A Re-evaluation of the Age and Nature of Cenozoic Erratics from McMurdo Sound, Antarctica

A Thesis

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for the Degree of Bachelor of Science

By

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ABSTRACT

Late Eocene and Miocene marine erratics recovered from Minna Bluff and Mt. Discovery in Southern Victoria Land, Antarctica range from micritic cemented, variably sorted sandstones and conglomerates to impure micritic limestones. Lithologically, the erratics are similar to strata of the same age recovered from the MSSTS 1 hole in McMurdo Sound and indicate one or more periods of glacial erosion of marine strata in the Ross Sea during the last 15 m.y.

INTRODUCTION

The purpose of this study is to place in stratigraphic context the extensive erratic collection recovered from Mt. Discovery and Minna Bluff in Southern Victoria Land (Figure 1). That such an objective is now possible has been brought about by the following two factors. First, because of the drilling of MSSTS 1 in McMurdo Sound in 1979, it is now possible to compare Cenozoic erratics with _in situ_ Cenozoic core. Secondly, the first known occurrence of marine diatoms in many of these erratics (Stott and Harwood, in progress) together with dinoflagellates and other known microfossils makes it possible to evaluate the lithologic similarity of the MSSTS 1 strata and erratics by comparing paleontological correlations. Until the present study it has been presumed by most workers that the Cenozoic erratics found in morraines in McMurdo Sound are all from a short stratigraphic interval in the Eocene (Cranwell et.al., 1964; Hertlein, 1969). More detailed work now necessitates a major modification of such a view. Erratics have been found to range from at least Late Eocene to Early or Middle Miocene.

Also present in these erratics is a finely-crystalline "micritic" carbonate found both as cement and as major rock forming constituent. In high latitudes such an occurrence appears anomolous and so its nature and occurrence is described in some detail.

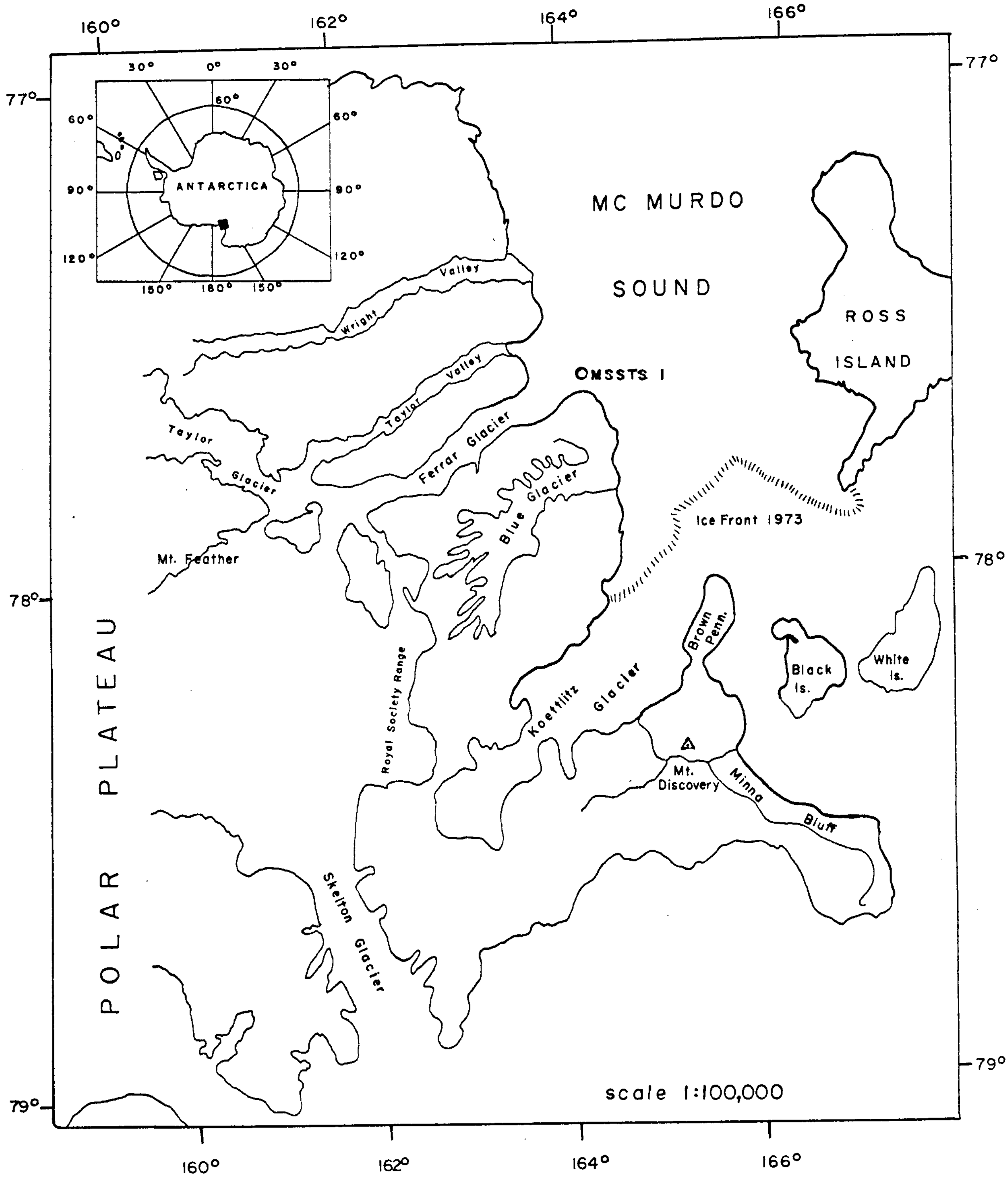


Figure 1: Location map, McMurdo Sound

General Geology

In Southern Victoria Land between the McKay and Koettlitz Glaciers, the basement complex is composed of Late Precambrian and Lower Paleozoic Skelton Group (Gunn and Warren, 1962) metamorphics intruded by plutonics and lamprophyre and porphyry dyke swarms of the Granite Habour Intrusives (Gunn and Warren, 1962). This is a 10,000 m thick sequence folded during the Ross Orogeny (Harrington, 1958).

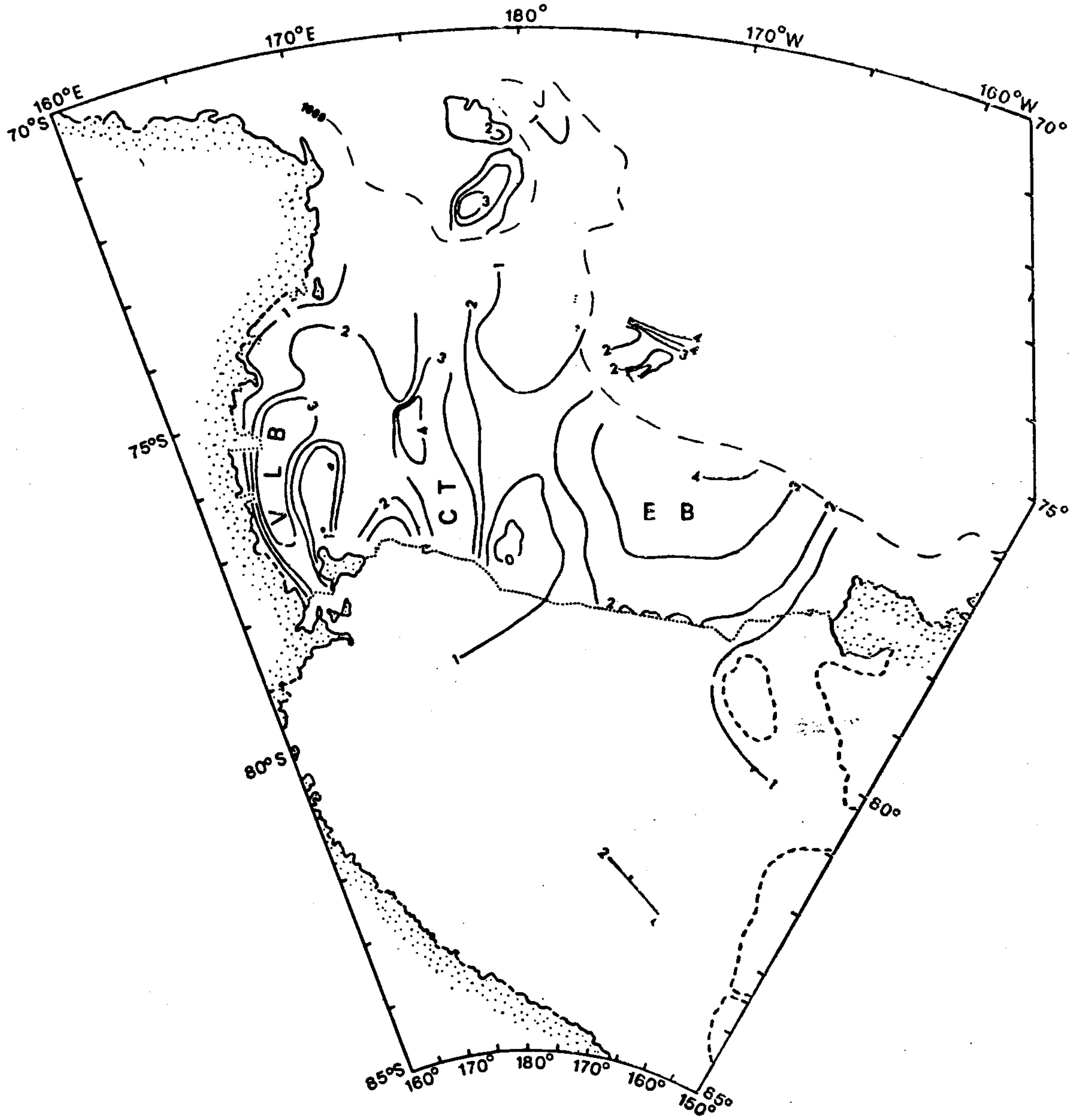
The Skelton Group includes a series of gneisses and marble-schists, the majority of which belong to almandine-amphibolite facies (Lopatin, 1972). Between the Skelton and Koettlitz glaciers, that part of the basement complex with the greatest exposure consists of coarse-grained graphitic marbles, with subordinate schist.

Pretectonic, syntectonic and post-tectonic (Gunn and Warren, 1962; Lapartin, 1972) granites, diorites and granodiorites intrude the basement complex of the central Transantarctic Mountains as lamprophyres and porphyry dykes. Radiometric dates (Deutsch and Webb, 1969) place intrusion of syntectonic diorites and granodiorites at 500-550 myr , while post-tectonic granite lamprophyres and porphyry dykes are dated at 430-490 myr (Deutsch and Webb, 1962).

The peneplained basement complex is overlain unconformably by more than 3500 m of unfolded cratonic Beacon Supergroup (Barrett, 1972). The Devonian and older Taylor Group consists largely of terrestrial quartzose sandstones with some mudstone horizons. The disconformably overlying Victoria Group is less mature and consists of basal tillite overlain by Permian and Triassic coal measures consisting of sandstones, shales and conglomerates.

Jurassic Tholeitic dolerites of the Ferrar Group intrude both the basement complex and the Beacon Supergroup rocks as sheets and sills totalling in some section 3000 m. In the Taylor Glacier region, aggregate thickness of sheets and sills is about 3000 m (Hamilton 1965; Bradley, 1965). Individual sheets may maintain a uniform thickness over thousands of square miles.

