A Smear Slide Analysis of Sediments from the Terra Nova Bay Polynya, Antarctica

by

Robert F. Rathbone

A senior thesis submitted to fulfill
the requirements for the degree of
B.S. in Geology, 1986

The Ohio State University

Thesis Advisor

Lawrence A. Krissek
Department of Geology and
Mineralogy

I. Introduction

The Terra Nova Bay polynya is an area of ocean, free of pack ice year-round, that is located in the western Ross Sea, Antarctica (Figure 1). Terra Nova Bay, like most areas in the Ross Sea, is characterized by a continental shelf with a rugged, irregular topography, typically sloping towards the coast. This results in a water depth that increases shoreward (to the west) from the shelf-slope break to the east. The polynya's relative proximity to the coast, locates it in an area of relatively deep water with respect to the central and outer shelf. Fluctuations of the polynya range from approximately 5000 km^2 to near 0 km^2 annually, although some portion always remains clear of ice (Kurtz and Bromwich, 1985). There are basically two reasons for the existence of the polynya. First, is the presence of westerly katabatic winds (from the mountains of Victoria Land) which force ice away from the coast. Second, the Drygalski Ice Tongue blocks the northward flow of pack ice into Terra Nova Bay (Bromwich and Kurtz, 1983).

Mechanisms influencing sedimentation in the Ross Sea include glacial and subglacial deposition, secretion of siliceous and calcareous material by marine organisms, aeolian deposition, and mass flow into basins and troughs (Dunbar et al.,1985). Glacial dedimentation is dominated by ice rafting near the coast (within a few tens of kilometers) with glacial meltwater streams having a minimal affect (Dunbar et al., 1985, Anderson et al., 1984). Reworking and winnowing of sediment by marine currents is also important in the western Ross Sea, but mainly in the relatively shallow water of the middle and outer shelf. Dunbar, Anderson, and Domack (1985) recognize several physical parameters influencing sedimentation in the Ross Sea, some of which are: light, wind, and bottom current intensities, seasonal ice coverage, and wave energy. In order to determine which of these processes are dominant, as well as to infer whether sediments were deposited out of suspension or subsequent to bottom transport, grain size, compositional, and textural analysis of core samples was completed by the researchers. A summary of the relative importance of the different oceanic processes as sedimentary agents was determined from data collected in the western Ross Sea.

In this study, some of the effects of the polynya on sedimentation in Terra Nova Bay was determined by examining ratios of biogenic to terrigenous sediment components. Using this information, past fluctuations in the polynya's size were inferred, by examination of subsurface sediment samples.

II. Methods

In order to microscopically examine sediments from the polynya area, smear slides were prepared from piston cores collected during the Deep Freeze 80 expedition. Locations of these cores are shown in Figures 2 and 3. The slides were examined for relative abundances of biogenic, volcanic, and terrigenous sediment components, as well as for ash character and mineral identification. Within the biogenic component, diatom, radiolarian, foraminiferan, spicule and silicoflagellate abundances were determined, while the terrigenous component was divided into quartz, feldspar, mafic, and silt and clay fractions. Estimation of sediment percentages was done primarily by two methods. A portion fo the slide was first observed for a percentage estimation of material present. If that section was covered approximately 100% by sediment, then a straight forward evaluation of component abundances was made. However, if the slide had substantially less than 100% sediment cover, then abundances were determined and recalculated for 100% cover.

The abundance of the diatom species, Eucampia antarctica, as a percentage of all diatoms present, was also determined in this study. Distinctive shape, high relief, and a rather restricted occurrence make this species very useful for interpretation of past depositional conditions. Other researchers (Burckle, 1984) have interpreted E. antarctica as a recorder of marine environments with ice cover.

In order to estimate the reproducibility of the slide analysis, three slides from different locations (the depths of which were chosen at random) were again examined for relative abundances of biogenic, volcanic, and terrigenous sediment components. Multiple analysis was completed because the largest source of error in the research is probably in the visual estimation of sediment abundances. Overestimation of the biogenic component, especially in the finer grain sizes, such as coarse silt, is most probable because of the ease of identification of this sediment type. Possibility of error is increased if sediment coverage on the slide is low, or conversely, if an excessive amount of material causes thick accumulations throughout the slide. Damaged slides and cover slips also contribute to estimation errors because portions of sediment may become separated from the slide. Another problem can arise if untwinned feldspars are present; these grains may be mis-identified as quartz, predominantly in the coarse silt-very fine sand size fractions. However, this error is probably insignificant, making compensation for it unnecessary. Other researchers indicate that an error of ±20% is common and acceptable in smear slide analysis, with similar variations between researchers.

III. Results

In order to clearly illustrate the results of this study, three types of figures are shown. Tables 1 a.-e. list abundances as they were determined under the microscope. Table 2 provides data collected from surface sediments, in order to summarize recent sediment types in the polynya, although the data was provided by a different researcher. Replicate analysis of the three slides used to estimate reproducibility of data, is shown in Table 3. Percent deviation from the original analysis is also shown in this table.

