Bering Land Bridge: Evidence of Spruce in Late-Wisconsin Times

Abstract. *A 14-meter core from a crater lake on Saint Paul Island in the Pribilofs has been examined by pollen analysis. Radiocarbon dating indicates that the core spans more than 10,000 years and probably more than 18,000 years. A spruce-pollen maximum about 10,000 years ago suggests that spruce advanced to the flanks of the southern coast of the Bering land bridge toward the close of the land-bridge period. The forests of Alaska and Siberia did not merge, however, and the environment of the southern coast of the land bridge remained cold.*

The Bering land bridge existed whenever eustatic lowering of sea level exposed the surface of the Bering-Chukchi platform (*1*). Pollen evidence (*2, 3*) and plant distributions (*4*) have shown that the central land bridge supported only tundra vegetation across which the forests of Asia and America did not merge during the Pleistocene. Ancestors of the American aborigines, who are believed to have arrived by way of the land bridge (*5*), would, according to this evidence, have been equipped for life in treeless regions. The mildest land-bridge climate, supporting the most mesic vegetation, may be expected to have been in the southern coastal regions. While analyzing pollen of sediments from the Pribilof Islands, which lie on the southern edge of the Bering-Chukchi platform (Fig. 1), I came upon unexpected evidence of an advance of trees near the southern coast of the land bridge.

Circular Lake Hill Lake on Saint Paul Island (Figs. 1 and 2), 200 m in diameter by 3 m deep, occupies the crater of Lake Hill; it has no inlet or outlet. A core (Table 1, A) taken from the center of the lake with a piston sampler shows that sediment is 14 m thick. A second core (Table 1, B), 9 m long, was taken about 60 m from the shore. The cores show that 5 to 6 m of greenish-brown organic deposit overlies a layer of grey-brown silty gyttja about 2 m thick. The bottom several meters of the deposit consists of irregular bands and layers of grey mud and sand.

Six radiocarbon ages have been determined for segments of core A (Table 1). The top four determinations are successively older with depth in the core, reaching a maximum of 17,800 years at 10.5 to 10.8 m; the bottom two are anomalously and successively younger: 7680 years at 13.0 to 13.2 m and 5760 years at 13.65 to 13.95 m. The cause of this inversion in apparent age of specimens deep in the core is uncertain: it cannot have resulted from overturning by sliding or slumping because the lake basin is too shallow and the bottom slopes are too gradual; nor can it result from a redeposition of older organic sediments from above the lake, because the steep and rocky slopes that rise uniformly to the crater rim, about 30 m above the lake, have no accumulation of organic matter. The validity of the upper dates was checked by dating a sample from core B, which (9250 years old) closely correlated by gross stratigraphy with the 9570-year sample from core A. These arguments together make it certain that the 5000- to 7000-year ages obtained near the bottom of core A do not represent true ages.

The anomalously young determinations on specimens from the bottom of core A may be explicable as follows. Water is probably retained in the lake by a plug of organic sediment that seals an originally permeable rock basin. Similar craters on Saint Paul Island, having sandy or rocky floors, hold water only during the wetter parts of the year. Between the permeable basin of Lake Hill Lake and the organic plug there are several meters of sandy deposit, including lenses of coarse sand. A flow of groundwater from inside the crater rim, through the gently shelving sand strata in the bottom of the basin—and so, by seepage down the cone, to the water table of the island—could enrich the sand with modern carbon and so produce the anomalously young radiocarbon ages. This mechanism suggests that even the 17,800-year age, also in the sandy part of the core, may