Outcropping Cenozoic strata in Southern Victoria Land are few and so far poorly known. A few relatively thin tillites of uncertain age are scattered throughout the Transantarctic Mountains at altitudes up to 3000 m (Mayewski, 1975; Brady and McKelvey 1979; Barrett and Powell, 1982). A Miocene-Recent sequence at least 400 m thick of marine and terrestrial outwash material was recovered from drilling the floor of Taylor Valley near the coast (McKelvey, 1982). Similar strata occur in Wright Valley (Brady 1978). Geophysical studies by Houtz and Meijer (1970), Houtz and Davey (1973), Hayes and Davey (1975), Wong and Cristofell (1981) identified thick areally extensive sedimentary sequences occurring below the Ross Sea. Houtz and Davey (1973) and Davey (1981) suggested that these sequences should contain strata at least as old as early Tertiary and possibly as old as Late Cretaceous. Davey and Bennett (1982) using seismic profiling across the Ross Sea showed that the sedimentary sequences occur in 3 major sediment basins. The western most, Victoria Land Basin (Figure 2) occurs in McMurdo Sound as a 3 km thick sequence running north-south along the eastern coast of the Transantarctic Mountains. Seismic profiling by Wong and Cristofell (1981) and Barrett and Bennett (per. comma) show the western flank of this basin flexed up and separated from the Victoria Land Coast by Barrett's major bounding fault along the Transantarctic Mountains. In 1979-80, drilling in western McMurdo Sound (MSSTS 1) penetrated part of the Victoria



VLB = Victoria Land Basin

CT = Central Trough

EB = Eastern Basin

Figure 2: Isopach map of Ross Sea showing 3 major sediment basins. From Davey and Bennett, 1982

Land Basin and recovered an incomplete sequence of Late Paleocene-Recent sediment. Five lithologic units representing 19 million years of glacio-marine deposition is recorded in 229 meters of core (Webb, 1982). A summary of these lithologies (McKelvey, preliminary report in progress) is included in this report (Appendix II).

In both the Victoria Land Basin of Davey and Bennett and in the uplifted Paleozoic rocks of the Transantarctic Mountains Late Neogene to Quaternary volcanics occur as the McMurdo Volcanic Group. Because the Cenozoic rocks are so poorly known, no formal nomenclature has been established. The only stratigraphy available for comparison and correlation is that of the MSSTS 1 and DVDP 9, 10, and 11.

Tectonic Setting

Initiation of the Victoria Orogeny block faulting movements has recently been dated at ∿55 m.y. (A. Gleadow, pers. comma), with uplift movements continuing through the Cenozoic at rates of ∿80 m per million years.

Ideas concerning mode of faulting are two fold. Barrett and McKelvey (1980) propose a major bounding fault running the length of the Transantarctic Mountains. Wrenn and Webb (1982), Webb (1978) and Gleadow (1982) have suggested that uplift of the mountains as well as subsidence of the Ross Basin has occurred as multiple discrete blocks each with an independent fault history.

Previous Work

To date most attention concerning Cenozoic erratics has focused on the microfossils contained within them. In the late 1950's Harrington and Speden both noted similarity between the fine grained "calcareous" erratics at Minna Bluff and the New Zealand Burnside Mudstone and Amuri Limestone. Paleogene palyomorphs and other microfossils of probable Eocene age were then described from the Minna Bluff erratics by Cranwell (1964); Cranwell, Harrington and Speden (1967). McIntyre and Wilson (1966) and Wilson (1967) and Vella (in Rowe 1974) described similar aged fossils from lithologically different erratics from Black Island.

Struthiolarid gastropods from a similar Ross Island erratic were described by Hertlein (1969). Hotchkiss and Fell (1972) identified a well-preserved ambalacral petal from a clypeasteroid echinoid taken from a Black Island erratic. The consensus of these workers is that the erratics are of Eocene age and were deposited in the Ross Sea under temperate marine conditions.

Petrography and provenance of Paleogene erratics has been limited to a petrographic note on an erratic from Ross Island (Landis 1979) and to a petrographic description of five Black Island erratics (Rowe unpublished, 1974). Rowe suggested a site within 150 miles south of Ross Island as the most likely source of the Cenozoic erratics based on a "uniformitarian" ice movement direction and the similarity of detritus in the erratics to the lithologies known to outcrop in that area of the Transantarctic Mountains.

GEOLOGY OF ERRATICS

The present study incorporates 60 sandstones, pebbley conblomerates and sandy limestones from which 98 petrographic thin sections have been cut. Fifteen erratics with sample numbers beginning with MB 69 were collected from Minna Bluff 30 km southeast of Mt. Discovery by H. J. Harrington during the 1968-69 field season. These erratics were provided for the present study by Professor H. J. Harrington. Erratics having numbers beginning with MA80 were collected on the East flanks of Mt. Discovery Figure 1) by Professor Peter Webb and Mark Leckie during the 1979-80 austral field season. The erratics were collected by systemmatic traversing of the extensive morraine-mantled terrain.

The original Mt. Discovery collection also included lithologies known to belong to the Pliocene Scallop Hill Formation (Leckie, Webb, 1980; Speden, 1962). These erratics were separated from the collection by this author on the basis of wholly basaltic composition. All samples used in this study are housed at The Ohio State University (Appendix III).

Petrography

The sandstone and conglomerate erratics consist of three major petrographically distinct groupings, two of which show considerable textural variation. Basement derived metamorphic arkoses together with granitic arkoses represent the greatest number of erratics with subordinate numbers of quartz arenite sandstones and limestones.

Most erratics are cemented with very finely crystalline carbonate (micrite) or else contain abundant "micritic" matrices. Subordinate numbers have sparry calcite cement and a few erratics are argillaceous. The following petrographic descriptions are specimens selected as being representative of each major lithologic group. It is understood that overlap occurs between each lithology and that the placement within one group does not imply a contemporaneous age with others of that group.

Metamorphic Arkose Lithology

Erratic MA80 040-1

Erratic 040-1 (Plate 1) was collected at 100 m elevation at collection site A (Figure 3). It is a strongly indurated, grey, pebbly diamictite of arkosic composition, derived from a metamorphic basement terrain. Pebbles (∿10%) up to 10-20 mm occur in the poorly sorted fine to coarse sand. A slight fabric of sub-parellel elongate pebbles and sand grains is decernable. The rock effervesces with cold hydorchloric acid.

In thin section (Plate 2), the detrital framework (70%) consists of quartz, feldspars and varied lithic fragments cemented by a finely crystalline calcareous "micrite."

Texturally, rock 040-1 is submature. Sorting and grain size distribution is similar to that of erratic 021-GE(a) (see Granitic Arkose Lithology). Pebbles and grains range in size between 15.0 mm and 0.03 mm with silts and clays comprising less than 1% of the non-calcareous component.

Quartz grains comprising 70% of the sand size framework, are subangular to subrounded and tend to be clear with unit extinction. Approximately 5% of the quartz grains are well rounded, many of these have syntaxial quartz overgrowths suggesting their inheritance from Beacon Supergroup lithologies.

Single feldspar is minor (<10%) and consists entirely of calcic plagioclase most of which is labradorite. A few feldspar grains are euhedral but most are subrounded to rounded. Average grain size of feldspar is 0.3 mm.

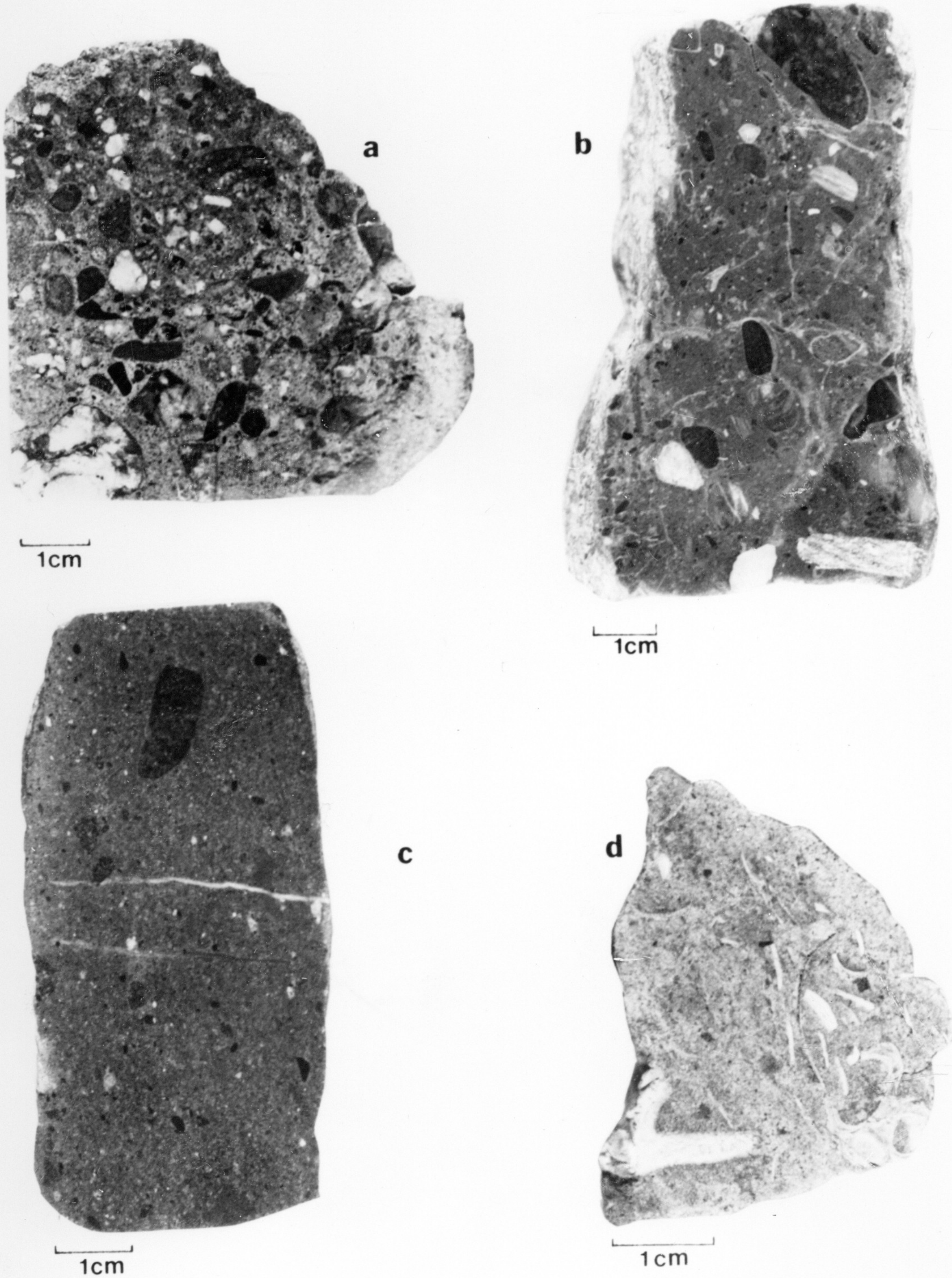
Dolerite and metamorphic fragments ranging from coarse sand to pebble size comprise 15-20% of the total detritus. Of these, texturally diverse ophitic pyroxene dolerites are most common. Carlsbad twinned labradorite (An_{55-60}) is the predominant feldspar and is generally fresh and unaltered.

Plate 1

Photographs of Selected Hand Samples

Figure a	Granitic Arkose Conglomerate, Erratic MA80-021GE(a), collection site A, Mt. Discovery
Figure b	Metamorphic Arkose Diamictite, Erratic MA80-029-A, collection site A, Mt. Discovery
Figure c	Metamorphic Arkose Diamictite, Erratic MA80-040-1, collection site A, Mt. Discovery
Figure d	Quartzitic Sandstone, Erratic MA80-045-1, collection site A, Mt. Discovery

Plate 1



Clinopyroxenes frequently show extensive alteration to carbonate.