Graphs of the three major component abundances, plotted as a function of depth below the sediment/water interface, are shown in Figures 4 a.-e., along with inferred volcanic/biogenic/terrigenous boundaries between subsurface and surface data. This type of plot illustratis variations in sediment abundances with depth and, to some extent, time. Ternary plots shown in Figures 5 a.-e., highlight changes in the three fraction abundances in different cores, as well as the dominant sediment type in each set of cores. In all samples, quartz grains are the dominant terrigenous component in the sand-size fractions. A small percentage of these grains consist of both plagioclase and potassium feldspar, such as microcline, and are identified by twinning characteristics. Pyroxenes and horneblende are the predominant mafic minerals present, and were identified mainly by distinctive relief, cleavage, and color. The term "clay" in this study refers only to a particular size fraction (2 microns), and not to the clay minerals. Opaline silica comprised essentially 100% of the biogenic sediment in the slides. Foraminifera tests, consisting of calcium carbonate, were not observed in this study. A majority of volcanic ash can be classified as the basaltic glass, sideromelane (Heiken, 1985), and is generally light brown to nearly opaque with low vesicularity. Orange colored glass shards exist, and have an appearance similar to sideromelane; these are interpreted here as oxidized sideromelane (Heiken, 1974). Some glass contains feldspar microlites, has medium-high vesicularity, is generally light-brown in color, and has been identified as tachylite.

Eucampia antarctica occurs throughout the samples, but usually in abundances less than 1% of all diatoms, and with the tests in poor condition. Four slides, however, contain sediment with *E. antarctica* tests in good condition, with abundances as follows:

DF80-107 (34-36 cm): 4-5% of diatoms
(38-40 cm): 2% of diatoms
DF80-110 (60-62 cm): 15% of diatoms
DF80-127 (61-63 cm): 5% of diatoms

All other slides contain an extremely sparse amount of *E. antarctica* tests, most of which are fragmented. The locations of these relatively abundant zones are indicated in Figures 4 a.-e..

IV. Discussion and Conclusions

Relationships between present polynya location and surface sediment-type were observed for deduction of past fluctuations in polynya size and location reflected in subsurface sediments(Figure3, Table 2). These data indicate that sedimentation processed within the polynya produce a terrigenous-dominated deposit, while sediments deposited beneath a pack ice cover contain a much larger percentage of biogenic material. This information coincides with data collected by Dunbar et al. (1985) and Anderson et al. (1984), who report similar relationships between biogenic and terrigenous sediments. Their research shows an increase in terrigenous sediment and fine grained material towards the coast, resulting from less winnowing in this area of deeper ocean. They also indicate that marine currents are important influences on distribution of biogenic sediment, but are weak in the inner shelf region, generally less than 8 cm/second. The larger percentage of terrigenous material in proximity to the polynya is attributed to ice rafting, subglacial deposition, and an aeolian influence from katabatic winds. Turbidity and debris flows are not currently considered significant in Terra Nova Bay, but are reported to occur north of the bay. A decrease in the biogenic component within the polynya is explained by possible frequent mixing of the water column by katabatic winds (Dunbar et al.,1985). Pelagic micro-organisms are believed to flourish to the east of Terra Nova Bay, in the central-outer shelf region, because of warmer, deep water upwelling over the contintental slope, resulting in sediments that are predominantly siliceous mud and siliceous ooze.

Volcanic sediment abundance is dependent on the combination of volcanic activity during time of deposition, distance from the volcanic source, wind direction and strength, and to some extent, the presence of ice cover. The latter control acts by decreasing the settling of ash fall particles through the water column.

Of the cores examined in this study, two, DF80-101 and DF80-105, are presently located in the area that is usually ice-free, despite short-term fluctuations in polynya size. Surface data from these cores show a large percentage of terrigenous sediment when compared to biogenic components, and minor volcanic shards (Table 2). Down-core samples at these two locations do not deviate significantly from the composition of the surface sediments. E. antarctica is rare throughout these cores, suggesting that they have been located within the polynya for at least the time required to deposit 125 cm (Figures 4 a.-b.). The surface sample from DF80-107 contains nearly equal amounts of biogenic and terrigenous sediment, suggesting that this location lies close to the open water / pack ice boundary, but is probably beneath ice a majority of the time (Figure 4. c.). Samples from above 40 cm subbottom correlate well with the surface composition, and also contain a relatively large percentage of E. antarctica tests in good condition, indicative of ice covered conditions. Below the 40 cm depth however, biogenic components decrease markedly in abundance, while terrigenous sediments show a corresponding increase. The polynya appears to have controlled deposition at this location during the sedimentation interval from 40 to 181 cm; no data are available below that level. Mass flow processes at this interval, as dominant depositional mechanisms, can be ruled out to due the relatively extensive and consistent sediment-type abundances present.

At site DF80-110, samples contain a consistent ratio of biogenic/terrigenous sediment to a depth of 60 - 62 cm subbottom. At that level, biogenics and E. antarctica tests increase significantly. Although all of these samples indicate the importance of ice-covering, the interval at 60 - 62 cm may reflect an advance of pack ice landward (Figure 4 d.). Below the 60 - 62 cm level, a slight decrease in the biogenic component and an increase in terrigenous abundance suggests an episode of polynya expansion. This expansion is especially indentifiable at the 121 - 123 cm level, where the biogenic abundance decreases sharply. Although this discreet anomaly may represent rapid polynya expansion, increased frequency of higher velocity marine currents producing a larger amount of winnowing cannot be dismissed without further evidence. Below 121 - 123 cm, biogenic abundance increases and terrigenous abundance decreases may record a decrease in the polynya's size due to encroaching pack ice (Figure 4 d.). This could possibly result from a decrease in size of the Drygalski Ice Tongue and / or a decrease in katabatic wind strength.

