

Paleoecology and Sedimentation in Part of the Arctic Basin

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INTRODUCTION

The Arctic Basin occupies an area of approximately 10 million sq. km. Information available suggests that the number of sediment cores taken from the Arctic Ocean by all students of the area is of the magnitude of one for every 10,000 sq. km. and these have not been uniformly spaced. The amount of detail provided by such coverage is not impressive to the geologist who may be accustomed to working with continual sediment sections along a mountain front or from wells which have been drilled at 10- to 20-mile intervals into the earth's sediment crust.

Most of the 1,000 or so sediment cores which have been taken from the Arctic Ocean floor are less than 4 m. long. Our best age determinations show that these cores provide little more than a million or a million and a half years of the sediment record. Thus the argument that we know very little concerning arctic paleoecology based on sediment studies is well founded.

HISTORY

The history of sedimentologic and resulting paleoecologic interpretations of the Arctic Basin can be divided quite easily into three parts. The first part is that interval of work, largely Russian, which was involved with sediment studies of the arctic coastal areas and rivers. This work extended from early in this century to about 1950; it was conducted from ground and shipboard stations and largely involved grab samples of surface sediment. One exception was work done on the Russian drifting station North Pole 1 which consisted of sampling the upper 20 cm. of sediment during 1937-38 (Androsova 1962). Emery (1949) summarized much of the Russian data for the Arctic and the first three volumes of the *Arctic Bibliography* (Tremaine 1953) neatly tabulate most of the sediment studies for this period.

The second chapter of sedimentologic work in the Arctic is that of the Russians during the past 20 years. This work has been done in many parts of the Russian Arctic as well as from more seaward parts of the Arctic Ocean. Shipboard work along coastal areas and from drifting ice islands has provided considerable data on surface sediments. In addition, and especially important for paleoecologic work, short sediment cores have been recovered and studied. Belov and Lapina (1959) summarized a study of 450 cores whose average length was 100 to 150 cm. These were taken from ice islands in the central Arctic Ocean. By 1950,

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more than 500 cores had been collected. From these cores, the distribution of sediment types and some microfaunal data were obtained (Belov and Lapina, 1962). Longer cores, some 6 m. long, were taken as some of 500 bottom samples collected from the central, eastern and southern parts of the Bering Sea (Gershovich 1962). More recently, Linkova (1965) has reported some details of sediment study from short cores taken from the Lomonosov Ridge. Ignatius (1961) reported on 41 one to three metre cores taken in the Barents Sea.

These studies and others which were based only on surface samples have furnished isolated facts on chemical, mineralogic, petrographic and faunal patterns for an enormous area. The data are still too few and the intervals of "no data" too large to give much more than a hint of the kind of comprehensive survey which is needed for the Arctic.

The third chapter of sediment study in the Arctic is a brief one and based mainly on the work of North Americans. Much of this has been sponsored by the United States and supported by NARL. This includes the Beaufort Sea studies of 1950 and 1951 during which 179 bottom samples were taken (Carsola *et al.* 1961), the U.S. Air Force Studies on T-3 (1959), the Kara Sea studies of the mid 1960's (Andrew and Kravitz 1968), and the Chukchi Sea studies (Creager and McManus 1961). Some of the other important studies include the work of Cromie (1960) who reported on 22 short cores taken from the drift station Charlie across the Chukchi Shelf, a study of 58 cores from the Arctic Ocean and 26 cores from the Greenland and Norwegian Seas by Ericson and others (1964), a study of cores from Baffin Bay by Marlowe (1966) and from the Alpha Cordillera by Herman (1964).

The Lamont Group, particularly K. Hunkins, has published a variety of small studies including work on some spectacular gravels from the Alpha Cordillera (Schwarzacher and Hunkins 1961) and several summary papers for parts of the same area (Hunkins and Kutschale 1967; Ku and Broecker 1967).