Metamorphic fragments are mostly fine-grained (<0.2 mm) biotite-bearing quartz-feldspar granulites and biotite schists, and less commonly quartzite and marble. Metamorphic grains are subrounded to rounded and are generally smaller (<2.0 mm) than those of dolerite.

Erratic MA80 029-A

Erratic 029-A (Plate 1) was collected at site A (Figure 3) on the east coast of Mt. Discovery. This indurated poorly sorted arkosic diamictite (Plate 2) is contrasted with the other metamorphic arkose erratics by its high percentage of marble fragments. Marble fragments ranging in size from 20 mm to 0.125 mm are common and together with fine-grained quartzose metasediments compose 70% of the total detritus. Subangular quartz, feldspar and dolerite are present in accessary amounts and are limited to the fine sand fraction. Framework is cemented by a finely crystalline calcareous "micrite."

Micritic Limestone with 10%
Metamorphic Contribution

Erratics MB69/10 and MB69/46 were collected on the northern coast of Minna Bluff (Figure 3). In thin section (Plate 6), erratic MB69-76 is 90% very finely crystalline "micritic" carbonate with 10% fine sand (< 0.25 mm) and silt. The detrital grains consist of subangular to subrounded quartz, alkali and plagioclase feldspars as well as fine-grained metamorphic and dolerite fragments. Fossils are not observed in thin section but were recovered from disaggregated residues (see paleontology). Rock MB69/10 is a similar micrite and contains only 10% very fine sand (<0.125 mm) and silt. Abundant globergerinid forams and ostracods are also present.

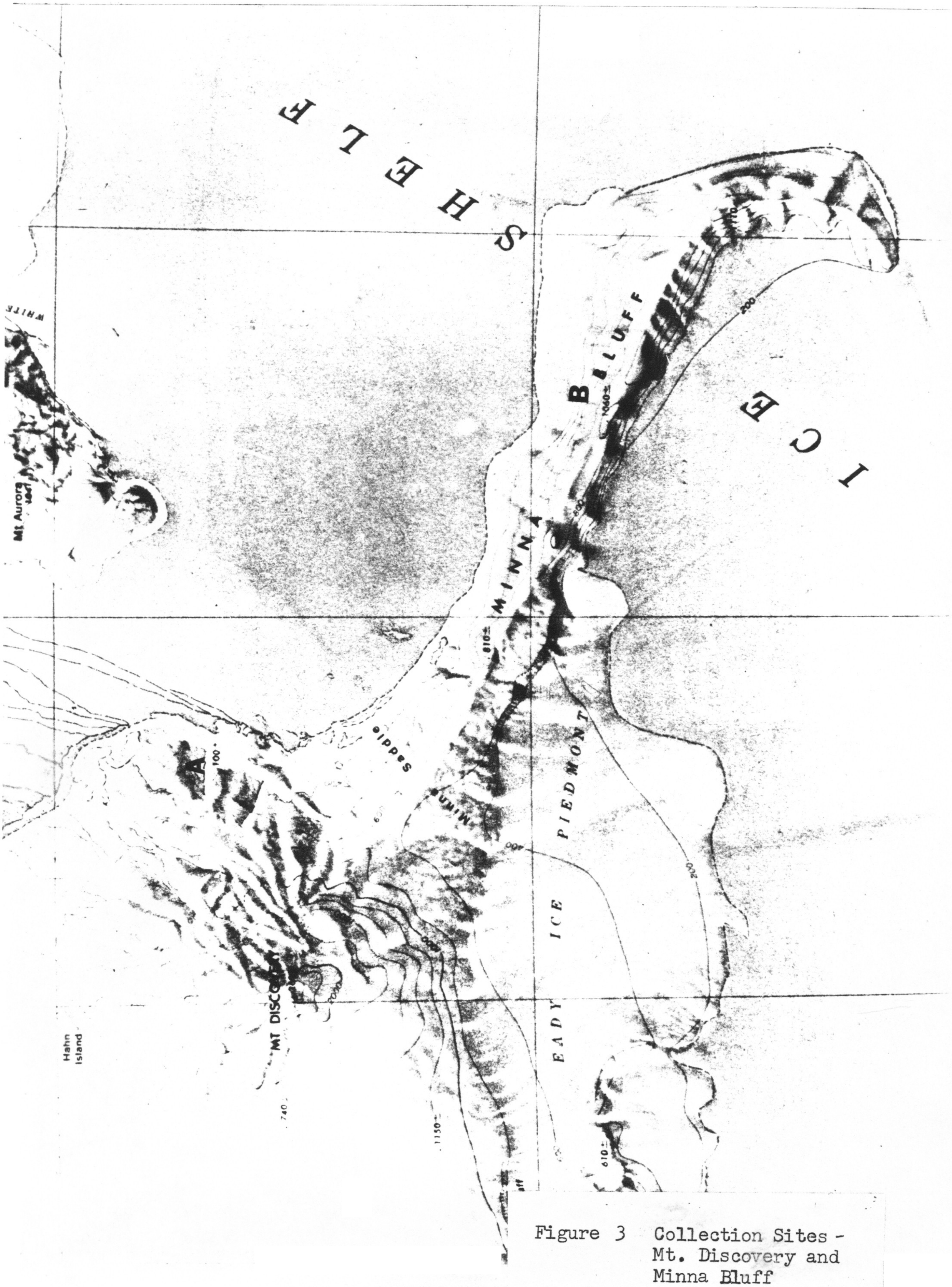


Figure 3 Collection Sites - Mt. Discovery and Minna Bluff

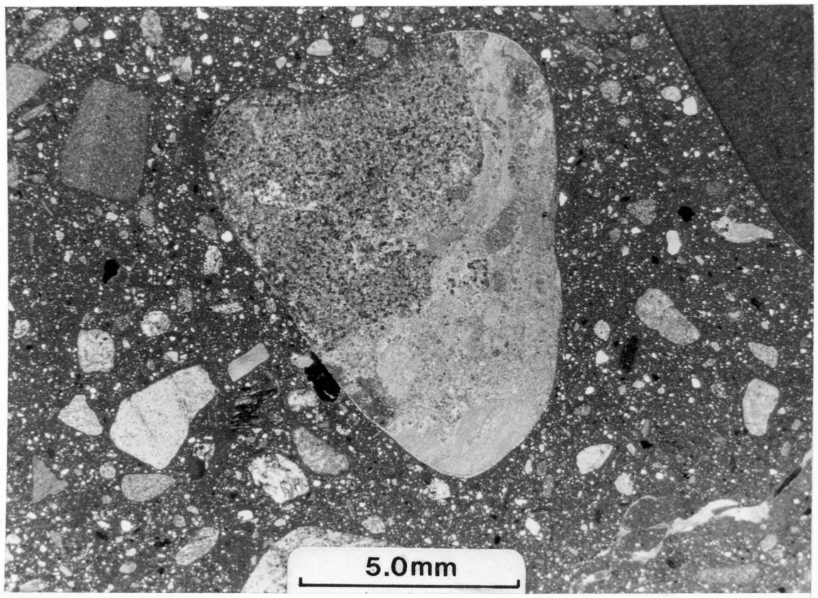
Plate 2

Photomicrographs of Erratics MA80-029 and MA80-040-1

Figure a	Photomicrograph of Metamorphic Arkose Erratic MA80-029-A (crossed polars)
Figure b	Photomicrograph of Metamorphic Arkose Erratic MA80-040-1 (crossed polars)

Plate 2

a



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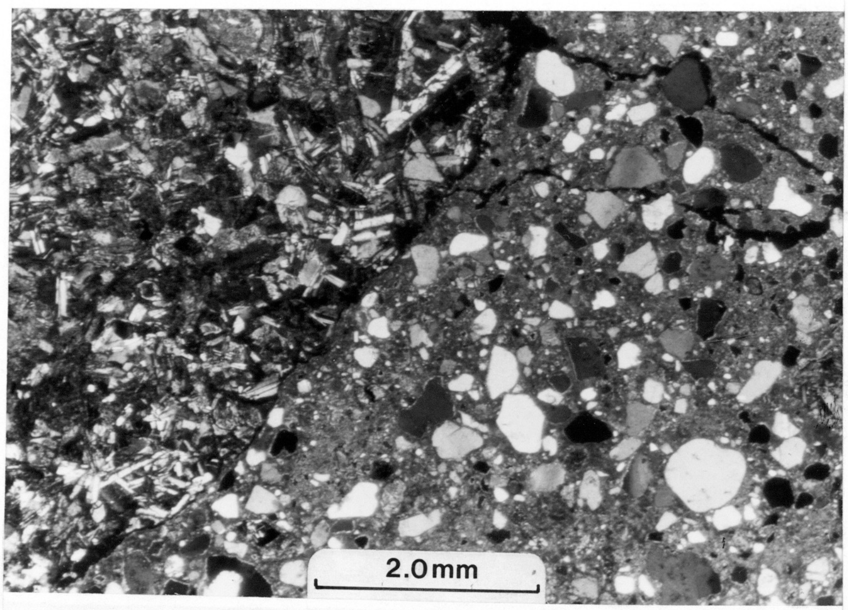


Summary

There exists among this group of erratics a complete gradation of textural variation from "micrite" cemented conglomerates to "micritic" limestones. These rocks all contain high grade metamorphic detritus derived from the basement complex of the Transantarctic Mountains. The type and amount of metamorphic contribution varies from rock to rock but consist heavily of biotite-schists, marbles and granulite. Beacon Supergroup derived quartz tends to be a minor constituent.

Tentative Correlation

Comparison of the metamorphic arkose erratics to strata of MSSTS 1 suggests a lithologic similarity to facies 2 (Appendix II) to which Webb, et al. (1982) assign a Late Oligocene age. For this lithofacies McKelvey reports a poorly-sorted (matrix bearing) angular arkosic sandstone lithology, containing less Beacon Supergroup quartz than that found in facies 3 and 4. The metamorphic arkose erratics bear no resemblance to the quartz-feldspathic lithofacies 1 of MSST 1 in which McKelvey noted a high basaltic glass contribution (see Appendix II). Diatoms were recovered from erratic MB69-46 that are known to range from Early Miocene to Recent (see Appendix I). This age is similar to that assigned the bottom of McKelvey's lithofacies 2.

Granitic Arkose

Erratic MA80 021GE(a)

Erratic 021-GE was collected at 100 m elevation at collection site A (Figure 3) on the east coast of Mount Discovery. It is an indurated buff, immature granitic arkosic conglomerate (Plate 1). No sedimentary structures can be observed in hand sample. The rock effervesces readily with cold 10% hydrochloric acid.

In thin section (Plate 3), the rock consists of 60% mineralogically and/or texturally immature detritus which includes quartz, feldspar and acid plutonic lithic fragments. Detrital grains are evenly dispersed in a microspar carbonate cement. Little or no compaction is observed.

Erratic 021GE(a) is texturally immature with grain sizes distributed between 10.0 mm and 0.03 mm. Fifty percent of these detrital grains fall between 0.50 and 0.125 mm, 7% between 0.125 mm to 0.625 mm, and 14% between 0.5 mm to 2.0 mm. Silts and clays contribute less than 1%. Gravel ranging in size from 2.0 mm up to 15 mm make up the remaining fraction.

Angular to subangular quartz grains comprise 70% of the detrital framework, most of which is unstrained and exhibit unit extinction. Derivation of this quartz is no doubt from the same acid plutonics present as lithic fragments. Grains of sub to well-rounded Beacon Supergroup derived quartz many with syntaxial overgrowths are present in moderate amounts (15%).