Interpretation of the results from core DF80-127 is complicated by the very small amount of sediment present on the slide. This lack of sediment, along with the differences in abundance estimations inherent between researchers, is the most probable cause for the differences observed between surface and subsurface compositional data (Figure 4 e.). Despite this potential error, a large increase in volcanic glass abundance relative to the other core locations is obvious, and occurs in both surface and subsurface samples. The proximity of a volcano to the west is responsible for this increase in volcanics, along with the location of the sample near the northern boundary of the polynya (Figures 1 and 3). The abundance of _Eucampia_ _antarctica_ at the 61 - 63 cm level of DF80-127 is difficult to interpret because the biogenic / terrigenous ratio remains constant; the latter observation suggests relatively static conditions with regard to size fluctuations, while the increase in _E. Antarctica_ suggests a decrease in polyna size. A possible explanation is that the rate of terrigenous sediment influx is increased at this location because of proximity to subglacial deposition, ice ratting, and to a lesser extent turbidity flows (more prominent north of Terra Nova Bay), while organisms such as diatoms flourish beneath the ice cover. It is therefore inferred that deposition at DF80-127 has taken place near the northern boundary of the polynya for the time required to deposit at least 95 cm of sediment. Marine currents may also have had a pronounced affect on the distribution of diatoms (and other micro-organisms) as is shown by a relatively small percent of the silt and clay fraction (Table 1.e.) when compared to similar depths at the sample DF80-110, DF80-107, and DF80-101 locations in Terra Nova Bay.

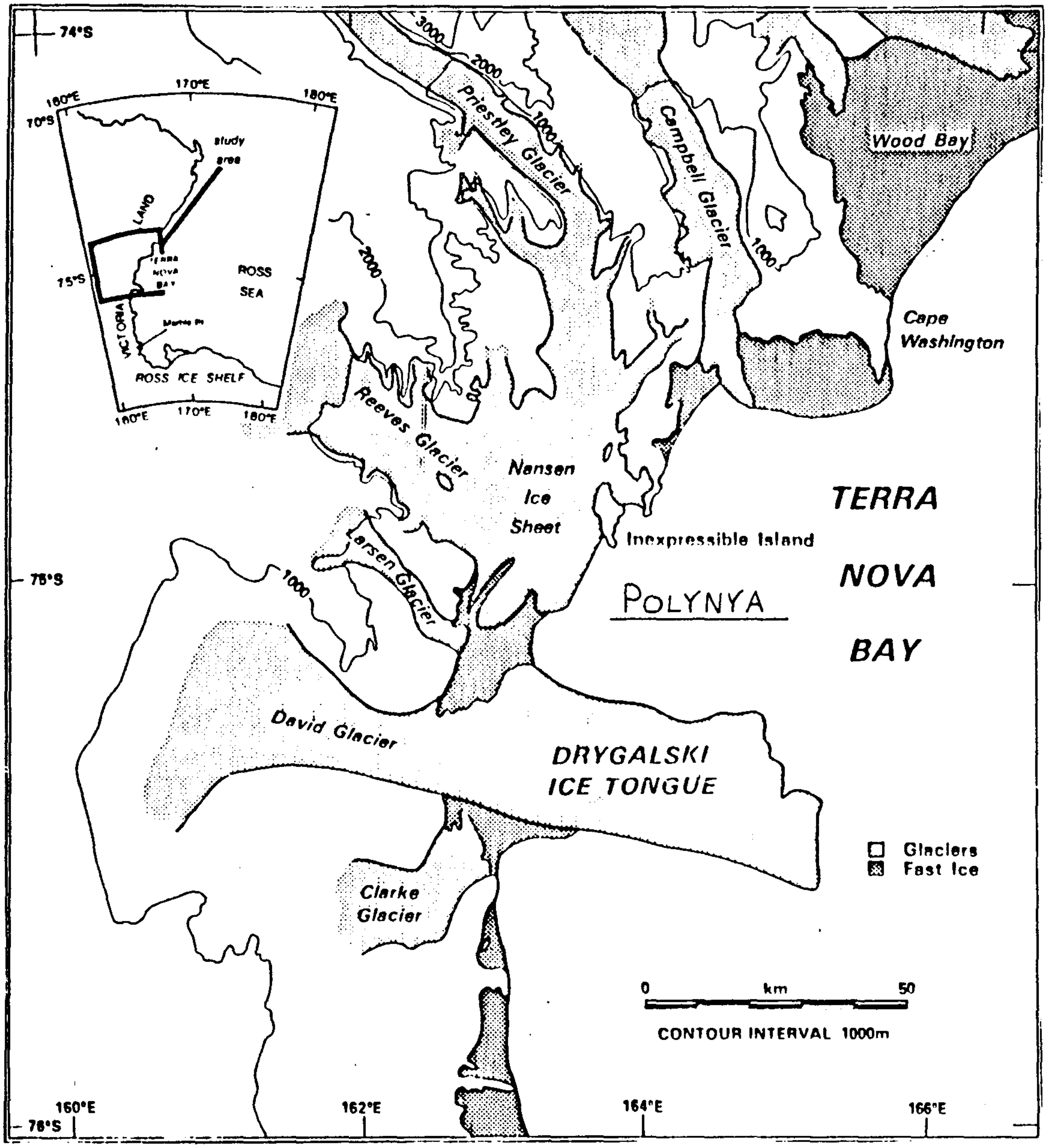


Figure 1. Location of study area. Polynya is in Terra Nova Bay, north of Drygalski Ice Tongue. (from Bromwich and Kurtz, 1984)

