Antarctic Ocean-Floor Fossils: Their Environments and Possible Significance as Indicators of Ice Conditions[1]

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ABSTRACT: Seven Antarctic marine environments are examined with respect to their geology and to the skeletal remains of marine microorganisms. While all assemblages live in the same water mass, they vary significantly from place to place. Geology and oceanography of each locality appear to produce less effect upon the character of populations than do topography and bay ice. The latter features suggest a possible use of fossils as indicators of conditions of bay ice.

DURING THE ESTABLISHMENT by the U. S. Navy of permanent scientific bases in the Antarctic, from 1955 to 1957, coring and Orange Peel sampling of the ocean bottom was carried out under the general supervision of Dr. Willis L. Tressler, Senior Oceanographer assigned to U. S. Naval Task Force 43. This subdivision of command was responsible for the Navy's commitment in Antarctica. The author of this report was Chief of Staff.

General areas of ocean-bottom sampling considered in this paper are: Ross Barrier, McMurdo Sound, Hallett Inlet, Robertson Bay, Sabrina Coast, and Knox Coast. During the period of this study the Bay of Whales, once carved in the Ross Ice Shelf, was not extant, having been erased by iceberg-calving some time between 1947 and 1954. Since it was not possible to carry out sampling there, the Gould material, collected from the Bay of Whales in 1929 and analyzed by Warthin (1934), is considered in this paper.

The region represented in Gould's sampling is from the Bay of Whales to the Knox Coast (Clark Peninsula) (Fig. 1). This sector encompasses ca. 2,100 miles of the periphery of Antarctica, extending through ca. 90° of longitude. This continental periphery is washed by the Circumpolar Countercurrent, an easterly current generated by prevailing winds and directed by Coriolis force. Surface temperatures range from —1.62°C to —2.13°C; bottom temperatures, from —1.00°C to —1.85°C. The surface current attains velocities as high as 3 knots (author's observation).

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THE STATIONS

Sampling was undertaken at the following stations:

Bay of Whales: In 1929 (when the Gould material was collected), the Bay of Whales was an indentation in the Ross Ice Shelf 13 miles long by 5 miles wide. During its life the embayment's shape and dimensions were constantly changing. As far as anyone knows, bay ice was swept out of the bay every year. Breakup generally occurred in January or February when winds produced waves which entered the bay and cracked the ice. The Gould collection of sediments was made at 78°34'S, 163°48'W in 548 m of water. The outer limits of the Ross Ice Shelf are known to fluctuate (Thomas, 1960) and an embayment (Discovery Inlet) once occupied the area where the sampling was made. However, this location now generally features hummocky sea ice during the greater part of the year. It is free of fast ice during the summer months.

Arrival Bay: This is a cove in Ross Island on the eastern side of McMurdo Sound. It is separated from Winter Quarters Bay (where Scott's "Discovery" was frozen in for two years) by Hut Point. Ross Island is of Tertiary orogeny and consists chiefly of beds of lava and tuff. Mt. Erebus, an active volcano, is situated on the northwest side and Mt. Terror (now extinct) on the northeast side. There