The data reported by these investigators and others are diverse and no important patterns of sedimentation or paleoecologic conclusions have been drawn from the reports. It is important to note that the early work involved bottom samples, not cores, but work from drifting ice masses during the past 30 years has facilitated recovery of hundreds of cores from many parts of the Arctic Ocean. Study of the cores will provide the framework for a thorough paleoecologic understanding of the Arctic Basin. Hopefully, new stations can be established in the Eurasia Basin so that "complete" coverage will be possible.

PRESENT STUDIES

To date, more than 300 sediment cores have been taken during the drift of T-3. After heat flow studies by Lachenbruch and Marshall on T-3 and sample examination in California, cores are sent to our laboratories at the University of Wisconsin in Madison. Throughout March 1969, more than 80 cores were received in Madison. Some 50 cores have been studied, the detail ranging from mineralogic analysis of top and bottom segments to a sediment, mineralogic and faunal study of every segment of some cores. Most of the cores for which we now have data

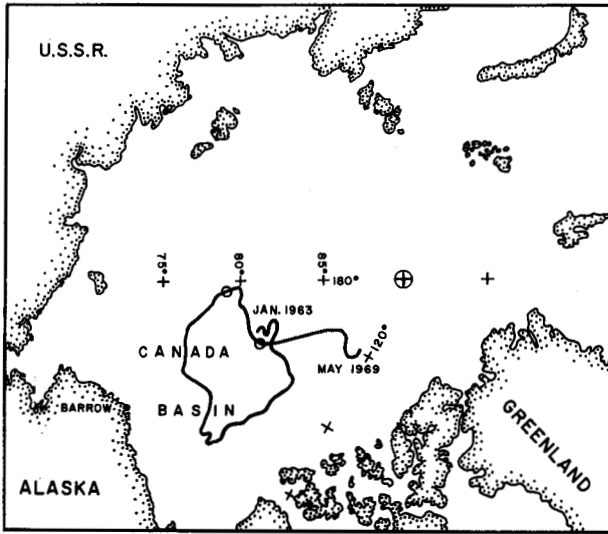


FIG. 1. Traverse of T-3 in Arctic Basin from 1963 to April 1969.

can be grouped as Canada Basin area cores or Alpha Cordillera area cores (Beal *et al.* 1966). Since 1963, T-3 has drifted from just off of the Alpha Cordillera, south the length of the Canada Basin, across the Chukchi Rise-Plateau, through the Charlie Gap, north to the Alpha Cordillera and now south, along the eastern edge of the Canada Basin (Fig. 1).

The study is in the data-gathering stage and only a few conclusions have been drawn from a mass of data. This report is a preliminary statement on our progress.

PROCEDURE

Cores are received in approximately 15 cm. segments. Samples for magnetic determinations are taken at approximately 5 cm. intervals in each segment. The remaining part of the sampled half-core is divided into portions for use in sedimentologic and faunal studies. Moisture content is determined for sub-portions of each segment and X-ray diffractograms are made for at least the top and bottom segment of each core. Samples are washed through a 250-mesh screen. Material passing through the screen is defined as "fine" and that caught on the screen is defined as "coarse." The percentage of coarse fraction for each sample is determined and studied for clastic and faunal components. The percentage of each is computed. To date, data for 50 cores have been determined. Present investigations are directed toward as complete a study as possible for top and bottom segments of every core. In addition, magnetic determinations and moisture and textural data are gathered for every segment of every core.

MAGNETIC STRATIGRAPHY AND RATES OF SEDIMENTATION

The most recent major reversal of the earth's magnetic field has left a good record in most of the cores which are 2½ m. long or longer (Fig. 2). The polarity