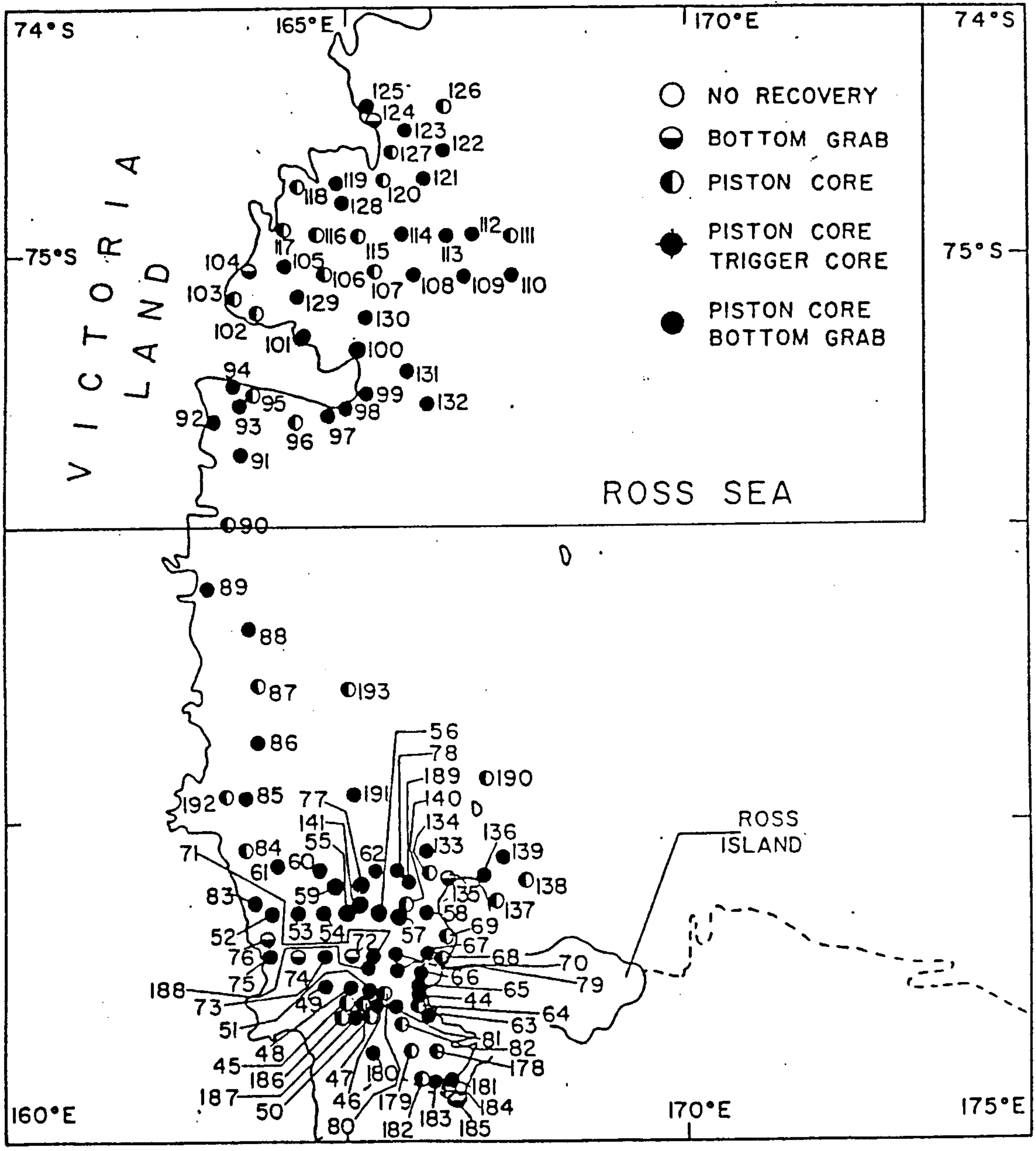


Figure 2. Deep Freeze 80 locations in the southwestern Ross Sea. Cores 101, 105, 107, 110, and 127 were examined in this study. (from Anderson and Kurtz, unpublished cruise report)