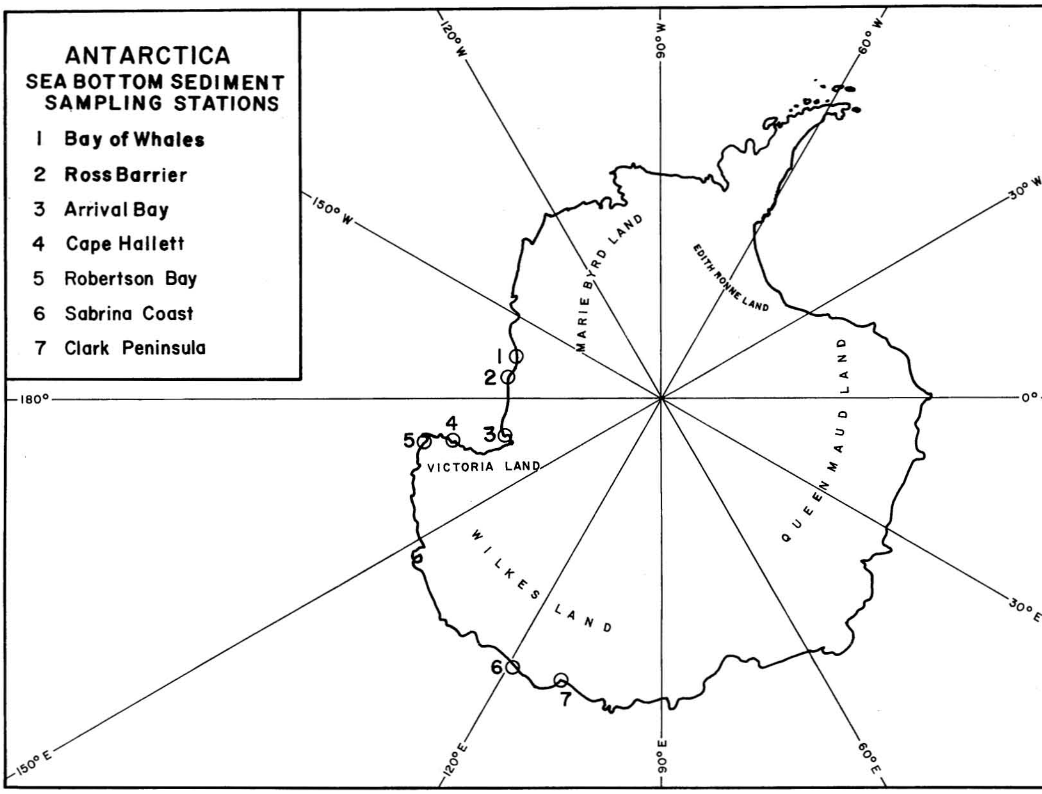

FIG. 1. Map showing sampling stations.

are several vestigial cinder cones on the island. The bay ice does not renew itself perennially. For this reason the U. S. Naval Air Facility was located at Hut Point, where heavy aircraft could land on the bay ice the year around. The sample from this location was collected in 46 m of water two days after the icebreakers "Glacier" and "Northwind" removed bay ice of 5-m thickness.

Cape Hallett: (72°18′S, 170°20′E). The cape headland (elevation ca. 1,500 m) consists of beds of lava and tuff cut by many dikes and occasionally faulted. It forms the east side of Hallett Inlet, which is 8 nautical miles long. The west side consists of Precambrian metasedimentaries which are only slightly metamorphosed and cut by intrusives. From this side Mt. Sabine rises sheerly to an elevation of 3,617 m. The mouth of the inlet is distinguished by a flat, triangular, raised beach beneath the cape headland. Hallett Beach serves seasonally as a rookery for an estimated 205,000 penguins (Carl Eklund, Scientific Adviser for the U. S. Department of Defense, personal communication). It is here that the U. S.–New Zealand Scientific Base is located. In 1956 bay ice was moving out of the inlet on the eleventh of February. In 1957, breakup of the bay ice occurred a month earlier, due no doubt to icebreaker preparation of a staging area at the entrance. On January 5, 1957 bay ice exceeded 3 m in depth throughout the length of the inlet. Dependability of the bay ice for aircraft operations most of the year was an important factor in its selection as a base site. The sample considered herein was collected near the mouth of the inlet in 200 m of water.

Robertson Bay: This is an embayment 20 miles long at Cape Adare (71°21′S, 170°00′E). The environment has been described by Priestly (1923). In brief, it resembles McMurdo Sound and Hallett Inlet geomorphologically, in that it was formed by a fault. The east side is of Tertiary origin and the west of earlier origin.

On the east side lava beds are cut by dikes and sills, while on the west side metasedimentary beds are intruded and heavily folded.

Ridley Beach, at the foot of Cape Adare, is a larger-scale version of Hallett Beach and supports a correspondingly larger population of penguins. Borchgrevink wintered here in 1898. The hut erected by him and used by Scott's northern party in 1912 is still intact.

The sample was taken in 402 m of water off Pressure Bay, on the west-central side of Robertson Bay. According to Priestly and Wright (1922) the ice in this location (as the name implies) is hummocky and unstable. Catastrophic breaks caused by violent winds and glacial activity create turbulent sea ice conditions. The present author steamed to the head of Robertson Bay in January, 1956 without sighting a vestige of bay ice. At the same time, the south part of McMurdo Sound and Hallett Inlet were frozen solid.