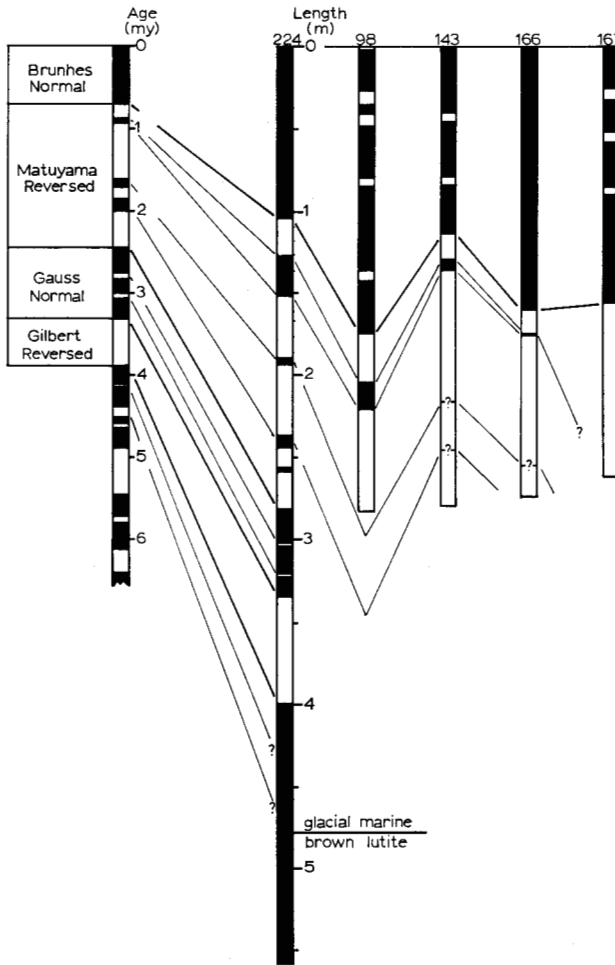


FIG 2. Magnetic stratigraphy and correlation of 5 cores from Canada Basin area (after Steuerwald *et al.* 1968).

change in the Arctic can be correlated with magnetic stratigraphy determined in other parts of the world (e. g. Cox *et al.* 1964; Opdyke *et al.* 1966; Hays and Opdyke 1967). Cores longer than 3 m. show the record of more numerous magnetic events. Core 224, for example, from 80°N., 158°W., is 5-6 m. long and may be correlated with magnetic events of the past 4 million years (Steuerwald *et al.* 1968).

The most recent major magnetic reversal (beginning of the Brunhes Normal) has been determined to be approximately 700,000 B.P. on the basis of varied radiometric measurements (Cox 1968); it has been found to occur between 100 and 200 cm. in many arctic cores. This fortuitous occurrence provides a very useful time line for a variety of studies. For example, using the assumption of a uniform rate of sedimentation and the time determination provided by the Brunhes polarity reversal, we have calculated apparent sedimentation rates of 1 to 3 mm. per 1,000 years for parts of the Arctic Basin. The highest rates of sedimentation have been found in the Canada Basin (Canada Plain area). There, cores taken in

the 80°N. area show minimum sedimentation rates of greater than 3 mm. per 1,000 years. In the 75°N. part of the Canada Basin, minimum rates of 2 to 3 mm. per 1,000 years have been found. Bathymetric data here show depths in excess of 3,600 m. and the high sedimentation rates are due, in part, to density flows which have been noted in cores from this area.

In contrast, cores from the Chukchi Plateau-Plain area have sedimentation rates of 1 to 2 mm. per 1,000 years. Water depths here are less than 2,000 m. or only one half as deep as the Canada Basin. Also, the Chukchi area contains sediment which apparently is free of density flows.

MOISTURE CONTENT

The percentage of moisture by weight for several intervals of each segment of each core studied was calculated. Moisture content is commonly but not always higher in the uppermost or surface sample. The percentages for each interval of the cores were plotted but no pattern of increase or decrease of moisture content with depth was apparent. The percentages range from 30 to 55 throughout the cores. However these data may be too few or post-coring treatment of the cores may be too unstable for meaningful results.

GROSS MINERALOGY

X-ray diffractograms have been prepared for every segment of 10 cores and for the top and bottom segments of 50 cores. The cores all contain approximately 15 to 25 per cent kaolinite, 15 to 25 per cent illite, 20 to 40 per cent quartz, and less than 10 per cent chlorite. The amounts of dolomite, calcite and feldspar tend to range more spectacularly than the clays or quartz, however. These three components were plotted on a triangular grid and some geographic pattern of mineralogy was apparent.