Feldspar, grains consist predominantly of microcline and perthite. They are generally euhedral, unweathered, and show little sign of abrasion. Accessory amounts of oligoclase is present but is generally more weathered than the alkaline feldspars. Total feldspar contribution is 25%. The coarse sand and pebble fraction consists entirely of acid plutonic fragments of hornblende granite and granodiorite. These plutonics exhibit textures

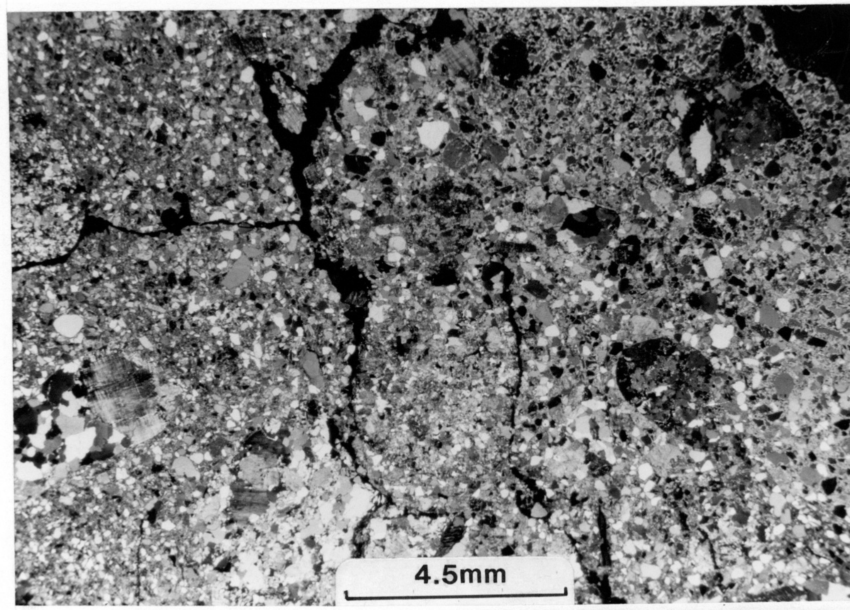
Plate 3

Photomicrographs of Erratics MA80-021GE(a) and MA80-029(b)

Figure a	Photomicrograph of Granitic Arkosic Erratic MA80-021GE(a) (crossed polars)
Figure b	Photomicrograph of Metamorphic Arkose Erratic MA80-029(b) (crossed polars)

Plate 3

a



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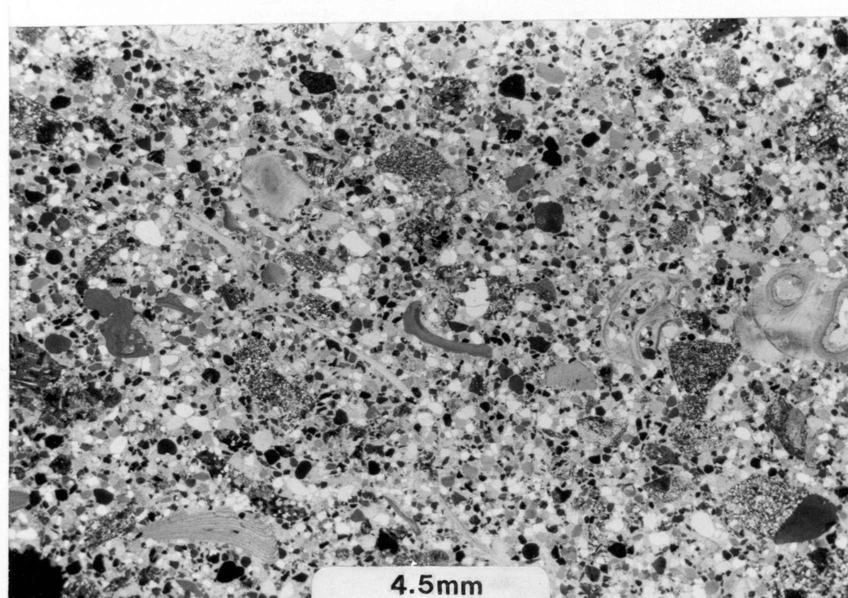


ranging from equi-granular to sub-porphyritic. Microcline is the predominant feldspar of the granites while oligoclase is most abundant in the granodiorite.

Accessary amounts of euhedral hornblende is present in the fine fraction as well as several rounded glauconite grains. There is a marked absence of any basement metasediments and Ferrar Group dolerites.

No depositional structures are apparent in thin-section but there is some indication of burrowing. Present are small circular areas, 2 mm across that are texturally much finer than the surrounding sediment.

Erratic 021GE(b)

Erratic 021GE(b) is a buff, fine-grained submature granitic arosic sandstone in which 95% of the detritus falls between 0.25 mm and 0.065 mm. The remaining detritus falls between 0.5 mm and 0.25 mm with clays and silts contributing less than 1%. Detrital composition is similar to that of erratic 021GE(a), consisting mostly of acid plutonic derived detritus. In addition to a textural difference, erratic 021GE(a) differs from 021GE(b) by having a much finer carbonate cement.

In erratic 021GE(b) the cement is a very finely-crystalline "micritic" carbonate similar to that found in other erratics described in this study. Micrite cement constitutes 20-30% of the rock by volume. Fossil diatoms were recovered from erratic 021GE(b) residues (see paleontology). No other fossils were recovered or seen in thin section.

Summary

Granitic arkosic erratics consist of moderately-sorted sandstone and poorly-sorted conglomerates all of which contain acid plutonic lithologies that were derived from basement complex strata of the Transantarctic Mountains. Amount of Beacon Supergroup derived quartz tends to be moderate. These rocks are cemented by either sparry calcite or a very fine grained "micritic" carbonate. There is no indication that the coarser spar is neomorphosed "micrite" observed in 021GE(b).

Tentative Correlation

Comparison of the granitic erratics to strata of MSSTS 2 suggests similarity to lithofacies 3 (see Appendix I). Lithofacies 3 consists of moderately-poorly sorted sandstones containing acid plutonic and high grade metasediments. Well-rounded Beacon Supergroup derived quartz is common in these rocks. McKelvey (see Appendix II) also noted a "micarb" cement in the better sorted sandstones of this facies.

Fossil diatoms recovered from erratic 021GE(b) suggest an Early to Middle Oligocene correlation with MSSTS 1. This age corresponds to a hiatus that occurs above lithofacies 3 in the MSSTS 1 sequence.

Quartzitic Lithology

Erratic MA80 078-1

Erratic MA80 078-1 was collected at 130 m elevation, collection site A (Figure 3) on the east coast of Mt. Discovery. The rock (Plate 4) is a medium grained supermature quartzose sandstone cemented with sparry calcite. Detrital grains consist entirely of very well-rounded, generally clear quartz, most of which are strained. Most grains are evenly dispersed in the carbonate and have tangential grain to grain contacts while a small percentage of the grains are very closely packed and show contact embayments. Syntaxial quartz overgrowths can be observed on many of the grains. These features suggest derivation and reworking of Beacon Supergroup quartzarenite in the absence of other detrital contributors.

Erratic MA80 045-1(a)

Erratic MA80 078-1 is considered the mature end member of the quartzitic lithologic group. Other erratics of this group contain less Beacon quartz and have dolerite and or other basement contributions. Erratic MA80 045-1(a), collection site A (Figure 3) is a mature fossilferous quartzo-feldspathic sandstone member of this group (Plate 1). In addition to 80% Beacon Supergroup derived quartz, the detrital framework contains 15% sub-angular to sub-rounded granitic quartz, microcline and perthite with a minor amount (<5%) of fine-grained doleritic fragments (Plate 4). Grains are dispersed in sparry cement and exhibit no fabric or depositional structures. Aragonitic pelecypod fragments form 5% of the total detritus. They are unabraided and have not been recrystallized. Preservation of unstable aragonitic fossils is enigmatic but may be explained by deposition in a

Plate 4

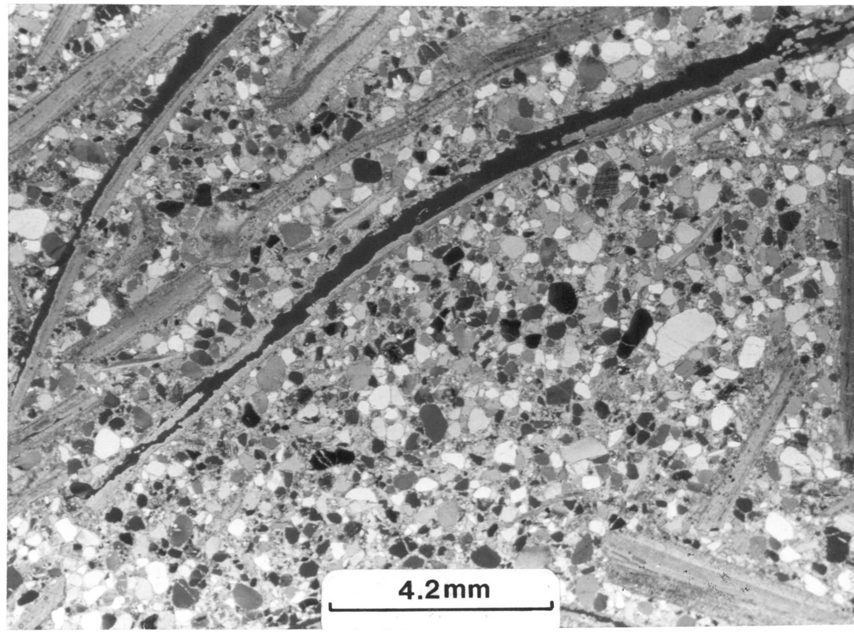
Photomicrographs of Erratics MA80-045-1 and MA80-078-1

Figure a Photomicrograph of Quartzitic Erratic MA80-045-1 (crossed polars)

Figure b Photomicrograph of Quartzitic Erratic MA80-078-1 (crossed polars)

Plate 4

a



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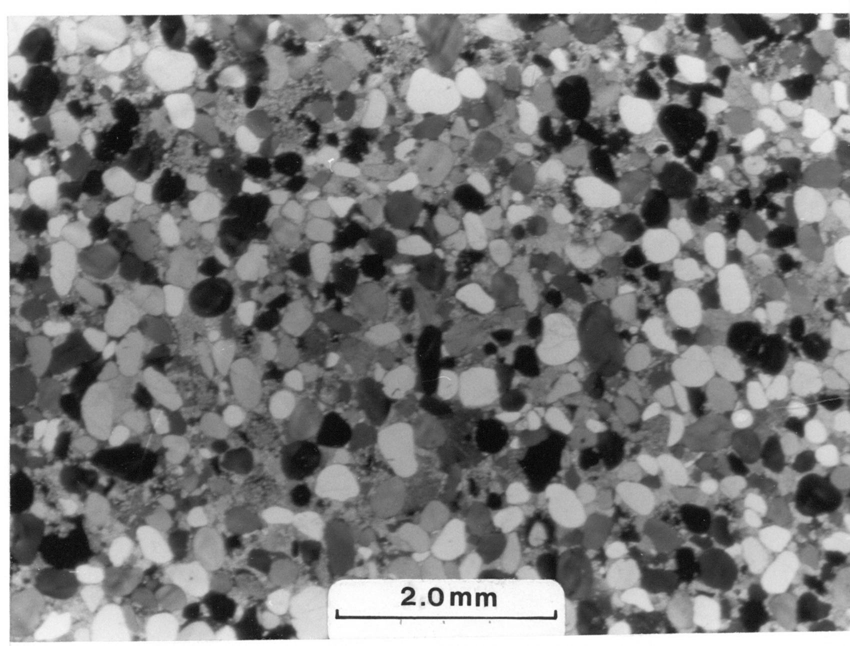


Plate 5

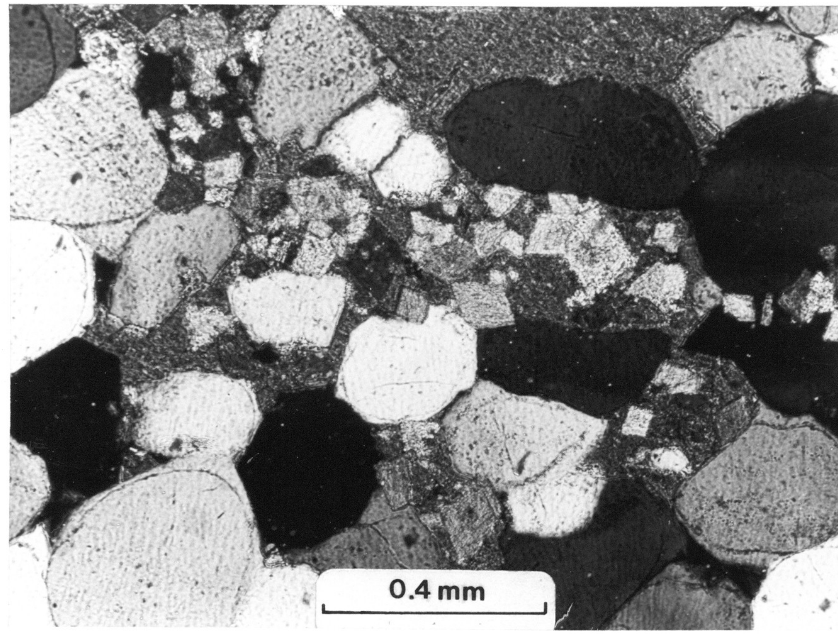
Photomicrographs of Erratics MA80-078-2 and MB65-A

Figure a — Photomicrograph of Erratic MA80-078-2 showing recycled quartz derived from Beacon Supergroup.