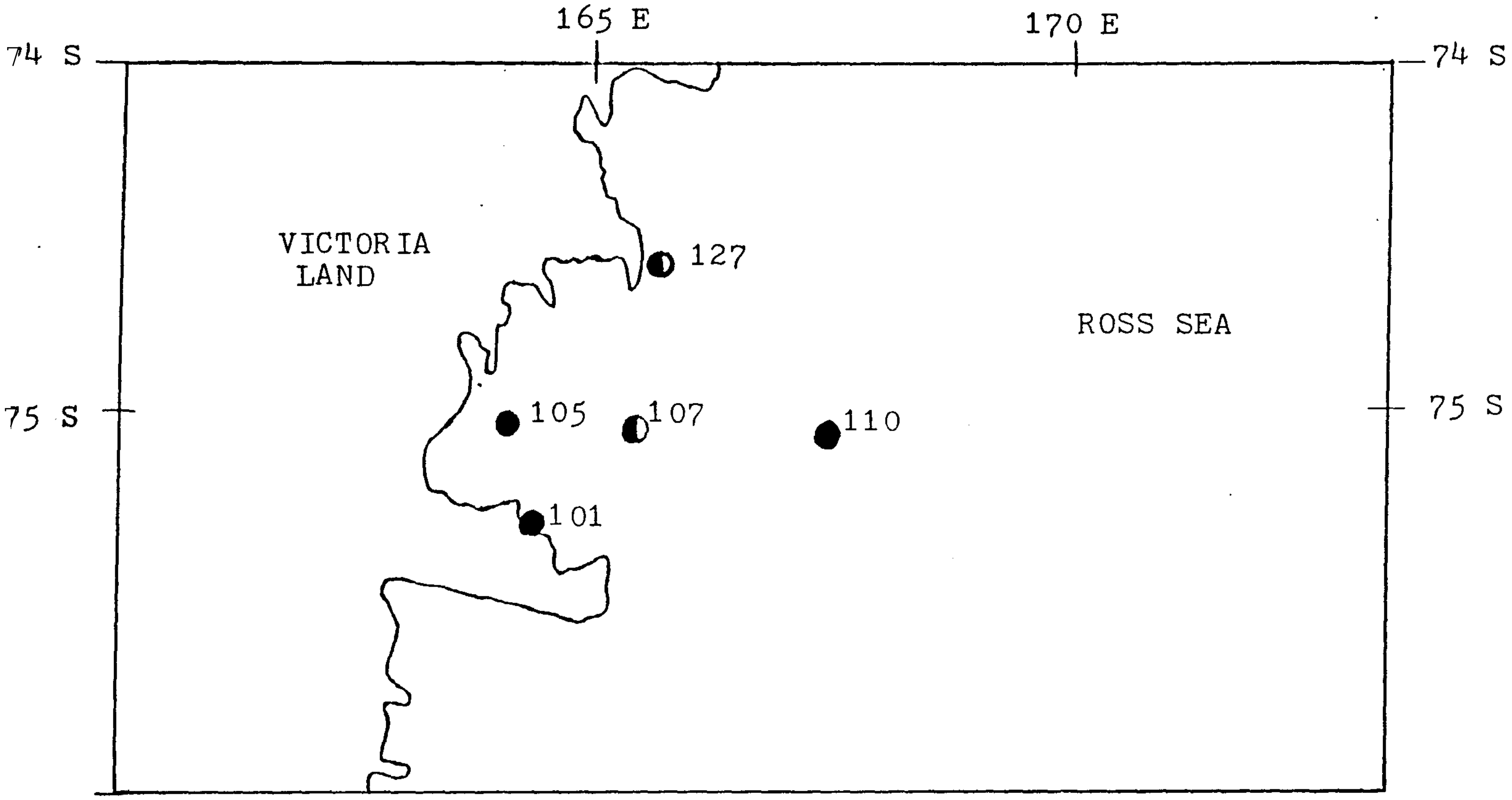


Figure 3. Location of cores studied in this report.

DF80 - 101

	Biogenic							Terrigenous				
Depth	Diatoms	Radiolaria	Foraminifera	Spicuoles	Silica Flag.	TOTAL	Volcanic	Quartz	Feldspar	Mafic	Silt & Clay (≤ 20μm)	TOTAL
9 - 11	7	2	-	1	-	10	5	35	12	5	33	85
18 - 20	2	1	-	1	1	4	8	30	15	5	38	88
38 - 40	2	-	-	1	-	3	10	32	15	7	33	87
58 - 60	3	1	-	1	-	5	7	30	13	5	40	88
78 - 80	3	1	-	1	-	5	5	28	15	7	40	90
98 - 100	2	1	-	1	-	4	5	20	10	5	56	91
118 - 120	4	-	-	1	-	5	3	10	5	7	70	92
126 - 128	4	1	-	2	-	7	5	25	8	5	50	88

Table 1. a.

DF80 - 105

	Biogenic							Terrigenous				
Depth	Diatoms	Radiolaria	Foraminifera	Spicuoles	Silica Flag.	TOTAL	Volcanic	Quartz	Feldspar	Mafic	Silt & Clay (< 20µm)	TOTAL
78 - 80	2	-	-	1	-	3	10	40	12	5	30	87
98 - 100	1	-	-	1	-	2	10	17 Lithic Frag-34	5	2	30	88
118 - 120	2	-	-	2	-	4	15	35 Lithic Frag-16	10	5	15	81

Table 1. b.