Sabrina Coast: The coast is an ice barrier throughout its length. No embayments of any consequence are carved in it. The pack ice is perennial, with consolidated fields of hummocky ice persisting until November or December. It stays this way until April, when floes break up, and then coverage varies between close and loose pack. The sea bed was sampled at 65°61′S, 119°21′E in a depth of 586 m.

Clark Peninsula: This is a headland approximately 3 miles long by 2 miles wide (maximum). It has been described in detail by Hollin and Cameron (1961). At the distal end of the peninsula the inland ice terminates in a heavily morained area. Outcrops are basically highly metamorphosed sedimentaries with garnet inclusions. These rocks have been intruded by granites and scored by dikes and sills of hornblendite, muscovite, and olivine, and by orthoclase and plagioclase feldspars.

Ice conditions at Vincennes Bay, wherein Clark Peninsula is located, are said to be turbulent with catastrophic breaks often producing open water in the winter. After breakup in the summer the area is kept generally ice-free by the Balaena Islets. These land masses dam the southwesterly drift of pack and glacial ice.

The bottom was sampled 450 m off Wilkes Station at 66°16′S, 110°34′E in 75 m of water. Organic remains in bottom sediments were exclusively diatomaceous.

DISCUSSION

An examination of sediment analyses (Tressler, 1957) shows the dominant material at each station: Kainan Bay (30 miles east of Bay of Whales)—feldspar, 50%; Arrival Bay—silicaceous sponge spicules and small shell fragments, 100%; Hallett Inlet—shells, 30%; Robertson Bay—feldspar, 40%; Clark Peninsula—feldspar, 50%.

No analysis was made of the Sabrina Coast material.

Table 1 shows the incidence of skeletal remains of microorganisms in each of the locations sampled.

In his discussion of the Gould collection of Bay of Whales sediments, Warthin (1934) remarks, "Although foraminifera with secreted calcareous tests comprise one-sixth of the species, they make up only 7.2 percent of the individuals present. This condition is markedly different from that found by the *Terra Nova* expedition on the western side of the Ross Sea where 60 percent of the species collected were calcareous."

The foraminifera listed in the table which have calcareous tests comprise the following percentages of species and individuals at stations indicated:

STATION	PERCENTAGE OF CALCAREOUS SPECIES	PERCENTAGE OF CALCAREOUS INDIVIDUALS
Ross Barrier	2.0	7.0
Arrival Bay	67.0	92.0
Cape Hallett	82.0	75.0
Robertson Bay	30.0	25.0
Sabrina Coast	33.0	35.0

Ostracod carapaces were present only in the Arrival Bay and Cape Hallett sediments. Radiolarian skeletons, on the other hand, were absent in these sediments and present only in the Ross Barrier, Robertson Bay, and Sabrina Coast materials. Warthin (1934) mentioned the presence of radiolaria in the Gould collection from the Bay of Whales. They were not identified.

