The pollen record may be taken as strong evidence that such an advance of trees and shrubs in fact occurred.

The pollen record does not contradict the conclusion that the forests of Siberia and Alaska did not merge during the Pleistocene; nor does it imply that spruce reached all the way to the Pribilofs, or even that any part of the land bridge could fairly be described as forested. Experience with pollen sections in arctic Alaska (*2, 3, 6*), shows that spruce 50 km distant or alders 10 km away are significantly represented in pollen diagrams. It seems probable that spruce came no closer than some tens of kilometers from the Pribilofs, possibly after they had already been cut off by the sea, probably on the Alaskan side, on which the distance to the present tree line is shorter. A broad strip of tundra would have still separated the forests of the two continents. Alder bushes may have advanced ahead of the tree line, as is their habit.

For the student of the land-bridge environment, this record shows that the southern plains of the land bridge, during the late life of the bridge, probably supported local groves of alders. Scrubby outliers of the spruce forest were to be encountered along the flanks of the bridge. The environment was still arctic.

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9. Samples of 0.5, 1, or 2 cm^3 were taken with stainless-steel tubes. Water content was determined on adjacent samples. Check samples (* in Table 2) were taken by packing sediment into a spoon spatula of known volume. In most samples it was possible to count every grain of spruce pollen present by using the low power of the microscope (Leitz Ortholux). In some slides of the spruce maximum, where pollen was crowded or broken, spruce content was calculated from counts of a portion of the slide by use of high power (× 400). Totals of all pollen types were calculated from high-power counts of 5 percent or less of each preparation if pollen was abundant; of the whole preparation if pollen was scarce.
10. The interval represents 110 cm of dry sediment deposited at 231 cm/year, or 25,410 years. Addition of 9570 for the top portion of the core gives 34,980 years.
11. D. McCulloch and D. M. Hopkins, *Geol. Soc. Amer. Bull.* **77**, 1089 (1966).
12. Pollen analysis of the 690-cm sample gave 21 percent spruce, 27 percent alder, and 11 percent birch, the remaining 41 percent being of tundra plants and *Sphagnum*. With *Sphagnum* subtracted from the pollen sum, these figures would be 25 percent spruce, 32 percent alder, 12 percent birch, and 31 percent other tundra plants.
13. Vegetation boundaries from U.S. Army publ. (map) EIS 301. In this map, alder is plotted together with shrub willows and poplar as "high brush." It may be that alder does not occur in some of the places in which it is indicated in Fig. 1.
14. Field work supported by grant ON3-322 from the Arctic Institute of North America; laboratory studies supported by NSF grants to Yale University (GB-1724) and Ohio State University (GB-3713 and GB-2989). I thank personnel of the Bureau of Commercial Fisheries for hospitality and cooperation, especially C. H. Baltzo; and D. M. Hopkins and D. A. Livingstone for critical comment.

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Foraminiferal Ooze: Solution at Depths

Abstract. *Samples of foraminiferal ooze were exposed to ocean water at various depths for 4 months, attached to the taut wire of a buoy in the central Pacific. Appreciable solution took place below 1000 meters and increased rapidly below 3000 meters and below 5000 meters. The fact that samples from different locations appear to dissolve at different rates suggests that the previous history of a sample determines its solubility. Solution is selective; it changes species composition, size distribution, content of damaged shells, and average particle weight of an assemblage.*

Much of Earth's history is recorded in various kinds of calcareous deposits. In the present era, the most widespread type of deposit is *Globigerina* ooze, which covers more of Earth's surface than any other sediment; it consists mainly of the shells of planktonic Foraminifera, which are ubiquitous in the plankton of the oceans.

Murray and Renard (*1*), the first to describe *Globigerina* ooze in detail, realized that its distribution and character are governed by the zoogeography of the living organisms in surface currents and by the chemistry of the ocean water that is responsible for modification of the sediment assemblage at depth. In particular they noted that solution works selectively, and that below a depth of about 4000 m in the central Pacific it destroys essentially all calcareous matter. This depth limit, usually called the "compensation depth," apparently rises toward high southern latitudes, occurring at about 500 m in the Ross Sea (*2*).