DF80 - 107

	Biogenic							Terrigenous				
Depth	Diatoms	Radiolaria	Foraminifera	Spicuoles	Silica Flag.	Total	Volcanic	Quartz	Feldspar	Mafic	Silt & Clay (≤ 20µm)	Total
34 - 36	23	1	-	5	1	30	5	15	4	1	45	65
38 - 40	25	3	-	4	1	33	7	20	5	5	30	60
48 - 50	2	-	-	1	-	3	15	25	11	6	40	82
51 - 53	7	1	-	3	-	12	10	15	5	3	55	78
72 - 74	10	2	-	3	-	15	5	30	10	5	35	80
82 - 84	8	1	-	1	-	10	5	30	10	5	40	85
86 - 88	4	-	-	1	-	5	8	35	7	5	40	87
92 - 94	5	-	-	-	-	5	10	30	15	10	30	85
96 - 98	7	3	-	-	-	10	7	28	15	5	35	83
116 - 118	7	2	-	1	-	10	7	24	15	7	37	83
136 - 138	5	2	-	2	1	10	5	25	15	5	40	85
156 - 158	8	2	-	2	-	12	6	25	13	9	35	82
179 - 181	9	1	-	2	-	12	7	25	10	6	40	81

Table 1. c.

DF80 - 110

	BIOGENIC							TERRIGENOUS				
DEPTH	DIATOMS	RADIOLARIA	FORAMINIFERA	SPICUOLES	SILICA FLAG.	TOTAL	VOLCANIC	QUARTZ	FELDSPAR	MAFIC	SILT & CLAY (≤ 20 µm)	TOTAL
12 - 14	34	2	-	3	1	40	5	7	4	4	40	55
15 - 18	34	3	-	3	-	40	5	6	5	4	40	55
35 - 37	35	1	-	1	-	37	5	5	2	1	50	58
55 - 57	30	1	-	3	1	35	5	14	4	2	40	60
60 - 62	50	5	-	10	3	68	2	8	5	2	15	30
75 - 77	30	1	-	3	1	35	5	20	8	2	30	60
98 - 100	20	2	-	7	1	30	7	25	5	3	30	63
103 - 105	23	3	-	8	1	35	7	15	8	3	32	58
121 - 123	7	-	-	8	-	15	10	40	10	10	15	75
141 - 143	20	1	-	8	1	30	5	8	5	2	50	65

Table 1. d.

DF80 - 127

	BIOGENIC							TERRIGENOUS				
DEPTH	DIATOMS	RADIOLARIA	FORAMINIFERA	SPICUOLES	SILICA FLAG.	TOTAL	VOLCANIC	QUARTZ	FELDSPAR	MAFIC	SILT & CLAY (≤20μm)	TOTAL
28 - 30	15	-	-	5	-	20	45	10	4	1	20	35
61 - 63	17	-	-	8	-	25	40	15	4	1	10	30
93 - 95	20	-	-	10	-	30	35	18	5	2	10	35

Table 1. e.

	Biogenic							Terrigenous				
Core Number	Diatoms	Radiolaria	Foraminifera	Spicuoles	Silica Flag.	TOTAL	Volcanic	Quartz	Feldspar	Mafic	Silt & Clay (≤ 20 µm)	TOTAL
DF80-101	→	→	→	→	→	34	1	→	→	→	→	65
DF80-105	→	→	→	→	→	5	1	→	→	→	→	94
DF80-107	→	→	→	→	→	46	3	→	→	→	→	51
DF80-110	→	→	→	→	→	38	4	→	→	→	→	58
DF80-127	→	→	→	→	→	15	80	→	→	→	→	5

<u>Table 2.</u> Surface core data from the western Ross Sea. (from Hughes, unpublished master thesis)

SAMPLE and DEPTH	VOLCANIC	%D		BIOGENIC	%D		TERRIGENOUS	%D	
DF80-101 78-80	2	3		3	2		95	5	
DF80-107 136-138	5	0		6	4		89	4	
DF80-110 75-77	3	2		40	5		57	3	

Table 3. Replicate analysis of three smear slides, showing deviation from original estimates.