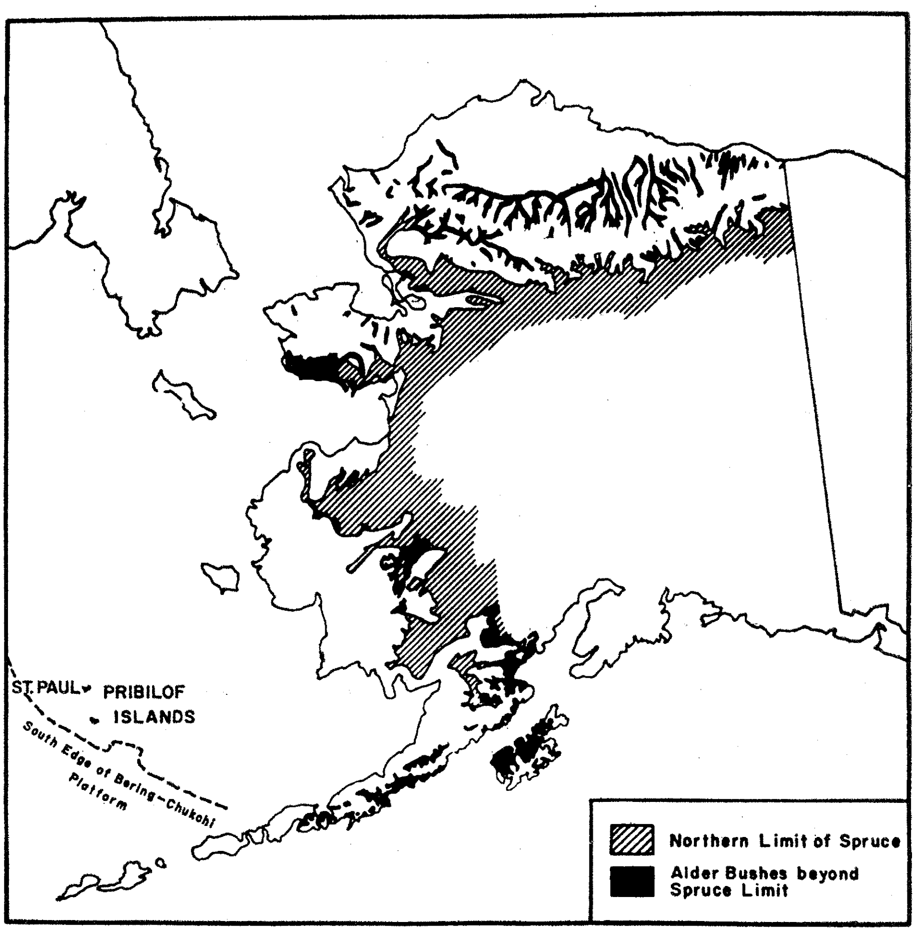

Fig. 1. The Bering Sea region, showing relation of Saint Paul Island to the Bering-Chukchi platform and the modern tree line (*13*) in Alaska. The portion of Siberia shown now supports only tundra.

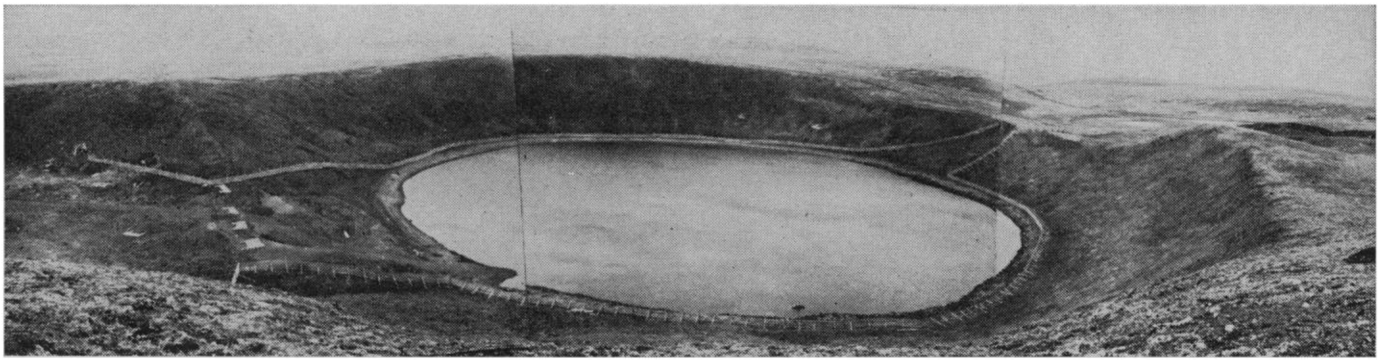

Fig. 2. Lake Hill Lake, Saint Paul Island, Pribilofs, lying about 85 m above sea level and 60 m above the surrounding plain. The only land above the lake is the 30-m rim of the crater. At left is a small subsidiary crater of the same main cone; the fence is a reindeer corral.

be too recent. The stratigraphically higher determinations of age lie within the plug of organic sediment and should represent true ages.