Figure b — Photomicrograph of Erratic MB69-65A. Micritic limestone with calcic plagioclase clast.

Plate 5

a



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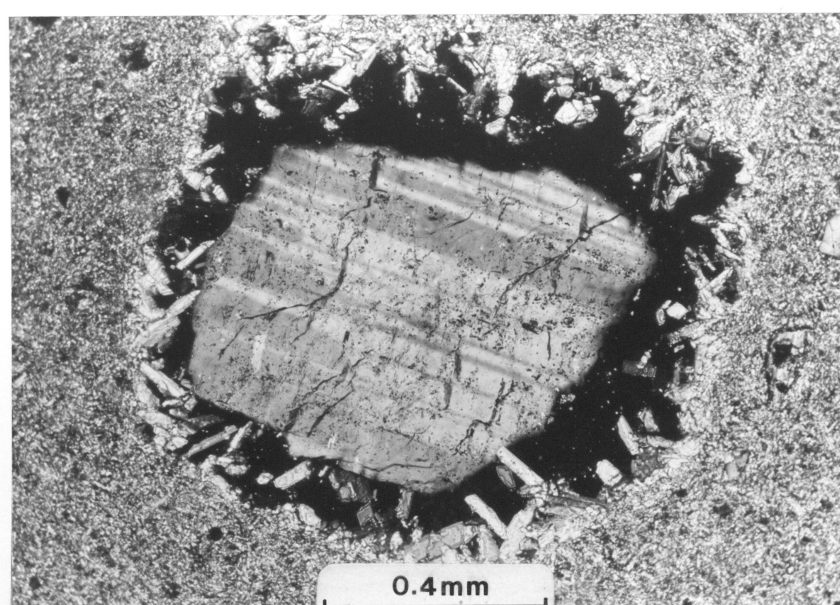


relatively quiet environment and early cementation by calcite. Early cementation would also explain the lack of compaction and the high porosity (high cement to detritus ration) observed.

Summary

The Quartzose erratics all contain a high percentage of well-rounded Beacon Supergroup derived quartz. Amounts of other detritus present (i.e., K-feldspar, metasediment) varies from absent (erratic 078-1) to minor (erratic 045-1(a)) so that this group includes those erratics which are considered subarkosic. Furthermore, while erratic MA80 045-1(a) contains minor K-spar, most subarkosic members contain minor metasediments instead. These rocks tend to be moderate to well-sorted sandstones and contain little or no clay and silt. Cementation is generally sparry carbonate although few contain a finer "micritic" matrix.

Tentative Correlation

The quartose erratics of this study are lithologically similar to strata that make up lithofacies 4 in the MSSTS 1 sequence (Appendix II). The lithofacies 4 strata consists of well-sorted sandstones in which well-rounded Beacon Supergroup derived quartz is the predominant constituent with only accessary amounts of dolerite, alkali feldspar and other acid plutonic fragments.

Webb et al. (1982) recovered planktic and benthic foraminifera from lithofacies 4 of the MSSTS 1 sequence and suggested a latest Late Paleocene to earliest Early Eocene age for the bottom of lithofacies 4 and a Middle to Late Miocene age at the very top. Dinoflagellates recovered from erratic MA80 045-1(b) of this study (see paleontology) reveal an Early Eocene to Late Eocene age and suggest that this erratic is equivalent to the top of lithofacies 4 or the bottom of lithofacies 3.

It is important to note that while the orthoquartzitic erratics composed entirely of Beacon Supergroup derived sediment may represent older, pre-basement (erosion) equivalents of lithofacies 4, no fossils were recovered from erratic MA80-078-1. Correlation to lithofacies 4 MSSTS 1 is therefore, based solely on lithologic similarity.

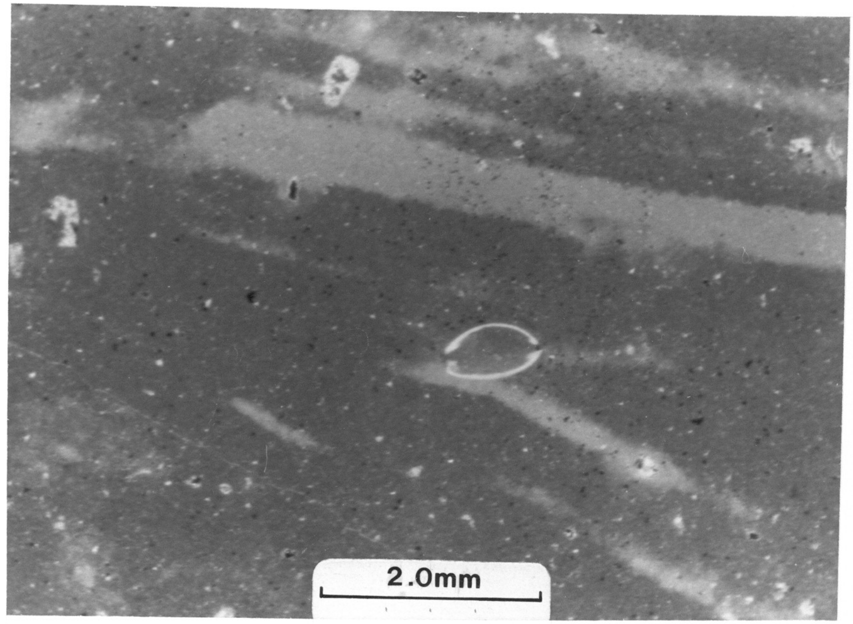
Plate 6

Photomicrographs of Erratics MB69-10 and MB69-46

Figure a	Photomicrograph of "Micritic" Arkosic Erratic MB69-10 (crossed polars)
Figure b	Photomicrograph of "Micritic" Arkosic Erratic MB69-46 (crossed polars)

Plate 6

a



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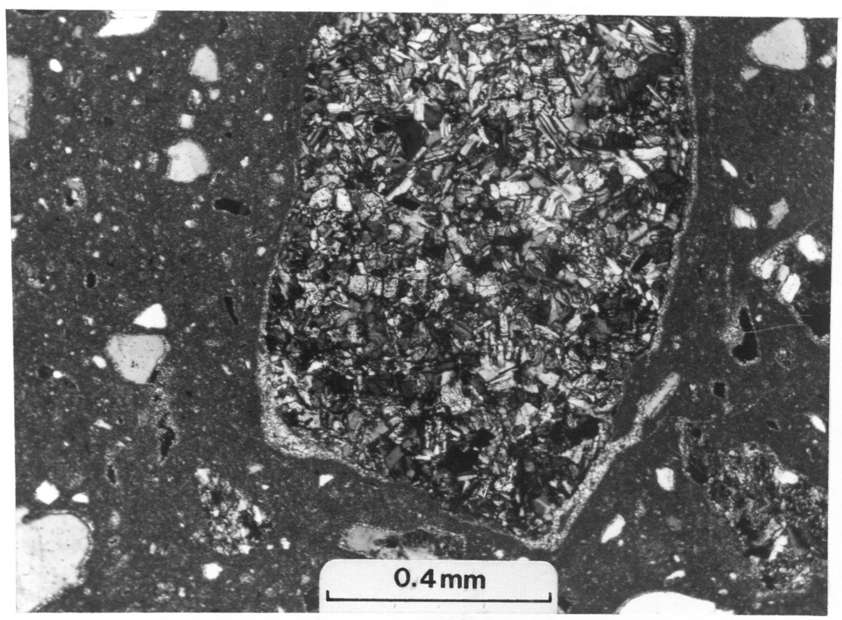


DISCUSSION

The occurrence of Cenozoic erratics in moraines in McMurdo Sound indicates a period or periods of glacial erosion of marine strata from the Ross Sea. The age(s) of the erosion cannot be determined. The collection rests on the McMurdo Group Volcanics of at least 15 m.y. (Middle Miocene) (Armstrong, 1978) and so the erosion must post date this figure.

The age of the youngest erratic is Miocene. However, it is considered that only the most durable (well-cemented) erratics have survived transport and subareal weathering and so younger rocks, indicating later erosion have not survived. All that can be said as stated above is that the erosion occurred less than 15 million years ago.

The source of eroded material cannot be stated other than to say the rocks come from within the Ross embayment. The provenance of the erratics shows derivation from the Transantarctic mountains in Southern Victoria Land. It is assumed the strata from whence the erratics were derived was laid down in some proximity to the Victoria Land coast. However, until various studies being presently carried out concerning the tectonic history of Southern Victoria Land are at a more advanced stage, no meaningful conclusion as to the precise source of the erratics can be made.

The outstanding petrographic feature of nearly all erratics is the occurrence of very finely-crystalline carbonate. Folk (1968) introduced the term "micrite" for microcrystalline (1-4 micron) carbonate. In the McMurdo erratics, the finely crystalline carbonate occurs either as cement or as in erratic MB69/10, the major rock constituent or matrix. The origin of this carbonate is enigmatic. Whether it was produced biogenically (i.e. an organic ooze) or else precipitated inorganically is not yet known. A smear slide of this "micrite" (MB69/10) revealed no obvious biogenic features. However, the micrite does contain recrystallized planktic forams and ostracods. Careful future examination of fracture surfaces with an electron microscope is essential in order to detect any biogenic nature in the "micrite." There are reports (Kinsman and Holland, 1969) of predominantly inorganically precipitated aragonitic mud (i.e. micrite) in the Abu Dhabi region as well as in the Bahama Banks west of Andros Island (Drew, 1914). But it is important to note that these inorganically precipitated carbonate muds are forming in tropical and temperate saline seas.

The "micrite" present in the McMurdo erratics, regardless of its genesis, is noteworthy. It is the only Cenozoic "micrite" known to have been deposited in latitudes above 70°. Climatically it indicates that McMurdo Sound experienced temperate marine conditions during at least parts of the Paleogene. These erratics then, represent important paleoclimatic data for the Ross Sea and so their stratigraphic relationship to *in situ* MSSTS Cenozoic strata is critical.