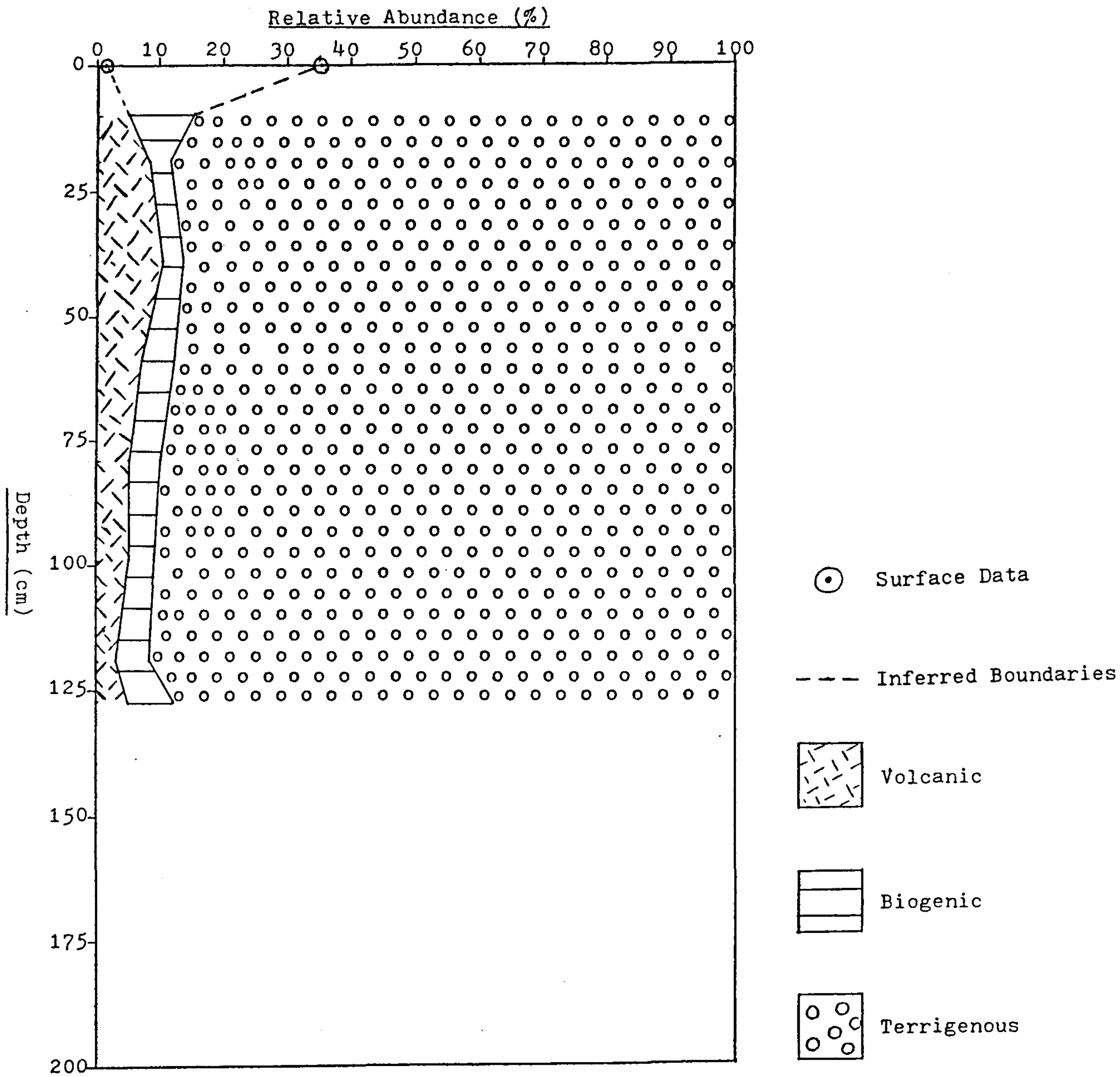


Figure 4. a. DF80 - 101

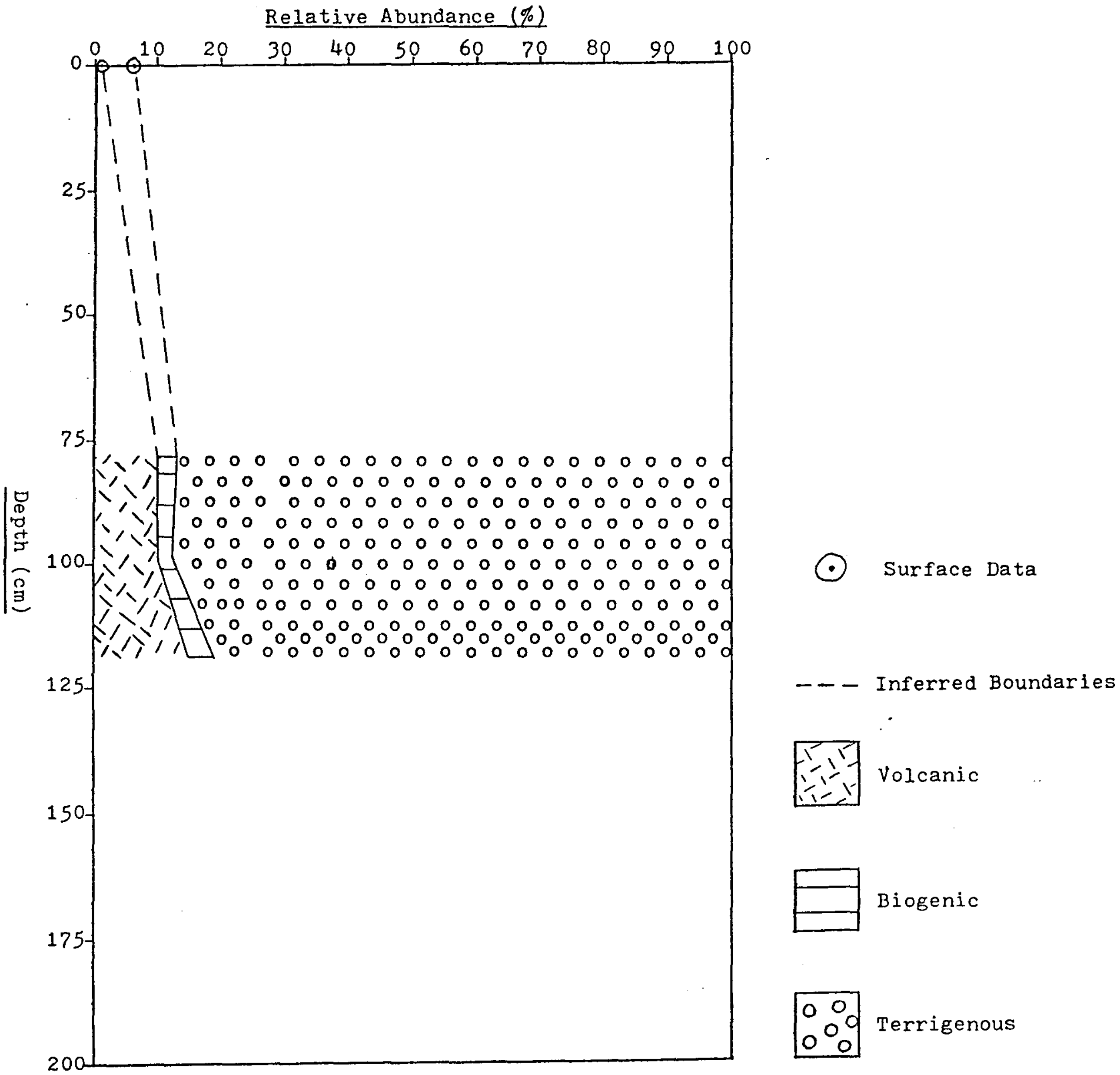