Recent predictions (*3*), based on laboratory experiments and thermodynamic theory, that the ocean is undersaturated with respect to calcium carbonate at all depths below the top layers have been verified (*4*) by field experiment in the central Pacific. It is therefore obvious that foraminiferal ooze should dissolve everywhere below the surface waters, with the rate rapidly increasing near the compensation depth.

I have investigated the manner in which the rates of solution differ at various depths and for *Globigerina* oozes of various origins. I attempt to show how several properties of foraminiferal ooze change in a regular manner upon exposure to solution.

Samples of foraminiferal sediment were attached to the taut wire of a buoy (*5*) moored in the central Pacific close to Horizon Guyot.

The samples consisted of two series each of 13 portions of a washed sample of sediment from the East Pacific Rise (Scripps Institution of Oceanography sample DWHD 81, from 22°07′S, 115°10′W; water depth, 3190 m). One series was washed in buffered, hot, demineralized water; washing removed any extraneous small particles that could have caused weight loss by current action rather than solution. The other series was boiled for 3 hours in buffered 10-percent solution of hydrogen peroxide. Presumably this treatment destroyed any organic coating or skeletal component present, so that the effect upon solubility could be studied. Blackman also furnished samples from the East Pacific Rise, taken at different latitudes; he has permitted me to use his data for comparison.

Each portion of sediment was about 0.1 g and consisted entirely of Foraminifera. The samples were enclosed in plastic tubes about 2.5 cm long and 2 cm in diameter, and the tube ends were closed with nylon gauze having openings of less than 62 μ; they were weighed before and after sealing. Each sample was placed in a wide mesh net (opening, 0.5 cm) and protected by a

heavy piece of plastic core liner, about 6 cm in diameter and 9 cm long, which was open at both ends. The core liner could rotate vertically on the attaching wire, thus probably aligning itself with the course of the current so that water could flow through freely. After 4 months the samples were recovered, immediately rinsed with water saturated with calcium carbonate, quickly rinsed with distilled water, and allowed to dry.

The percentage weight loss for each sample appears in Fig. 1. The tropical samples show a very slight increase in loss of weight between 250 and 2250 m—nil to about 5 percent, respectively (*6*). At 2750 m the weight loss of the treated portion exceeds 10 percent, while it stays near 5 percent for the untreated portion. Within the next-deeper 500 m the loss by solution more than doubles. Between 3250 and 4750 m there is no significant increase in loss for the untreated sample, while the treated sample at 4750 m shows twice the loss at 3250 m. Within the following 500 m, weight losses again double. The most pronounced steps in increase in solution appear to be at 3000 and 5000 m.

The change in weight loss at about 3000 m may reflect a reaction of the sample to displacement below the depth of its original source—3190 m. The change at 5000 m undoubtedly reflects the pronounced undersaturation of the abyssal water. Loss by solution of the samples depends on both the undersaturation of the water and the rate at which water flows through the container and replaces the more saturated water that is in direct contact with the sample. This effect can be neglected only if the rate of flow through the container is equal at all depths—which it probably is not (*7*). For all samples, solution rates may be expected to decrease with time as the more susceptible parts of the assemblage are eliminated.

Inside a container the rate of flow through the samples enclosed in it is probably similar, so that any differences between samples in losses by solution are of interest. The tropical samples treated with hydrogen peroxide show somewhat higher losses than the other tropical samples; treatment seems to have weakened the resistance of the tests to solution. The high-latitude samples show less weight loss than the rest, the fossil Pleistocene assemblage being the most resistant.

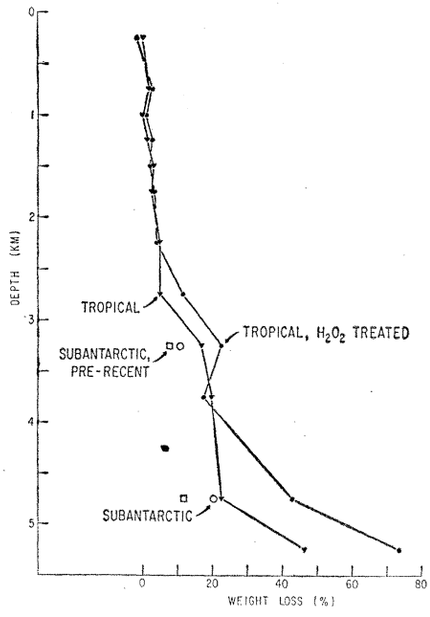

Fig. 1. Loss of weight by solution during 4 months at various depths in the central Pacific. Depth is in uncorrected meters. The values at 4250 m have been omitted (see text).