Webb (1982) has reported cold water benthic forams together with warm planktic forms in McKelvey's lithofacies 2 and 3 of MSSTS 1 (see Appendix II) thereby indicating some stratification of the water column. Unfortunately, oxygen isotope derived temperatures from the MSSTS1 fauna are not possible due to poor preservation of the fauna and the dominance of agglutinated forms. Other workers (Savin, et al. 1975) also report cooler southern oceans temperatures during Late Eocene, Oligocene and Early Miocene.

There are several possible explanations for the discrepancy between the formation to "micrite" and the presence of cold water benthic organisms in the Ross Sea during the Paleogene. One possible explanation is that the McMurdo erratics of this study which contain abundant "micrite" were derived from strata deposited in shallower water, warm enough to support the deposition of "micrite."

Gleadow (1982) and Webb (1982) maintain that downfaulting of the Ross Basin has been produced by movement between series of large blocks moving independently of each other. Because these blocks move independently, some remain higher than others and have given rise to the trough and ridge topography observed on the floor of the Ross Sea (Robertson and Bentley et al., 1982). Initiation of this block faulting has been dated by Gleadow (1982) at 55 m.y. and has continued at an average rate of 90 m/m.y. through the Cenozoic. The "micritic" bearing erratics could have been laid down on a block that was still topographically high enough during the Paleogene to have been within the upper portion of the water column. This conceivably would allow for an environment compatible with the production of "micrite."

An alternative explanation is that the "micrite" bearing erratics represent warmer depositional periods in the Ross Sea that are not recorded in the MSSTS 1 sequence. Webb et al. (1982) reports that only about 32 m.y. of the 63 m.y. to 2 m.y. sequence is represented in the drill core. Webb (1982) explains these major hiatuses as either periods of non-deposition or alternatively that they represent major erosional features. In both cases major advances of the Antarctic ice sheet is proposed to explain these unconformities. This would mean that within the Ross Basin there should occur strata deposited between and even during ice advances and retreats. These strata should be similar to the lithologies at the top of individual MSSTS 1 lithofacies, i.e. deposited prior to glacial advances, and to those at the bottom of the succeeding younger facies, i.e. laid down after ice retreat. The "micritic" erratics of this study may well represent such interglacial sedimentation. For instance erratic MB69-10 apparently belongs to lithofacies II of McKelvey and contains Miocene planktic microfossils.

In MSSTS 1 however, all of lithofacies 2 recovered is of Late Oligocene age. This suggests that this facies extended into the Early Miocene but that younger horizons were removed by erosion and the only record of their former presence is seen in erratics.

This study has shown that "micrite" has occurred in high latitudes presumably during warmer interglacial periods. Folk (1968) has stated that the presence of "micrite" generally indicates rapid rates of precipitation in an environment not influenced by strong currents. However, many of the McMurdo erratics have sand and gravel dispersed about in abundant (>40%) "micrite" matrices. Ice rafting of sediment appears to be the only viable mechanism to explain these rock types. Barrett, et al. (1982) reports that in McMurdo Sound today, frozen beach and shallow subtidal sand is ice-rafted and carried out to sea where it becomes an important source of moderately well-sorted sea-floor sediments. Studies by Bentley (1979) demonstrated that wind blown detritus carried by floating ice can also be important means of dispersing fine detritus far from it's source. Therefore, while "micrite" is not forming there today one is forced to conclude that either organic or inorganic micrite can form at high latitudes where glacial ice persists on adjacent terrains.

Additional mechanisms must be considered in order to produce the coarser more poorly-sorted erratics which also contain high percentages of the fine-grained carbonate matrix (020-A). Kurtz and Anderson (1979) have reported on the importance of sediment gravity flows on the Antarctic Continental Shelf. Barrett et al. (19) states however, that in McMurdo Sound the muddy character of the basin floor in comparison to the sandy margins tends to be incompatible for widespread gravity flow deposition.

The micrite cemented sandstone erratics cannot yet be accounted for at this stage of the study. Either it is a post depositional chemical precipitate cement or else these sediments also represent rafting of sandy detritus into a quiet "micrite" terrain.

The examples mentioned thus far are mechanisms for distributing clastic material on the seafloor today and are largely dependant on present day glaciomarine influences. They serve only as possible analogies for comparison.

Direction for Future Work

Of utmost importance is a detailed investigation of the nature and genesis of the "micrite" present in McMurdo erratics. Is it of biological origin, i.e., is it a high latitude nannofossil ooze? Alternatively, is it a chemical precipitate? It is conceivable that both mechanisms are involved. Once it's origin, chemical and isotopic composition is determined what then is the paleoenvironmental significance of the "micrite" bearing Antarctic sediments? None is known to be forming today in the Ross Sea; there being no record in Quaternary-Recent horizons of any of the DSDP 28 holes. What presumably major paleoclimatic change does this indicate?

It is important to test every erratic for microfauna so as to achieve as complete a dating of the collection as possible. In this way it will be possible to obtain a more detailed stratigraphic succession recording the history of the Ross Sea. Because of their durability and occurrence in these sediments, diatoms and dinoflagellates are of greatest utility in this regard.

CONCLUSION

The Mt. Discovery and Minna Bluff erratics represent Late Eocene-Miocene marine sediment that was derived from the Transantarctic Mountains. The erratics have subsequently been glacially eroded from the floor of the Ross Sea near the Victoria Land Coast, possibly the Victoria Land Basin. The presence of micrite in nearly all of the erratics suggests major climatic variations over the last 55 m.y.

APPENDIX I

Paleontology

Sample: 021GE(a) and 021GE(b)

Samples 021GE(a) and 021GE(b) were processed for siliceous and organic microfossils. Small samples were disaggregated in hydrochloric acid and then seived. Three species of well preserved marine diatoms were found in the 38μ residue of sample 021GE(2). Present are Coscinodiscus marginatus Ebrenberg, (1841); Actincyclus ehrenbergii Ralfs in Pritchard (1861) and Cestodiscus puchellus Geville (1866)(Plate 8). C. marginatus predominates the assemblage but A. ehrenbergii and C. puchellus are not uncommon.

Cestodiscus puchellus was reported by Jouse (1978) to range from Early to Late Oligocene in samples from Barbados. The genus Cestodiscus has a reported range of Late Eocene to Late Oligocene. Further work is necessary (Stott and Harwood, in progress) in order to refine the ranges of diatoms in latitudes above 78° S. in the McMurdo Sound Region.

Sample 021GE(1) contained no diatoms but several specimens of Nothafagus (pollen) similar to those described by Cranwell, Harrington and Speden (1964) were encountered. No macrofossils were found in either of the samples.

Samples MA80 040-1 and MB 69/46

Erratic MA80-040-1 was processed for siliceous and palynomorph fossils using the same technique described above. Only small (10-20μ), poorly preserved specimens of Melosira(?) (Plate 8) were recovered in the 38μ residue. Melosira is a diatom resting spore of little chronostratigraphic value. It is important environmentally as no open-ocean diatoms are known to produce resting spores (Jouse, 1978).

Occurrence of *Melosira* in sample 040-1 indicates deposition in coastal and shallow-water conditions of sedimentation (Jouse, 1978).

No palynomorph fossils were found in residue from this sample.

Erratic MB 69/46 was found to contain well preserved marine diatoms. Present are *Thalassiosira eccentrica* (Ehr.) Cleve var. *leasareolatus* Kanaya as in Fenner (1977), and *Actmocyclus ehreubergi* Ralfs. Schrader and Fenner (1976) reported a range for *T. eccentrica* of Miocene-Recent, but noted the lower age limit is uncertain.

Sample MB 69/10 contained no diatoms or dinoflagellate but did contain several globigerine (planktic) foraminifera together with ostracods. No benthic forams were observed.

Sample: MA80-045-1(b)

Erratic MA80-045-1(b) was processed for siliceous and organic microfossils using the method described earlier. Dinoflagellates are common and quite varied (Plate 7). Present are *Delflandrea asymmetrica* Wilson; *D. aff. antarctica* Wilson; *Hystrichosphaera ramosa* (Ehrenberg) var. ramosa Davey and Williams; *Areosphaeridium diktyoplokus* (Klumpp); *Operculodium* sp; and *spindinium aperturum* Wilson (not pictured). These dinoflagellates all range from Middle to Late Eocene as reported by Wilson (1968) and Kemp (1975).

Plate 7

Dinoflagellates

Figure 1	*Deflandrea asymmetrica* Wilson. Sample MA80-045-1(b) (X 490).
Figure 2	*Deflandrea* aff. *antarctica* Wilson. Sample MA80-045-1(b) (X 490).
Figure 3	*Hystrichosphaera ramosa* (Ehrenberg) var. Davey and Williams, Sample MA80-045-1(b) (X 490).
Figure 4	*Areosphaeridium diktyoplokos* (Klumpp) Sample MA80-045-1(b) (X 490).
Figure 5,6	*Operculodium* sp. Sample MA80-045-1(b) (x 490).
Figure 7	Genus and species uncertain. Sample MA80-045-1(b) (X 490).
Figure 8	*Selenopemphix nephroides*(?) Benedek. Sample MA80-045-1(b) (X 490).