Windom (1969, p. 776) has provided significant data on the <2 micron clay mineralogy of dust from Greenland ice and has compared this to Arctic Ocean sediment. The kaolinite and chlorite percentages show some correlation with our percentages. Most interesting is Windom's conclusion that atmospheric dust may accumulate at rates of 1 mm. per 1,000 years. If this figure is valid for the Arctic, all or a considerable percentage of the total "fine" sediment which has accumulated in the Arctic, is of atmospheric origin.

Cores in the northern part of the Canada Basin have surface concentrations of dolomite and calcite in approximately equal parts. Lesser amounts of feldspar are present. In this same area the feldspar increases in relation to calcite and dolomite with depth in the cores.

In the central and southern parts of the Canada Basin, calcite concentration is nearly equal to that of dolomite and feldspar in surface samples but with depth the calcite shows a relative decrease compared to dolomite and feldspar.

The Chukchi area cores are more variable. In some cores the surface material is primarily dolomite and feldspar and in others calcite is present in amounts equal to the dolomite. In all surface samples feldspar predominates. In these cores there

is either no change in relative amounts with depth or there is a relative increase in feldspar with depth.

Clearly, these data provide little more than a hint of patterns of mineral distribution. Smaller-scale studies on diagenesis or authigenic minerals or trace element distribution which are planned may reveal more significant mineralogic patterns.

CARBONATE CONTENT

The total carbonate percentage of samples was determined by solution studies (Table 1). In the Canada Basin area, both tops and bottoms of cores have carbonate contents ranging from 7 to 28 per cent. In the Chukchi region, carbonate contents range from 9 to 16 per cent. In the northern part of the Canada Basin there is a general decrease in percentage of carbonate from the top segment to the bottom segment of 3-m. cores. For example, 14 per cent to 7 per cent, 26 to 7 per cent, 28 to 9 per cent, 24 to 14 per cent and 11 to 9 per cent are averages from top segments to bottom segments in 5 cores. In the southern part of the Canada Basin (75°N.) there is a general increase of carbonate with depth (11 to 15 per cent, 11 to 20 per cent, 11 to 28 per cent, 13 to 19 per cent, 17 to 20 per cent) but there are exceptions to this trend in this area too. In general, both parts of the Canada Basin have low numbers of Foraminifera but at least two of the cores from the Canada Basin have relatively numerous forms.

In the shallower Chukchi Plateau area, both increase and decrease of carbonate with depth was noted. All of these figures show some correlation with the X-ray data.

TABLE 1. Carbonate content of surface segment and bottom segment of selected cores*.

	Depth (m.)	(surface) % Carbonate	(bottom) % Carbonate
Northern Canada Basin	2245	14.0	7.9
	2213	26.5	7.2
	3415	28.5	9.6
	3492	24.6	14.2
	3746	11.1	9.5
	3741	11.0	15.8
	3757	11.9	8.6
	3695	11.0	20.2
3672	14.0	13.5	
Southern Canada Basin	3680	11.3	15.1
	3677	11.0	20.9
	3677	11.8	28.2
	3665	13.4	19.1
	3613	17.2	20.6
Chukchi Plateau	1564	14.4	8.0
	1845	9.0	13.4
	1870	16.3	7.7

*Based on weight loss due to treatment in 10% NCL.

TEXTURE ANALYSIS

Coarse or fine, by our definition, is sediment larger or smaller than 61 microns. The fine material is a remarkably uniform lutite. The coarse material consists primarily of Foraminifera tests and clastic particles. Almost every core has at some point at least one larger pebble. Some of these are striated and apparently were deposited from melting glacial ice which rafted these erratics to their site of deposition. Most of the erratics are carbonate.