One may speculate that the high-latitude samples have been exposed to the aggressive southern bottom waters, and that the more soluble members of the assemblage were destroyed in its original site. Such a selective solution process, combined with a continuing supply of less-resistant specimen from above, should tend to bring any bottom assemblage into solution adjustment with the surrounding bottom water. Bramlette (*8*) considers it probable that near-equilibrium exists for all pelagic sediments having low sedimentation rates; this idea implies that solution rates on the bottom may be much lower than those I report. On the ocean floor, calcareous materials may also be protected by a diffusion barrier (*9*), which may be identical with the viscous layer 1 cm thick postulated by Munk (*10*). In any case, the properties of the foraminiferal assemblage should be a clue to the degree of saturation of the bottom water.

The more obvious properties of *Globigerina* ooze that are useful as solution indicators are species composition, size distribution, quantity of broken specimens and fragments, and average weight of particles. The untreated tropical samples were analyzed for these properties by separating the size fractions, weighing them, and determining their faunal and fragmental composition; about 1200 items were counted in each portion. The properties were ranked, according to the loss (by solution) sustained by the portions, to discover the trends of change (Tables 1–4).

Table 1 illustrates the varying susceptibility to solution of the species abundant enough for statistical treatment. The spinose genera *Globigerina, Globigerinoides*, and *Globigerinella* are less resistant to solution than the smooth-surfaced genera *Globorotalia, Globigerinita*, and *Candeina*; fundamental differences in wall structure probably account for the difference.

Table 2 shows the ratios between the weights of the various size fractions, averaged for four classes of weight loss of the samples. The coarser fractions decrease in weight relative to the finer fractions with increase in solution, but this relation is not very pronounced for these low values of weight loss.

If the phenomenon is real, an explanation may be found in Table 3. Table 3 indicates that production of broken shells by solution is most active in the coarser fractions (correlations of .90 and .71 versus .29 and .44 in the fine fraction), whereas the quantity of fragments increases more consistently in the finer fractions (correlations of .78 and .57 versus .19 and −.01 in the coarse fraction).

Table 1. Rank-difference correlations between amounts of broken specimens per species and weight loss in the portion; correlation varies with susceptibility to solution. In parentheses are average percentages of the species in the different fractions. The coefficients are most reliable for high percentages.

Particle size (μ)		
>250	177–250	125–177
	Globigerinoides ruber	
.54 (38)	.61 (86)	.27 (32)
	G. conglobatus	
.76 (22)		
	G. sacculifer	
.70 (12)		
	Globorotalia tumida	
−.12 (5)		
	G. truncatulinoides	
−.13 (5)		
	G. crassaformis	
−.11 (5)		
	Globigerinita glutinata	
	.41 (5)	−.12 (17)
	Globigerinella siphonifera	
	.74 (2)	
	Candeina nitida	
	Near 0 (1)	
	Globigerinoides tenellus	
		.65 (15)
	Globigerina rubescens	
		.75 (9)
	Globigerinita humilis	
		Near 0 (6)

Table 2. Average weight ratios between various size fractions. Numbers of samples appear in parentheses.

Weight loss (%)	Size fractions (μ)			
	>250/<250	>177/<177	>125/<125	>250/<125
0–4 (4)	.184	.372	.847	.288
5–9 (3)	.185	.372	.830	.285
10–19 (2)	.175	.364	.795	.268
>20 (1)	.153	.297	.664	.220

Table 3. Rank-difference correlations between the percentages of broken specimens (A) and fragments (B) and weight loss by solution. Positive values indicate increasing amounts of damaged shells with progessive solution.

Case	Size fractions (μ)			
	>250	177–250	125–177	62–125
A	.90	.71	.29	.44
B	.19	−.01	.78	.51

Table 4. Rank-difference correlations between average weight of particles and weight loss by solution. Positive values indicate that the average weight decreases with progressive solution.