Plate 7

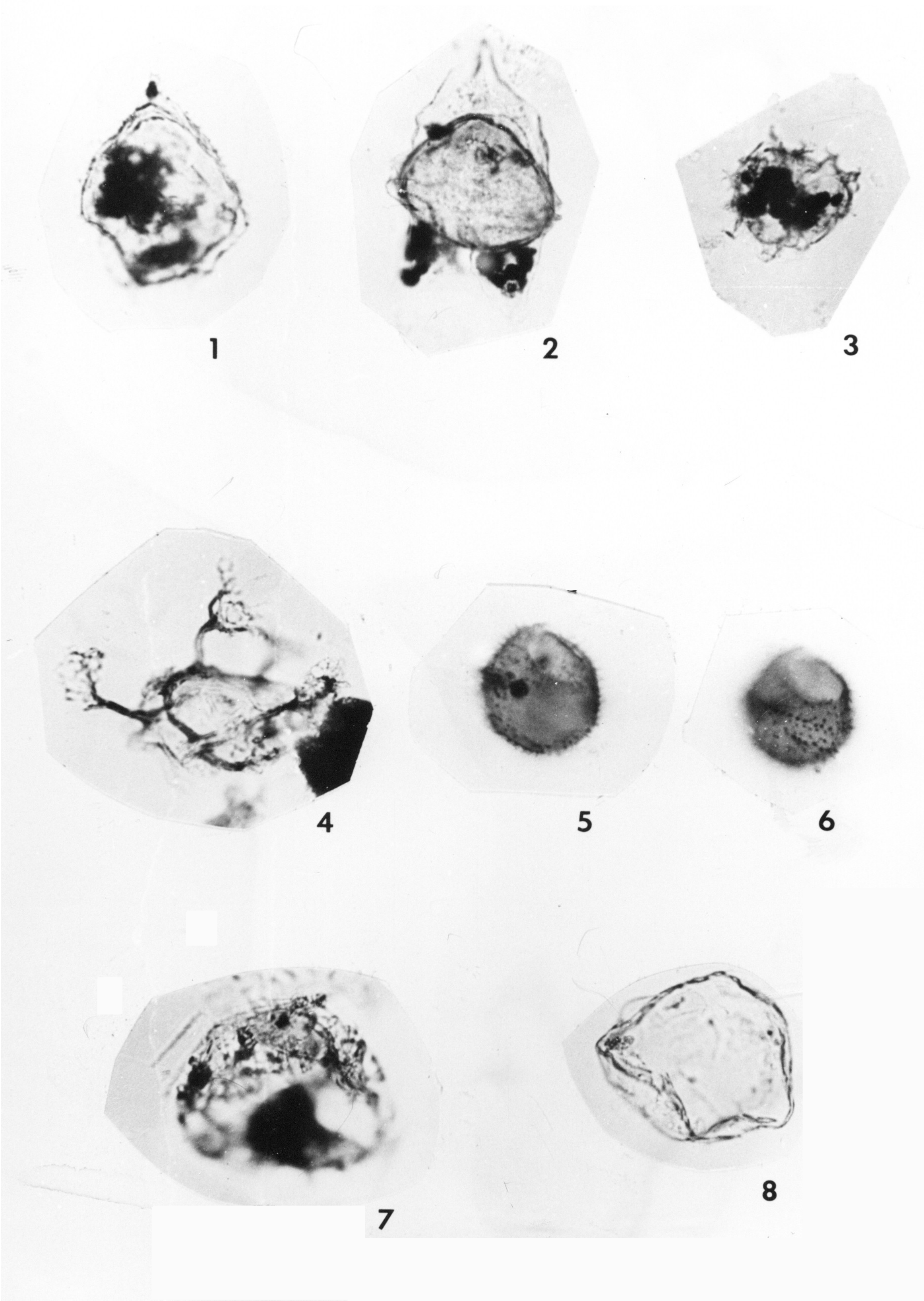
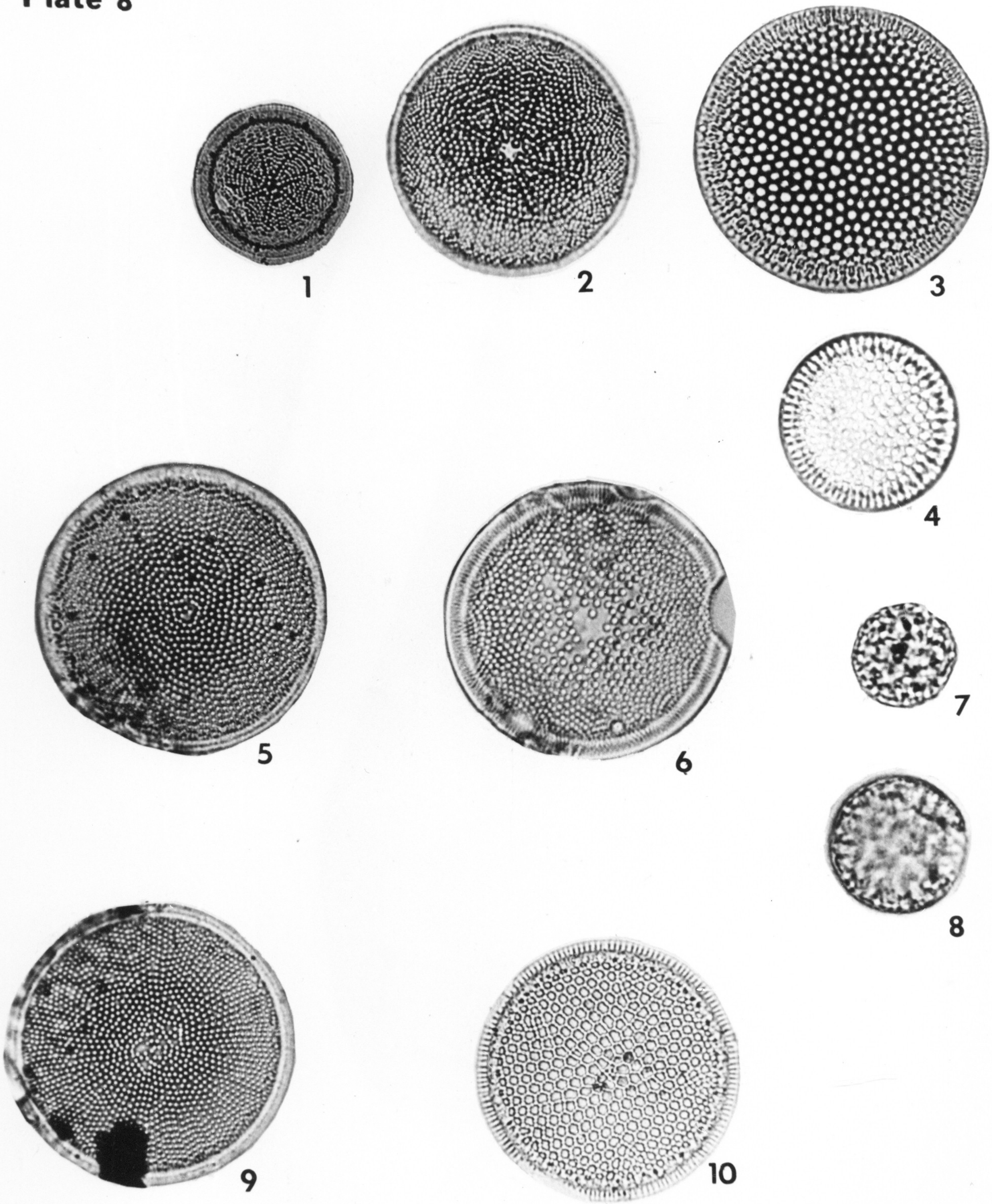


Plate 8

Diatoms

Figures 1,2	Cestodiscus pulchellus Greville. 1. Sample MA80-021GE(b) (X 565). 2. Sample MA80-021GE(b) (X 750).
Figures 3,4	Coscinodiscus marginatus Ehrenberg 3. Sample MA80-021GE(b) (X 750). 4. Sample MA80-021GE(b) (X 565).
Figures 5,6,9	Actinocyclus ehrenbergi Ralfs Sample MA80-46MB (X 750).
Figures 7,8	Melosira(?) poorly preserved Sample MA80-040-1 (X 1225).
Figure 10	Thalassiosira eccentrica (Ehr.) Cleve var leasareolatus Kanaya as in Fenner (1977). Sample MA80-46MB (X 750).

Plate 8



Appendix II

MSSTS No. 1 Petrographic Summary

	Bulk petrography	Interval	T.S.
Facies 1	Lithofeldspathic (largely volcanoclastic)	24.9m - 63.2m	1 - 4
Facies 2	Arkosic (slight Beacon contribution)	117.8m - 134.7m	5 - 10
Facies 3	Arkosic (moderate Beacon contribution)	141.5m - 163.3m	11 - 19
Facies 4	Quartzose (abundant Beacon contribution)	167.3m - 194.4m	20 - 30
Facies 5	Quartzofeldpathic (in part volcanoclastic)	204.0m - 226.6m	31 - 41

Facies 1. 24.9m - 63.2m

Lithofeldspathic (largely volcanoclastic) sandstones (Fig.1) consisting predominantly of texturally diverse basaltic rock fragments and basaltic glass, basement derived alkali feldspars (including perthites) and various plagioclase species; including spongy (resorbed) volcanic varieties mantled by glass sheaths. Detrital quartz is relatively minor (%), generally fine grained and almost invariably subangular to angular. (Well rounded varieties so abundant in facies 3 and 4 are virtually absent). Accessory minerals (present in all 5 facies) include clinopyroxenes, and much subordinate amphiboles, muscovite and biotite.

The salient petrographic feature that so characterizes this facies is the abundance of volcanic glass and the abundance and textural diversity of the fine-grained basaltic rock fragments. Originally hemicrystalline or holohyaline fragments containing microlites, fine-grained alteration has rendered most turbid and some even opaque. The sediments of facies 1 still retain observable primary porosity.

Note

Sample 004 at 63.2m does differ in having some grains of rounded Beacon Supergroup derived quartz; a micaceous and quartzofeldspathic matrix containing scattered grains of microcrystalline carbonate (micarb); and less basaltic rock fragments. Soft sediment injection (dewatering) structures are apparent in thin section. However such data from only one thin section is not sufficient to justify another facies.

Facies 2. 117.8m - 134.7m

Poorly sorted (matrix bearing) angular arkosic (quartzofeldspathic) medium to fine grained sandstones containing also a small admixture of rounded quartz grains presumably derived from the Beacon Supergroup. Granular micarb is scattered throughout the matrices. In very marked contrast to facies 1 the basaltic component is only very minor. Both extensive bioturbation and also soft sediment injection (dewatering) structures are common.

Facies 3. 141.5m - 163.3m

Moderately poorly sorted and bioturbated arkosic (quartzofeldspathic) sandstones containing small (2-4mm) dropstones of acid plutonics, high grade metasediments and dolerite. Approximately half the detrital quartz grains are rounded and so presumably derived from the Beacon Supergroup (cf facies 2,4). Any obvious basaltic contribution is restricted to one or two holohyaline grains per slide. The better sorted sandstones of this facies contain a micarb cement in contrast to the more poorly sorted lithologies which exhibit largely non-resolvable (in part micaceous) matrices.

Facies 3 samples (and also facies 4 and 5) contrast with those of facies 2 in being more indurated (sample 11 is seismic K) to the extent of containing carbonate filled veins; are coarser and contain much more Beacon Supergroup derived quartz. Dewatering textures are largely absent.

Facies 4. 167.3m - 194.4m

Well sorted sandstones composed predominantly of rounded Beacon supergroup derived quartz (Fig.3). The sandstones are cemented by either sparry calcite (0.01mm) (Fig.4) or else a cryptocrystalline brown stained? clay mineral (Fig.5). These two cements appear to be mutually exclusive. Rarely patches of opaque iron oxide cement are also present. Some samples are largely uncemented and friable. Accessory framework grains include alkali feldspars (often perthitic), plagioclases; and dolerite, acid plutonic and metamorphic basement derived lithic fragments. Pyroxenes, amphiboles and opaques may comprise up to 2% of the framework (Fig.6). With the exception of single scoriaceous grains observed in each of three slides, a basaltic contribution is entirely absent. This feature together with the inherited textural maturity of the detrital quartz contrasts sharply this facies with the underlying facies 5.

Three samples (24 at 182.7m, 25 at 183.4m and 26 at 185.3m) are less well sorted, have a bimodal framework and contain largely non-resolvable matrices and/or micarb.

Facies 5. 204.0 - 226.6

Relatively well sorted arkosic (quartzofeldspathic) sandstones containing a small (5%) but noticeable basaltic glass component (Figs. 7 & 8). In marked contrast to facies 1 (the other volcanic rich facies) the volcanic fragments of facies 5 were originally holohyaline and have a translucent light brown (?chlorophaeite or smectite) colour. They are isotropic. Some have arcuate (shard, or hyaloclastite fragments?) boundaries.

The quartzo-feldspathic framework is generally subangular. Rounded (Beacon Supergroup) quartz is only minor. Both detrital and secondary (patches of cement) opaques are noticeable. Both interstitial micarb and non resolvable matrix are present, the latter being more abundant in those samples containing the greatest proportion of volcanic fragments.

Note Sample 35 (213.17m) differs somewhat and may represent a disconformity or hardground (Fig.9). It is a pebbly conglomeratic horizon with basaltic and find grained dolerite clasts set in a clear carbonate spar. Intra-formational clasts and ? faecal pellets are also present.

APPENDIX III

Erratic Collection

Mt. Discovery Erratics

Quartzitic		Granitic Arkose		Metamorphic Arkose	
MA80	037-1	MA80	021-GE(a)	MA80	002-1
MA80	038	MA80	021-GE(b)	MA80	029-A
MA80	040	MA80	029-B	MA80	031-A
MA80	041	MA80	036-1	MA80	031-B
MA80	041-2	MA80	041-A	MA80	035-1
MA80	045-A	MA80	042-1	MA80	036-1
MA80	047-1	MA80	042-2	MA80	041-1
MA80	048-1	MA80	044-2	MA80	045-2
MA80	050-A	MA80	045-2(a)	MA80	047-A
MA80	064-A	MA80	045-2(b)	MA80	047-B
MA80	065-A	MA80	045-3	MA80	047-1
MA80	066-A	MA80	048-A	MA80	047-4
MA80	078-1	MA80	053-A	MA80	056
MA80	078-2			MA80	064-A
				MA80	067
				MA80	067-A
				MA80	074-2
				MA80	078-3

Minna Bluff Erratics

MB 69-10	MB 69-46
MB 69-11	MB 69-47
MB 69-12	MB 69-51
MB 69-31	MB 69-65
MB 69-32	MB 69-70
MB 69-33	
MB 69-35	
MB 69-36	
MB 69-42	
MB 69-45	

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REFERENCES

Barrett, P.J. and B.C. McKelvey. 1981. Cenozoic Glacial and Tectonic History of the Transantarctic Mountains in the McMurdo Sound Region: Recent Progress from Drilling and Related Studies. Polar Record, vol. 20, No. 129, p. 543-548.