Brown lutite is the dominant sediment type in the Chukchi area and 5 to 16 per cent of the sediment by weight is composed of coarse material. The Foraminifera fauna ranges from 30 to 90 per cent of the coarse fraction by weight.

In the Canada Basin, the coarse fraction of any sample is 1 to 3 per cent of the total. Generally, faunal elements comprise a smaller percentage of the coarse than in shallower waters. A gray colour predominates.

MICROFAUNA DISTRIBUTION

Some 30 species of Foraminifera have been identified. All, apparently, are benthonic with the exception of *Globigerina pachyderma*. No nannoplankton or radiolarians have yet been identified. Cores from all areas of the Arctic which have been studied have a greater microfaunal percentage in the upper segments than in the lower.

Foraminifera are much less frequent in the sediments of the Canada Plain than in the cores from other parts of the Canada Basin or shallower areas. Commonly, in the Chukchi area 30 to 90 per cent of the total coarse fraction (from 5 to 16 percent of each segment) is Foraminifera. Foraminifera in the Canada Basin samples comprise 0 to 80 per cent of the coarse fraction which is 1 to 3 per cent of each segment.

Different faunal realms are apparent but are not understood yet. Arenaceous Foraminifera are common in the Canada Basin but uncommon in shallower parts of the Arctic. *Globigerina pachyderma* is the dominant species in all samples and comprises up to 100 per cent of the fauna of some samples.

The *G. pachyderma* fauna provides a range of possible studies. The coiling direction of specimens and its relationship to water temperature is one. Another is a study of the ratio of young to mature individuals and their distribution in the various bathymetric provinces. Paleoecologic interpretations from these data as well as the composition of the benthonic Foraminifera and related ecologic parameters is a major area of investigation.

SOME PALEOECOLOGIC CONCLUSIONS

Climatic Change

It has been suggested that sediment of the glacial and interglacial periods may be identified on the basis of quantity of planktonic Foraminifera and ice-rafted debris found in Arctic Ocean cores (Ericson 1964). An abundance of *Globigerina pachyderma* with abundant ice-rafted material should indicate relatively open,

ice-free conditions, according to this idea. The arctic cores show pronounced fluctuations in abundance of *G. pachyderma* and coarse detritus. In some cores there is a general parallelism of these factors but in others, some closely spaced, there is no correlation. A high percentage of coarse content in a particular sample was often due to a high percentage of Foraminifera tests only. Rarely, a high percentage of coarse material was found to be due to high faunal and high clastic content. A regression graph of per cent detritus versus per cent fauna for several cores showed little relationship (Steuerwald *et al.* 1968).

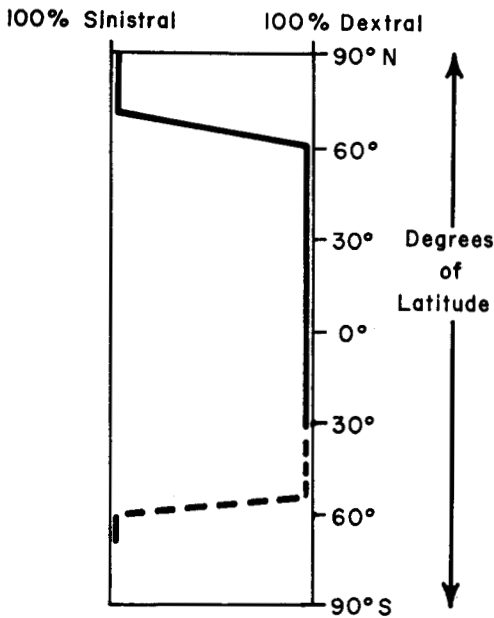


FIG. 3. Direction of coiling of *Globigerina pachyderma* and its relationship to latitude (after Bandy 1960).