Most of the pollen throughout core A (Fig. 3) is of tundra plants. Changes revealed in the composition of the tundra are not without interest (*3*), but pollens of birch (*Betula*), alder (*Alnus*), and spruce (*Picea*) also occur in apparently significant amounts.

Birch pollen is common in diagrams of mainland arctic pollen because dwarf birch (*B. nana*) is present in many tundra communities. A significant appearance of alder pollen is usually taken to mean alder bushes within a few tens of kilometers; similar appearance of spruce pollen, that the tree line was no more than about 50-km distant (*2, 3, 6*). No dwarf birch, alders, or spruce now grow on the Pribilof Islands (*7*); the nearest plants of all three genera are hundreds of kilometers away on the Alaskan and Siberian mainlands. My series of surface pollen samples from the Pribilofs shows that alder pollen may reach 5 percent of the modern pollen rain. Spruce and birch pollens always occur, but in trace amounts of less than 1 percent. These amounts of alder, spruce, and birch pollen must have been blown to the islands from the mainland, so that one may infer that similar quantities blew there in the past. Most of the alder-birch spectrum (Fig. 3) can be explained in this way, although a maximum at about 7 m is sufficiently dramatic to warrant closer investigation.

This birch-alder maximum coincides with a spruce maximum reaching 20 percent of the total pollen. In the top 5 m of the core, as in the surface samples, spruce pollen is present only in trace amounts—perhaps less than 0.1 percent. On the mainland, 20 percent of spruce pollen would suggest that