Barrett, P.J. and R.D. Powell. 1982. Middle Cenozoic Glacial Beds at Table Mountain, Southern Victoria Land. Antarctic Geoscience, C. Craddock, ed., University of Wisconsin Press. p. 1059-1076.

Bentley, P.N. 1979. Characteristics and distribution of wind-blown sediment, western McMurdo Sound, Antarctica. Unpublished B.Sc. (Hons) thesis, Victoria University of Wellington, New Zealand, 46 pp.

Blank, H.R. and Cooper, R.A.; Wheeler, R.H.; Willis, I.A. 1963. Geology of the Koettlitz-Blue Glacier region, Southern Victoria Land, Antarctica. Transactions of the Royal Society of New Zealand Geology 2, p. 79-100.

Bradley, J. 1965. Intrusions of Major Dolerite Sills. Transactions of the Royal Society of New Zealand, Vol. 3, No. 4, p. 27-55.

Brady, Howard and McKelvey, B. 1979. The interpretation of a Tertiary Tillite at Mount Feather, Southern Victoria Land, Antarctica, Journal of Glaciology, Vol. 22, No. 86, 1979.

Cande, S. and Mutter, J. 1982. A Revised Identification of the Oldest Sea-Floor Spreading Anomolies Between Australia- and Antarctica. Earth and Planetary Science Letters, vol. 58, p. 151-160.

Cranwell, L.M.; Harrington, H.J. and Speden, I.G. 1960. Lower Tertiary microfossils from McMurdo Sound, Antarctica. Nature, Lond., 186 (4726), p. 700-702.

Cranwell, L.M., 1964. Hystrichospheres as an aid to Antarctic dating with special reference to recovery of Cordosphaeridium in erratics at McMurdo Sound. Grana palynol., Vol. 5, No. 3, p. 397-405.

Cranwell, L.M. 1964. Extra-Antarctic Correlations in Noting of Erratic Deposits at McMurdo Sound, Antarctica. Abst. Eighth Ann. Meet. Ariz. Acad. Sci., April 4, 1964.

Davey, F.J. 1981. Geophysical Studies in the Ross Sea Region. J. Roy. Soc. of New Zealand. Vol. 11, p. 465-479.

Davey, F.J. and Bennett, D.J. and Houtz, R.E. 1982. Sedimentary Basins of the Ross Sea, Antarctica. New Zeal. J. Geol. and Geophys. Vol. 25, p. 245-255.

Drew, G.N. 1914. On the precipitation of calcium carbonate in the sea by marine bacteria and on the action of dentrifying bacteria in tropical and temperate seas. Papers Tortugas Lab., Carnegie Inst. Wash. Publ., 182:7-45.

Fenner, J. 1977. Cenozoic Diatom Biostratigraphy of Equatorial and S. Atlantic Ocean. In: Supko, P.R., Perch-Nielson, K., et al., Initial Reports of the Deep Sea Drilling Project, Volume 39: Washington (U.S. Government Printing Office), p. 491-624.

Folk, R. 1968. Petrology of Sedimentary Rocks. University of Texas publication. p. 170.

Gleadow, A.J. 1982. Fission-Track Geochronology of Granitoids and Uplift History of the Transantarctic Mountains, Victoria Land, Antarctica. Fourth International Symposium on Antarctica, Adelaide Aust.

Grindley, G. and Warren, Guyon. 1963. Stratigraphic Nomenclature and Correlation in the Western Ross Sea Region. In: Antarctic Geology, Scar Proceedings, Aclie, R., (ed.)p. 314-333.

Gunn, B.M., and Warren, Guyon. 1962. Geology of Victoria Land between the Mawson and Mulock Glaciers, Antarctica. New Zealand Geological Survey. Bulletin n.s. 71. N.Z. Dept. of Scientific and Industrial Research.

Hamilton, W. 1965. Diabase sheets of the Taylor Glacier Region Victoria Land, Antarctica. Geological Survey Professional Paper 456-B.

Harrington, H.J. 1969. Fossiliferous rocks in moraines at Minna Bluff, McMurdo Sound. Antarctic Journal of the U.S., Vol. 4, No. 4, p. 134-135.

Hayes, D.E. and Davey, F.J. 1975. Geophysical Study of the Ross Sea, Antarctica. In: Hayes, D.E. et al. Initial Reports of the Deep Sea Drilling Project 28, Washington, U.S. Government Printing Office, pp. 263-278.

Hertlein, L.G. 1969. Fossiliferous Boulder of Early Tertiary Age from Ross Island Antarctica. Antarctic Journal of the U.S., Vol. 4, No. 5, p. 199-201.

Hotchkiss, F.M.C. and Fell, B.H. 1972. Zoogeographical Implications of a Paleogene Echinoid from East Antarctica. J. Roy. Soc. N.Z., Vol. 2, No.3, p. 369-372.

Houtz, R.E. and Meijer, R. 1970. Structure of the Ross Sea Shelf from Profiler Data. J. of Geophys. Res. Vol. 75, p. 6592-6597.

Houtz, R.E. and Davey, F.J. 1973. Seismic Profiler and Sonobuoy Measurements in the Ross Sea, Antarctica. J. of Geophys. Res. Vol. 78, p. 3448-3468.

Jousé, A.Y. 1978. Diatom biostratigraphy on the generic level. Micropaleontology, Vol. 24, No. 3, p. 316-326.

Kemp, E. 1975. Palynology of Leg 28 Drill Sites, Deep Sea Drilling Project. In: Hayes, D.E., Frakes, L.A. et al., 1975. Initial Reports of the Deep Sea Drilling Project, Vol. 28, Washington (U.S. Government Printing Office), p. 599-623.

Kemp, E.M. and Barrett, P.J. 1975. Antarctic glaciation and early Tertiary Vegatation. Nature, v. 258; p. 507-508.

Kinsman, D.J.J. 1969. The co-precipitation of cations with $CaCO_3$. IV. The co-precipitation of Sr^{2+} with aragonite between 16^o and 96^oC. Geochim. Cosmochin. Acta, Vol. 33, pp. 1-17.

Kremp, G.O.W. 1963. Antarctica, the Climate of Tertiary and a Possible Cause for our Ice Age. In: Adie, R.J. (ed.) Antarctic Geol.; Proceedings of the First Intl. Symposium on Antarctic Geology. pp. 736-746.

Kurtz, P.D., Anderson, J.B. 1979. Recognition and sedimentologic description of recent debris flow deposits from the Ross and Weddell Seas, Antarctica. J. Sedimentary Petrology, Vol. 49., No. 4, p. 1159-1170.

Landis, C.A. 1974. Petrography of an Early Tertiary Fossiliferous Sandstone from the Ross Sea Area, Antarctica (Note). N.Z. J. of Geology and Geophysics, Vol. 17, No.3.

Lopatin, B.G. 1972. Basement Complex of the McMurdo 'Oasis', Southern Victoria Land. Antarctic Geology and Geophysics, Oslo, R. Adie, ed. p. 287-292.

Mayewski, P. 1975. Glacial Geology and Late Cenozoic History of the Transantarctic Mountains, Antarctica. Institute of Polar Studies, Report No. 56.

McIntyre, D.J. and Wilson, G.J. 1966. Preliminary Palynology of Some Antarctic Tertiary erratcis,N.Z. Jl. Bot., Vol. 14, No. 3, p. 315-321.

McKelvey, B.C. 1982. Late Cenozoic Marine and Terrestrial Glacial Sedimentation in Eastern Taylor Valley, South Victoria Land. Antarctic Geoscience, C. Craddock, ed., University of Wisconsin Press. p. 1109-1116.

Mercer, J.H. 1972. Cainozoic Temperature Trends in the Southern Hemisphere: Antarctic and Andean Glacial Evidence. In: Van Zinderen Bakker, E.M. (ed.) Palaeoecology of Africa and Antarctica. Vol. 8.

Robertson, James D. and Bentley, C.; Clough, J.; and Greischar, L. 1982. Sea-Bottom Topography and Crustal Structure below the Ross Ice Shelf, Antarctica. Antarctic Geoscience, C. Craddock, University of Wisconsin Press. p. 1083-1090.

Savin, S., Douglas, R., Stehli, F. 1975. Tertiary Marine Paleotemperatures. Geol. Soc. Am. Bull., 86, p. 1499-1510.

Schader, H.J., and Fenner, J. 1976. Norwegian Sea Cenozoic Diatom Biostratigraphy. In: Talwani, M., Udintsev. G., et al. Inttial Reports of Deep Sea Drilling Project Vol. 38, Washington, U.S. Printing Office.

Speden, I.G. 1962. Fossiliferous Quaternary Marine Deposits in the McMurdo Sound Region, Antarctica. N.Z. J. Geol. and Geophysics, Vol. 5, No.5, p. 746-777.

Stott, L., and Harwood, D. In Progress. Paleogene Diatoms in Erratics from Mt. Discovery and Minna Bluff.

Truswell, E. 1982. Palynology of Seafloor Samples Collected by the 1911-17 Australasian Antarctic Expedition: Implications for the Geology of Coastal East Antarctica. J. Geol. of Australia 29, p. 343-356.

Webb, P.N., 1982. Review of Late Cretaceous-Cenozoic Geology of the Ross Sector, Antarctica. Presented At: Fourth International Symposium on Antarctic Earth Sciences, Adelaide, Australia.

Webb, P.; Leckie, M. and Ward, B. 1982. Paleogene-Neogene Foraminifera from the MSST-1 Drillhole, McMurdo Sound, Antarctica. Submitted to New Zealand J. of Geology and Geophysics.

Webb, P.N. and Neall, V.E. 1972. Cretaceous Foraminifera in Quaternary Deposits from Taylor Valley, Victoria Land. Antarctic Geology and Geophysics, Oslo, R. Adie, ed., p. 653-657.

Wilckens, O. 1911. Die Mollusken der Antarktisdien Tertiarformation. Wissenschaftliche Engebnisse der Schwedischen Sudpolar-Expedition 1901-1903, Band 3 Lieferung 13:1-42.

Wilson, A.T. 1973. The Great Antiquity of some Antarctic Landforms--evidence for an Eocene temperate glaciation in the McMurdo Region. Paleoecology of Africa and Antarctica Van Zinderen Bakker, E.M. ed., Vol.8, Ch. 3, p. 23-35.

Wilson, G.J. 1967. Some new Species of Lower Tertiary Dinoflagellates from McMurdo Sound, Antarctica. N.Z. Jl. Bot. Vol.5, No.1, p. 57-83.

Wilson, G.J. 1968. On the Occurrence of fossil Microspores Pollen grains and Microplankton in bottom Sediments of the Ross Sea, Antarctica. N.Z. Jl. Freshwat. Res. Vol.2, No.3, p. 381-389.

Wong, H.K. and Cristofell, N.A. 1981. A. Reconnaissance Seismic Survey of McMurdo Sound, and Terre Nova Bay, Ross Sea. In: McGinnis, L.D. ed., Dry Valley Drilling Project, Antarctic Research Series. Washington, American Geophysical Union, pp. 37-62.