A more interesting attempt at climatic interpretation has been made by tabulation of the sinistral or dextral coiling patterns of *G. pachyderma* (Steuerwald *et al.* 1968, Fig. 4). Various students have demonstrated that the present distribution of sinistral coiled *G. pachyderma* is related to water temperature (Bandy 1960; Ericson 1959). Present distribution of *G. pachyderma* as well as the distribution of this species during the Pleistocene is such that greater than 70 per cent of the population have sinistrally-coiled tests in cold water or during time of colder water (Bandy 1960), (Figs. 3 and 4). Relatively warmer waters support populations in which 90 to 100 per cent are coiled dextrally. Sinistral coiling forms were found to be dominant throughout several cores, usually at greater than 90 per cent. The only sustained trend noted throughout the core segments was toward less sinistral coiling specimens at the tops of cores. This has been summarized as follows: "If the water temperature control for coiling is related to climate, this coiling trend suggests that the Arctic has not been warmer than at present for at least the last one and one half million years. Altogether, these data do not indicate the existence of an interglacial or glacial ice-free Arctic during a great part of the Pleistocene" (Steuerwald *et al.* 1968, p. 83).

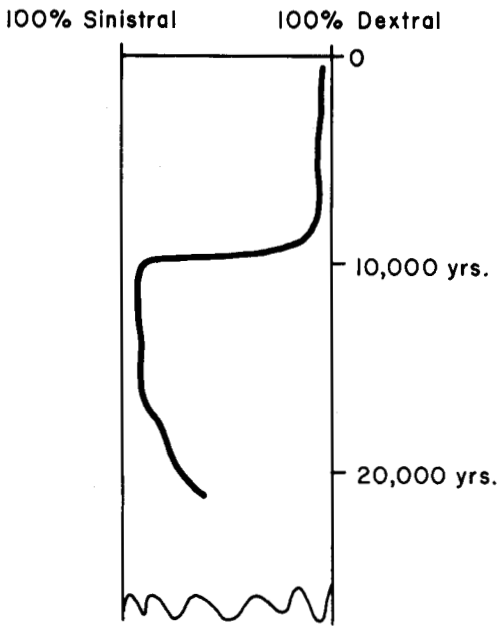


FIG. 4. Direction of coiling of *Globigerina pachyderma* and its relationship to time at 30° to 40° N. Composite section of cores from the Pacific off Southern California (after Bandy 1960).

Pollen data from terrestrial cores in several parts of Alaska have pointed to this same conclusion (Colinvaux 1964, 1967).

Magnetic Reversals and Faunal Change

It has been suggested that the removal of the magnetic shield associated with a reversal of the earth's magnetic field could be responsible for extinctions and/or rapid evolution of life. This idea that removal of the magnetic shield which, through the dual mechanism of sterilization and increased mutation, would be responsible for both the extinction of species and for the production of new species has been challenged (e. g. Black 1967). In the Arctic cores there is some correlation between times of magnetic reversals and faunal changes. Generally, there is a higher percentage of *Globigerina pachyderma* after the most recent reversal and correspondingly, there is generally a higher abundance of benthos below the most recent reversal. In all cores studied for this, there is an interval of few or no benthonic species at and following the magnetic reversal (Fig. 5) (Steuerwald *et al.* 1968). The specific composition changes little, however, and there is no indication of mass extinction of species such as has been noted in the Antarctic with radiolarians (Watkins and Goodell 1967).

Whether the correlation between faunal changes and times of magnetic reversals is fortuitous or a cause and effect relationship may be answerable from other paleoecologic data.

The Pleistocene in the Arctic

Several cores from approximately 80°N. on the eastern edge of the Canada Deep are 5 m. or longer. Magnetic stratigraphy of one of these indicates that the lower part of the core includes sediment which may be in excess of four million