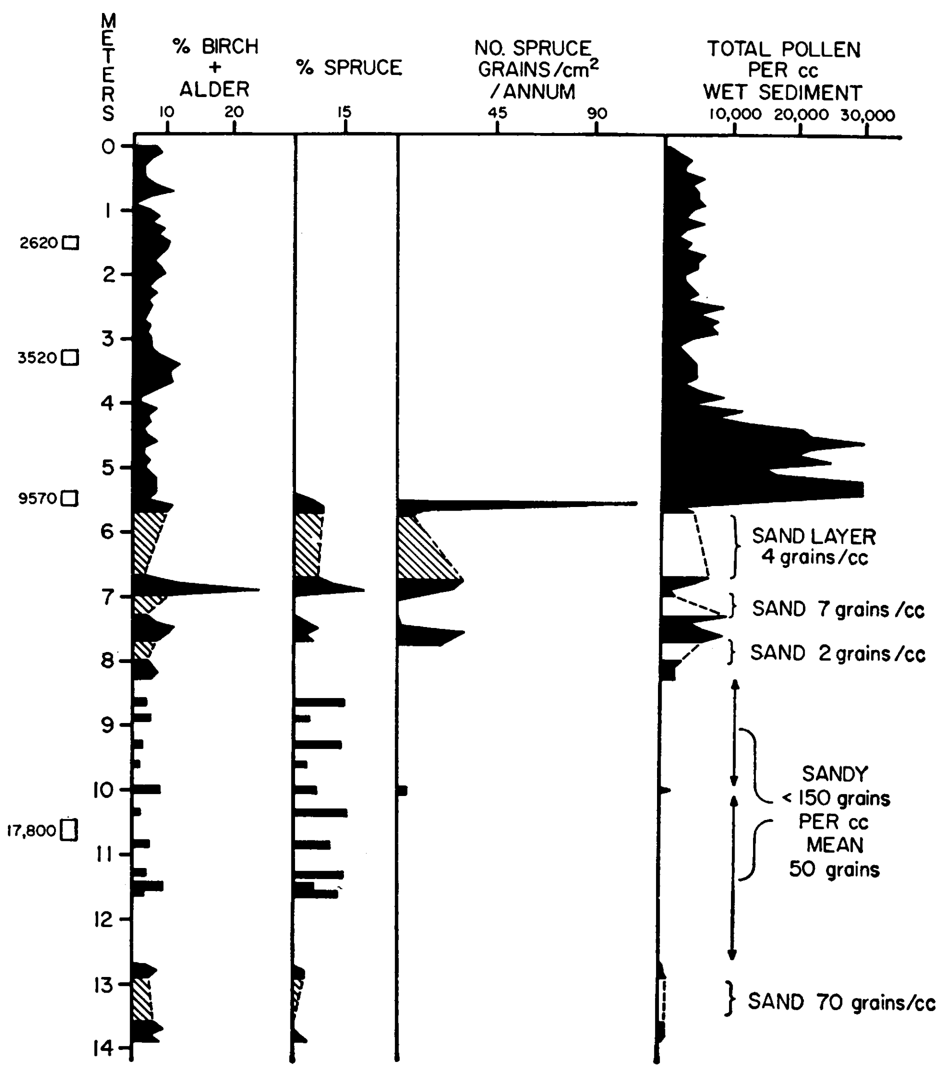

Fig. 3 (right). Partial pollen diagram for Lake Hill Lake core A. Hatched intervals in individual diagrams represent sand layers bearing little or no pollen. Histograms represent sums of several adjacent samples. Pollen sums were about 150 pollen grains, pteridophyte spores, and *Sphagnum* spores. Amounts less than 1 percent are not shown. Fall of spruce pollen per annum calculated on the assumption of a constant rate of deposition of dry sediment between dated segments of core. Falls of less than one grain per annum are not shown. Values at left are years ago.

Table 1. Radiocarbon dating (1950) on two cores from Lake Hill Lake, Saint Paul Island.

Sample No.	Depth (m)	Age (yr)
	Core A	
Y-1388	1.4 – 1.6	2620±160
Y-1389	3.2 – 3.4	3520±100
Y-1390	5.4 – 5.6	9570±160
Y-1391	10.5 –10.8	17,800±700
I-1848	13.0 –13.2	7630±270
I-1846	13.65–13.95	5760±180
	Core B	
I-1990	4.6 – 4.9	9250±150

the tree line was within 50 km. The Pribilof sediments containing considerable percentages of spruce pollen were deposited more than 9500 years ago in times when the site must have been near the coast of the Bering land bridge. This spruce maximum, with its hint of trees on the land bridge, is, if real, a remarkable discovery deserving close examination.

The spruce maxima are of two kinds. Between 5.5 and 8.3 m the samples containing spruce pollen were rich in other pollens also (Fig. 3). In these samples a considerable rise in the percentage of spruce pollen may possibly mean a real increase in the absolute number of spruce grains being deposited. But throughout most of the sandy sediment below 8.3 m the total pollen content of the samples was very small (Fig. 3), so much so that it was necessary to sum the counts from several samples (where histograms are used in Fig. 3) before percentages were calculated. In these samples it is not unreasonable to attribute the high percentages of spruce pollen to relative reduction in the amount of all other pollen rather than to an increase in the amount from spruce. The reality of both sets of spruce maxima may be tested by calculating the annual fall of spruce pollen.

Pollen fall on unit area in unit time may be calculated if the pollen and water contents of subsamples are known and if the sedimentation rate can be determined by some independent means such as radiocarbon dating. Such calculation provides the most satisfactory pollen statistic (*8*), but may be time-consuming. Fortunately my counting of spruce grains was simplified by their distinctive size, which enabled them to be sought and identified under the low power of the microscope (*9*).

For the calculated fall of spruce pollen per square centimeter per annum (Fig. 3; Table 2, C), a constant rate of deposition between the radiocarbon-dated core segments was assumed. The results suggest that the upper portion of the spruce maximum is real, there being an increase of between one and two orders of magnitude in the fall of spruce pollen on the lake. On the other hand, the results confirm the suspicion that the lower high-spruce percentages (histograms) do not represent significant incidence of spruce.

These calculations suggest that during much of Wisconsin time the fall of spruce pollen on Saint Paul Island was comparable to that of the present day, but that during a period of unknown duration, before 9500 years ago, there was a massive increase in the fall of spruce pollen. The rate then fell back to the very low level that has continued throughout postglacial time.

