicate that the last temperature rise began not earlier than about 13,500 years ago, while cores A172-6, A180-48, and 189 indicate that it began not later than about 15,500 years ago. This discrepancy may be due to different reworking by bottom animals in different cores, a factor that is probably inherent to aerobic deep-sea sediments.

It is difficult to draw satisfactory conclusions from the data of Table 2. One may choose as the most probable date the average of the undisturbed cores (14,800 years), or one may prefer the age given by Core A172-6 (15,900 years) on the grounds that its faster and yet undisturbed sedimentation permitted better identification of the exact level corresponding to the beginning of the last temperature rise. In either case, an age of about 15,000 years is suggested.

Some evidence that this may be about the right age is that 11,000 years ago sea level had already risen to within about 30 meters of the present surface (*14, 16*), indicating that about 70 percent of the glacial ice had already melted. Two wood samples from the sand-to-silt transition at depths of 30 to 45 meters in the Mississippi delta were dated at 10,000 to 11,000 years (*14*). This was taken to date an important climatic change (*5*), but it is possible that this date refers to the opening of the St. Lawrence waterway by retreating ice, which reduced the Mississippi River discharge by at least one third and correspondingly reduced capacity and competency.

Ericson *et al.* (*5*) stated that the age of 11,000 years refers to the midpoint of the rising temperature curve and that the temperature rise took place in 1000 to 2000 years. While an age of 11,000 years for the midpoint of the rising temperature curve probably is about correct and is in agreement with my previous conclusion (*1*), all undisturbed long cores as well as all pilot cores (*1*, Figs. 8–10) clearly indicate that the temperature rose gradually and that the process lasted about 8000 years.

Four radiocarbon age measurements have been published for levels a few centimeters below the tops of the cores (*12–14*). These are shown in Table 3 together with the ages calculated from postglacial rates of sedimentation based on radiocarbon dates from older levels. An average discrepancy of 2000 years occurs between these two sets of data. This might result from failure to recover the top portion of the sediment during coring operations. Comparison, however, of the

Table 3. Radiocarbon ages of core levels near the tops.

Core No.	Depth below top of core (cm)	Radiocarbon ages (yr)			Corresponding sediment thickness (cm)
		Calculated	Measured	Difference	
A172-6	5.0	1,400	3,700	2,300	8.0
A179-4	5.0	2,300	3,950	1,650	7.5
A180-73	4.0	1,700	2,960	1,260	3.0
A180-74	2.5	1,500	3,630	2,130	3.6
R10-10	3.5	440	4,160	3,720	30.0
Average (excluding core R10-10)				1,835	

isotopic temperature graphs of core A179-4 and its pilot core A179-TW4 (*1*, Figs. 2 and 7) shows clearly that nothing was lost from the top of core A179-4. It is not unreasonable to assume that the cores of Table 3, which were all raised with Ewing's piston corer (compare *4*), are also complete. If so, the discrepancy may be explained by assuming that burrowing organisms mixed the top few centimeters of the sediment. Complete homogenization could occur only within thicknesses of a centimeter or so, and mixing would be smaller for greater thicknesses. Very little mixing, if any, is believed to have occurred between levels 10 centimeters apart. Failure of the isotopic data of pilot cores (*1*, Figs. 7–10) clearly to reveal temperature variations corresponding to the Wisconsin substages may be an indication of such mixing.

If mixing is occurring at the present sedimentary surface, the same process may be assumed to have disturbed sediments deposited at earlier times. If the radiocarbon age of the modern, superficial sediment is 2000 years, it might be necessary to reduce all radiocarbon dates so far obtained from deep-sea cores by that amount. Consequently, the previous estimate of 15,000 years for the beginning of the last temperature rise would be reduced to 13,000 years.

It is apparent, from this discussion, that dating of the last temperature rise of the superficial waters of the oceans is unsatisfactory at present. Further research of greater detail is needed. In particular, closely spaced samples from deep-sea cores, covering the last 20,000 years, should be analyzed isotopically, and radiocarbon measurements should be performed on foraminiferal shells from critical core levels.