Bearing in mind that the Bay of Whales, Ross

TABLE 1

TABLE OF ORGANIC REMAINS

SPECIFIC NAME	INCIDENCE OF OCCURRENCE[1] ROSS BARRIER	ARRIVAL BAY	CAPE HALLETT	ROBERTSON BAY	SABRINA COAST
FORAMINIFERA					
Rhabdammina discreta Brady	O	O	O	A	A
Marispella cylindrica Brady	A	O	O	R	O
M. elongata Norman	R	O	O	O	O
Saccammina sphaerica M. Sars	O	O	O	R	O
Lagenammina languncula Rhumbler	O	O	O	A	A
Bathysiphon filiformis M. Sars	R	O	O	O	O
Psammosphaera fusca Schultze	O	O	C	A	A
P. testudinaria Rhumbler	O	O	O	R	O
Psammophax conscoiata Rhumbler	R	O	A	O	O
Saccorhiza ramosa (Brady)	R	O	O	O	O
Thurammina protea Earland	R	O	O	O	O
T. spumosa Earland	O	O	R	O	O
Pelosina elongata Wiesner	O	O	O	A	R
P. bicaudata Parr	O	O	O	C	R
Reophax tubulata (Rhumbler)	O	O	O	A	A
R. fusiformis Williamson	O	O	O	C	A
R. longicolis Wiesner	O	O	O	A	A
R. bulbosa Chapman and Parr	R	O	O	O	O
R. difflugiformis (Brady)	R	O	O	O	O
R. distans Brady	C	O	O	R	O
R. nodulosus Brady	O	O	O	C	A
R. pilulifera Brady	C	O	O	O	O
R. dentaliniformis Brady	C	O	O	C	O
Hormosima ovicula Brady	O	O	O	C	O
H. globulifera Brady	O	O	O	R	O
Trochammina ochracea Williamson	O	R	O	C	O
T. globigeriniformis Parker and Jones	O	R	O	O	O
T. rossensis Warthin	R	A	O	R	O
T. rotaliformis Wright	C	R	O	O	O
T. turbinata Brady	R	O	O	O	O
T. nana Brady	C	R	O	O	O
Ammodiscus incertus d'Orbigny	O	R	C	O	O
Ammoglobigerina globigeriniformis Parker and Jones	R	C	O	O	O
Patellina antarctica Parr	O	R	R	O	O
Haplophragmoides canariensis d'Orbigny	A	A	A	A	A
Alveolophragmium wiesneri Parr	R	O	O	O	O
A. subglobosum (G.O. Sars)	O	O	O	R	R
Cyclammina orbicularis Brady	O	O	O	O	R
C. ousilla Brady	O	O	O	C	A
Textularia tenuissima Earland	R	O	O	A	C
Miliolinella wiesneriana Rhumbler	O	O	R	A	A
Miliammina arenacea Chapman	O	O	O	A	R
Biloculinella lata Wiesner	O	R	R	O	O
Cruciloculina triangularis d'Orbigny	O	O	R	O	O
Silicosigmoilina groenlandica Cushman	A	O	O	O	O
Sigmoilina obesa Heron-Allen and Earland	O	O	C	O	O
Pyrgo depressa d'Orbigny	O	O	C	O	O
P. elongata (d'Orbigny)	O	O	R	O	O
Lagena hertwigiana Brady	O	O	R	O	O
L. substriata Williamson	O	O	C	O	O
L. subacuticosta Parr	O	O	A	O	O

TABLE 1 (*Continued*)

SPECIFIC NAME	INCIDENCE OF OCCURRENCE[1]				
	ROSS BARRIER	ARRIVAL BAY	CAPE HALLETT	ROBERT-SON BAY	SABRINA COAST
L. globosa Montagu	O	O	R	O	O
Oolina melo d'Orbigny	O	O	C	O	O
O. heteromorphia Parr	O	O	C	O	O
Fissurina fissicarinata Parr	O	O	A	O	O
F. trigono-marginata Wiesner	O	O	A	O	O
Vaginulinopsis tasmanica Parr	O	O	R	O	O
Glandulina antarctica Parr	O	O	R	O	O
Lenticulina asterizans Parr	O	O	A	O	O
Nonion sp.	O	R	A	O	O
N. pompilioides (Fichtel and Moll)	O	R	O	O	O
Astronomion stellatum Cushman and Edwards	O	R	O	O	O
Bulimina aculeata d'Orbigny	O	O	O	O	R
Angulogerina earlandi Parr	O	O	R	R	A
Uvigerina bassensis Parr	O	A	C	O	O
Ellipsolagena ovata Wiesner	O	O	O	O	R
Discorbis araucanus d'Orbigny	O	R	O	O	O
D. globularis d'Orbigny	O	R	O	O	O
Ehrenbergina glabra Chapman and Parr	O	A	A	O	O
Cassidulina crassa d'Orbigny	O	R	R	O	O
C. crassa var. porrecta Heron-Allen and Earland	O	R	R	O	O
C. subglobosa Brady	C	A	R	O	O
Globigerina bulloides d'Orbigny	O	R	O	O	A
G. pachyderma Ehrenberg	O	R	O	O	A
Globorotalia hirsuta d'Orbigny	O	R	O	O	O
G. scitula Brady	O	R	O	O	O
G. truncatulinoides d'Orbigny	O	R	C	O	O
Cibicides cf. *refulgens* Montfort	R	O	O	O	O
C. subhaidingerii Parr	O	O	O	O	R
OSTRACODA					
Krithe bartonensis (Jones)	O	A	O	O	O
K. tumida Brady	O	A	R	O	O
Macrocypris inequalis Muller	O	O	C	O	O
Xestolebris kerguelensis Muller	O	R	R	O	O
X. meridionalis Muller	O	R	R	O	O
Cythereis devexa Muller	O	O	C	O	O
C. polylyca Muller	O	C	O	O	O
Cytheridea spinulosa Brady	O	C	A	O	O
Cytherepteron irregularis Muller	O	O	C	O	O
C. fallax Muller	O	A	A	O	O
Paradoxtoma kerguelensis Muller	O	O	C	O	O
P. antarcticus Muller	O	R	C	O	O
Erpetocypris helenae Muller	O	R	R	O	O
RADIOLARIA					
Cenosphaera cristata Haeckel	R	O	O	A	A
C. favosa Haeckel	C	O	O	O	O
Carposphaera nobilis Haeckel	A	O	O	A	A
C. prunulum Haeckel	R	O	O	A	A
Carposphaera sp.	O	O	O	A	R
Cromyosphaera antarctica Haeckel	O	O	O	C	A
Haliomma sp.	C	O	O	O	O
Spongoplegma antarcticum Haeckel	O	O	O	O	R
Tessara pelma sp.	O	O	O	O	R
Lonchosphana spicata Popofsky	O	O	O	O	R