The greatest possibility of error in these calculations lies in the estimation of sedimentation rates, especially because the 17,800-year age is somewhat suspect. The apparent spruce maximum can be made to disappear by selection of an arbitrarily low sedimentation rate for the core segment that includes it. The rate used in the calculation was 1 cm/33 years (dry matter), but the overlying organic sediment was deposited at a rate of 1 cm/231 years: and the top meter of the core (which contains 98 percent water), at 1 cm/870 years. Spruce fall was recalculated (Table 2, D) on the assumption that a constant rate of 1 cm/231 years (dry matter) prevailed for all material below the 9500-year age. That this is a conservative assumption is shown by consideration of its implications for the age of the core: the bottom of the spruce maximum at 7.7 m would have an age of about 35,000 years (*10*). Even on this conservative assumption, the spruce maximum is still significant. Therefore it must be considered proven that there was a real increase in the amount of spruce pollen falling on Saint Paul Island in late-Wisconsin time.

It seems highly unlikely that the spruce-pollen maximum may have resulted from increased transport by wind from a tree line as distant as today's; the alternative is that spruce grew much closer to the island than it now does.

At the time of the spruce maximum the Wisconsin glaciation, and hence the life of the Bering land bridge, was drawing to a close. The retreat of the ice should have been accompanied—perhaps anticipated—by climatic warming. Such climatic warming may have favored an advance of spruce from refugia in Alaska or Siberia to the southern plains of the land bridge. Such spruce stands on the land bridge would have maintained themselves until they were drowned by the returning sea or until they were reduced by the maritime climate that preceded the advancing coast.

This postulated history parallels that of a temporary advance by spruce in northwestern Alaska at the close of the Wisconsin glaciation (*11*). It satisfactorily accounts for the spruce-pollen maximum. An associated advance of dwarf birch and alder would have accounted for the high birch and alder percentages near the 7-m level (*12*).

Table 2. Spruce-pollen counts and calculations of spruce-pollen fall per square centimeter per annum for Lake Hill Lake core A. Pollen fall is based on two assumed rates of sedimentation (dry): a constant rate between each pair of radiocarbon ages (C), below the 17,800-year age at 10.5 m, the rate being assumed to be that of the interval bounded by the 9570- and 17,800-year ages (1 cm/33 years); the rate between the 3520-year segment (3.3 m) and the 9570-year segment (5.5 m) (1 cm/231 years) applying to all material below 5.5 m (D). Values in parentheses are means from multiple samples.

Sample: Depth (cm)	Sample: Pollen count (grains)	Pollen deposition (grains cm^{-2} yr^{-1}): C	Pollen deposition (grains cm^{-2} yr^{-1}): D
0–460	(5)	(1)	(1)
470–530	(1)	(0.05)	(0.05)
537*	0	0	0
540	2	0.04	.004
545*	0	0	0
550	74	109	15.6
560	124	12.6	1.8
561*	15	6.1	0.9
570	159	8.3	1.2
580–660 (sand)			
670	46	29.7	4.2
680	32	26.7	3.8
690	30	24.2	3.5
700	2	0.09	0.01
710–720 (sand)			
730	4	.18	.03
740	54	1.7	.25
750	162	30.6	4.4
753*	65	17.3	2.5
760	27	24.3	3.5
770	34	20.0	2.9
780–790 (sand)			
800	1	0.1	0.01
810	2	.2	.02
820	1	.1	.01
830	4	.3	.04
840–990	(4)	(.3)	(.04)
1000	(14)	5.3	.75
1010–1350	(7)	(0.3)	(.04)
1360–1390	(15)	(.3)	(.04)

*Resampled and checked.

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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References and Notes

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3. ———, in *The Bering Land Bridge* (*1*).
4. E. Hultén, *Outline of the History of Arctic and Boreal Biota during the Quaternary Period* (Akliebolaget Thuel, Stockholm, 1937); I. Hustich, *Arctic* **6**, 149 (1953).
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8. M. B. Davis, *Amer. J. Sci.* **261**, 897 (1963).
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 ($\times$ 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.
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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