References and Notes

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3. D. B. Ericson and G. Wollin, *Micropaleontology* 2, 257 (1956).
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8. Temperature variations as shown by deep-sea cores permit subdivision in stages and corresponding ages. Age 1 is the present warm interval, age 2 the preceding cold one, and so on. Thus, even numbers refer to cold stages and odd numbers to warm stages. The stages are numbered backward in time. This classification was introduced by G. Arrhenius [*Repts. Swedish Deep-Sea Expedition 1947–1948*, vol. 5, fasc. 1 (1952)]. See also my article (*1*, p. 547).
9. C. Emiliani, *J. Geol.* 64, 281 (1956).
10. The Russian experiments mentioned by Ericson and Wollin (*4*) were conducted on finely precipitated $CaCO_3$. Rapid isotopic exchange may take place between this material and water under the proper conditions. H. C. Urey *et al.* [*Bull. Geol. Soc. Amer.* 62, 399 (1951)] and Lowenstam and Epstein [*J. Geol.* 62, 207 (1954)] showed that Cretaceous chalks exchanged considerably with percolating continental waters. These authors stressed the fundamental differences between fossils and matrix. On the other hand, oxygen isotopic analyses of bulk core material by Epstein [in G. Arrhenius *et al.*, *Tellus* 3, 222 (1951)] showed that the finer carbonate fraction did not appreciably exchange with surrounding water in more than 60,000 years.
11. A paper describing core 280 is in preparation.
12. M. Rubin and H. E. Suess, *Science* 121, 481 (1955).
13. ———, *ibid.* 123, 442 (1956).
14. W. S. Broecker, J. L. Kulp, C. S. Tucek, *ibid.* 124, 154 (1956).
15. Core 280 indicates that the normal rate of sedimentation for the area where core R10-10 was raised is about 7 cm per 1000 years.
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Recruitment of Women in the Engineering Profession

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The widespread use of the term *manpower* in connection with problems of labor shortages and the utilization of human resources suggests a pervasive cultural bias, for what about "womanpower" in the labor force? To contend that this is merely a manner of speaking overlooks the fact that language is related to cultural and social phenomena. This bias may result in ignoring or underestimating one major source of supply in the current efforts to solve the shortage of engineers.

The underrepresentation of women in engineering is marked indeed. In 1955, 0.2 percent (or 62) of 22,589 engineering graduates were women (*1*). And the proportion of women in the engineering profession as a whole, as of 1950, was 1.24 percent (*2*, p. 230, Table VIII. 1). This is a notably smaller proportion than is found in any of the other professions which are not predominantly female. (In the "predominantly female" category are nursing, social work, library work, and school teaching.) In 1950, the proportion of women in medicine was 6.1 percent; in law, 3.5; in the ministry, 4.1; in college teaching, 23.2; and in journalism, 32.0 (*2*). Thus, both in absolute and in relative terms, the role of women in engineering is negligible.

What are the obstacles to recruitment of women in engineering? What factors, if any, favor recruitment? What are the policy implications of the analysis of this problem?

Obstacles to Recruitment

Of all factors that may account for the negligible number of women engineers, those pertaining to biology—allegedly, IQ and temperament—are least relevant. Psychologists have found that intelligence is normally distributed and is not related to sex. Likewise, temperament, about which little scientific knowledge exists, would not account for the low rate of recruitment of women in engineering. Whatever the temperament of engineers, assuming that it is distinctive, it has not been established that it is a common—much less exclusive—attribute of males.

Psychological factors in terms of personality development *are* relevant. Again, such factors may vary independently of sex, though the possibility is by no means excluded that engineers tend to have, or tend to develop, characteristic modes of thinking and feeling, and characteristic interpersonal relations, which are less commonly found among American women.

Such an old psychological dichotomy as "tough-mindedness" versus "tender-mindedness" may be related to sex. Assuming that engineers are generally "tough-minded" because of the occupational demands for "rational" and "factual" analysis, women, who may be predominantly "tender-minded" and given to "intuitive" and "emotional" patterns of behavior, would not be attracted to the profession. These psychological differences may exist, though they have been inadequately studied insofar as occupational recruitment in general is concerned and engineering recruitment in particular.

Of central importance are the sociological aspects of the problem, namely, the cultural and social factors impeding

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