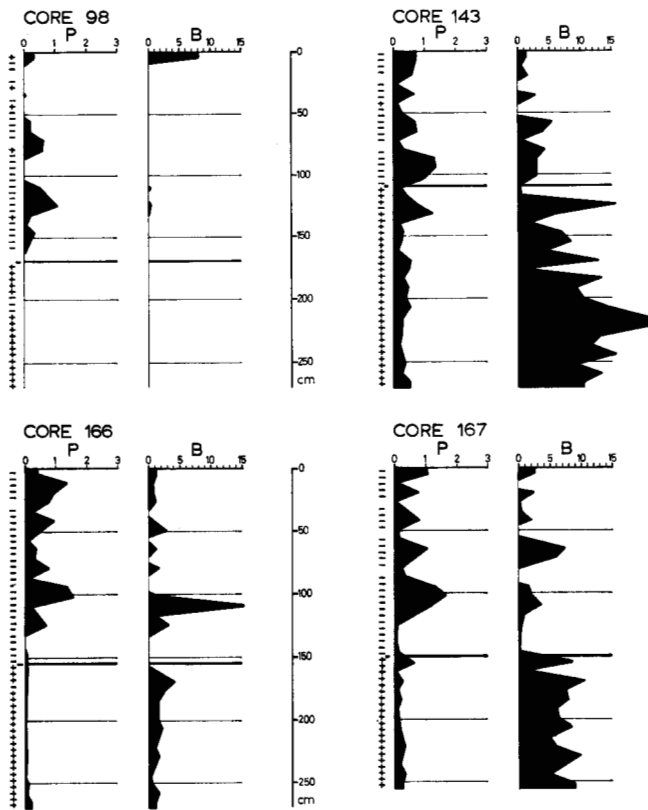


FIG. 5. Four cores from Canada Basin, their magnetic stratigraphy (+, -) and relationship of time of Brunhes reversal (heavy horizontal line) to percentages of planktonic (P) and benthonic (B) Foraminifera. (After Steuerwald *et al.* 1968).

years old. If so, the entire Pleistocene of the Arctic may be represented.

There is little sediment change throughout the core with the exception of a colour change near the base. This colour change occurs at an extrapolated age of approximately four and a half million years. Detailed faunal study of this core is in progress. Hopefully, this will furnish information on the paleoecology of the beginning of the Pleistocene in the Arctic.

FUTURE PALEOECOLOGIC STUDIES

Work up to the present has provided a foundation, even if insecure, on which significant paleoecologic research may progress. Promising lines of investigation in the next few years include:

- 1) Magnetic stratigraphy of the Arctic Ocean,
- 2) Oxygen isotope history of the Arctic Ocean,
- 3) Detailed microfauna studies,
- 4) Sediment dispersal pattern studies.

One of the most powerful new tools for ocean sediment studies is the spinner magnetometer. The widespread recognition of rather precise times of reversals of the earth's magnetic field and their confirmation in terrestrial and marine rock has provided paleoecologists with excellent time planes for their studies. A mag-

netic stratigraphy for the entire Arctic Basin can be determined. The time points thus provided will permit correlation of events which is more precise than techniques used in conventional terrestrial stratigraphic studies. It will be possible to reconstruct a detailed history of the Arctic Ocean including precise rates of sedimentation and times and duration of ecologic and climatic changes. The only limit on a thorough understanding of times and rates of the evolution of the Arctic Basin is the limitation on length of cores which can be taken. Additional stations are needed in the "unknown" parts of the Arctic Basin to provide a comprehensive picture.

The oxygen ($O^{18}:O^{16}$) ratios from Foraminifera tests provide determinations of paleotemperatures, paleosalinities and, indirectly, such factors as run-off, evaporation and vertical mixing of water in the Arctic during the geologic past (Craig and Gordon 1965; Van Donk and Mathieu, *in press*). The wealth of data which may be obtained through such studies should be correlated with sediment and paleomagnetic data.

Much paleoecologic information is to be obtained from a study of the distribution and composition of benthonic Foraminifera, especially the fauna in the remote parts of the Arctic. Shell porosity of the planktonic *Globigerina pachyderma* may be another excellent climatic index (Bé 1968).

Sediment distribution in the Arctic Basin appears to be as diverse as the Arctic Basin differs topographically. The arctic ice drifts and deposits clastic material. Some sediment is transported by density currents. Trace element or other small-scale studies may be more significant for interpretation of sediment dispersal patterns than other studies to date.

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