TABLE 1 (*Continued*)

SPECIFIC NAME	INCIDENCE OF OCCURRENCE[1] ROSS BARRIER	ARRIVAL BAY	CAPE HALLETT	ROBERTSON BAY	SABRINA COAST
Spongodiscus sp.	A	O	O	A	C
S. favus Ehrenberg	O	O	O	A	A
S. radiatus Haeckel	O	O	O	A	A
Stylotrochus craticulatus Haeckel	C	O	O	R	O
Stylotrochus sp.	C	O	O	R	C
Spongotrochus sp.	O	O	O	C	C
Dicolocapsa microcephala Haeckel	O	O	O	C	C
Tristylospyris sp.	O	O	O	R	O
Dictyocephalus sp. A	O	O	O	R	O
Dictyocephalus sp. B	O	O	O	R	O

[1] Explanation of symbols:
A = Abundant (more than 1 specimen per cm^2)
C = Common (more than 0.1 and less than 1.0 per cm^2)
R = Rare (less than 0.1 per cm^2)
O = None

Barrier, Robertson Bay, and Sabrina Coast environments are ones of unstable sea ice conditions, it seems significant that silicaceous or arenaceous skeletal remains are dominant among organic material in the sediments. And it appears equally significant that calcareous shells are dominant in the sediments of Arrival Bay and Cape Hallett—where the sea ice cover is stable and smooth.

McKnight (1962) said, ". . . the calcareous benthonic populations (of foraminifera) are believed to be in areas of little or no bottom current, and the arenaceous populations to be in areas of either greater depths or bottom currents." McKnight attributed the high percentage of calcareous benthonic foraminifera to a lack of deposition of ice-rafted clastics, giving an apparent increase in production.

The evidence seems to support McKnight's postulation of ice-rafting, since feldspar dominates the sediments where sea ice is unstable. Tressler (1957) measured the thickness of unstable hummocky pack ice in the western Ross Sea in late October. He found that most of the ice scarcely exceeded 3–4 ft in thickness. It is indeed possible for an iceberg to plow through this kind of ice and to enter embayments such as Robertson Bay. But an iceberg cannot penetrate stable bay ice that is thick, to encroach upon an embayment.

In concurrence with McKnight's belief (1962) the evidence shows that calcareous shells are dominant in embayments where the ice-cover is stable and bottom currents are weak. This might well result in an "isolated" benthonic environment where the amount of bound carbonate enhances the production of calcareous shells. Since radiolaria are planktonic, it is unlikely that their skeletal remains will be found in embayments which are isolated from the body of the current.

CONCLUSION

From the foregoing it appears that knowledge of the amount of calcareous remains in the sediments of an unobserved Antarctic location would be of value in determining the suitability of the ice-cover for aircraft and staging operations. Moreover, such information is likely to be of even greater value to submarine stratigraphy and its application to paleo-oceanography.

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