Size fractions (μ)			
>250	177–250	125–177	62–125
All particles			
.59	.39	.71	.90
Without fragments			
.60	.30	.38	.87

Preferential solution of large specimens and associated accumulation of fragments in the finer fractions are consistent with these findings.

It would be presumptuous to expect similar relations in all foraminiferal oozes that undergo solution. Fragments are expected to dissolve more quickly than whole tests because (i) the specimens producing them must have been less resistant to solution than the undamaged shells in the assemblage, and (ii) fragments have more effective surface area per unit weight than whole tests. Thus, the destruction of fragments may keep pace with their production at moderate rates of weight loss. This tendency should make it very difficult to recognize the effects of solution on the basis of damaged shells alone. The weight ratios, however, may still provide a clue if, indeed, large specimens dissolve more quickly than small ones.

The average particle weight in each size fraction was investigated also. The data (Table 4) demonstrate that particle weight decreases as solution progresses. That the effect is not due wholly to the increasing amounts of low-weight fragments is shown by the values in the second row. In many instances the effect of solution is a layer-by-layer removal of shell material, which makes tests lighter without leaving much evidence of damage; in this manner, solution should decrease the maximum particle weights for given sizes in each species.

There is evidence, from counting thin- and thick-shelled specimens separately, that thin-shelled varieties of a species dissolve much faster than thick-shelled ones. Thus the more delicate tests would be eliminated while the remaining thick tests were only somewhat thinned by the process just outlined, in foraminiferal ooze undergoing moderate solution. Ultimately, strong clustering of individual weights around a rather high value for each size bracket in each species should indicate the effects of selective solution.

My evidence indicates that *Globigerina* ooze is affected appreciably by the undersaturated ocean water well above the compensation depth, even over extremely short time spans. Some protection on the ocean floor therefore seems to be necessary, where exposure times are much longer than the duration of my experiment. Such protection may be provided by a semisaturated layer of bottom water. The end effect is adjustment of the assemblage to the surrounding ocean water.

The mechanism of adjustment seems to be selective solution. In the samples studied, the spinose species and the larger specimens of the various species appear to dissolve more rapidly. Solution tends to reduce the diversity of an assemblage, change the size distribution, and decrease the range of weights of single tests for each size in the various species.

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5. Set by M. N. A. Peterson at 18°49′N, 168°31′W; I was permitted to use it.
6. Weight loss and solution rate are related as follows: solution rate (percentage per day) = [4.60517—log (100—weight loss)]/120. For values lower than about 20 percent it is sufficient to divide the weight losses given in Fig. 1 by 120, for similar results. The two samples at 250 m show weight increases of 0.3 (untreated) and 2 percent (treated with hydrogen peroxide); this gain may be due to either precipitation of calcium carbonate or experimental error.
7. Comparison with the solution profile for calcite spheres on the same buoy (*4*) shows that the values at 4250 m are unrealistically low; for this reason they were omitted when the lines were drawn in Fig. 1. All other samples in this container (I have not reported on them) show the same effect. I suspect that the container did not turn freely into the current.
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Chemical Exfoliation of Vermiculite and the Production of Colloidal Dispersions

Abstract. *Chemical treatments involving ion exchange cause gross one-dimensional swelling in water of single crystals of vermiculite minerals. A delicate balance of forces holds the individual silicate layers (10 angstroms thick) parallel to one another although separated by several hundred angstroms. Colloidal dispersions produced from the swollen crystals are morphologically unique and show strong film-forming characteristics.*

Vermiculites are hydrated magnesian aluminosilicate minerals with a layer structure similar to that of the micas (*1*). Like the micas, they occur as plate-shaped crystals consisting of 10-Å-thick silicate layers superimposed as in a pack of playing cards. The silicate layers are negatively charged and electrical neutrality is preserved by the presence of cations between layers. In the case of micas, these interlayer ions are usually K^+, whereas in the vermiculites they are usually Mg^{2+} or Ca^{2+} and are associated with double layers of water molecules. Under appropriate conditions, vermiculites are able to im-