Figure 4. b. DF80 - 105

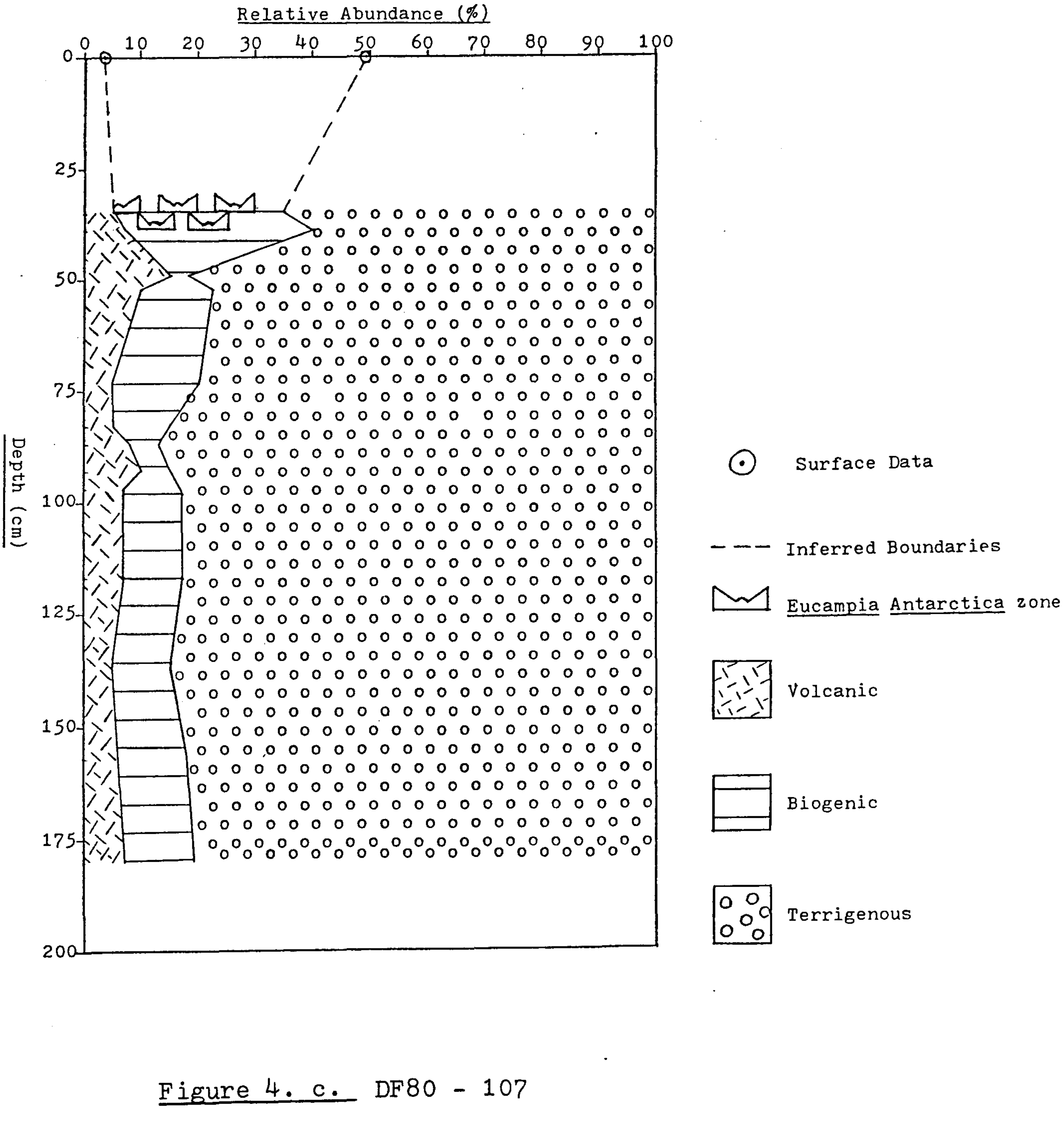


Figure 4. c. DF80 - 107

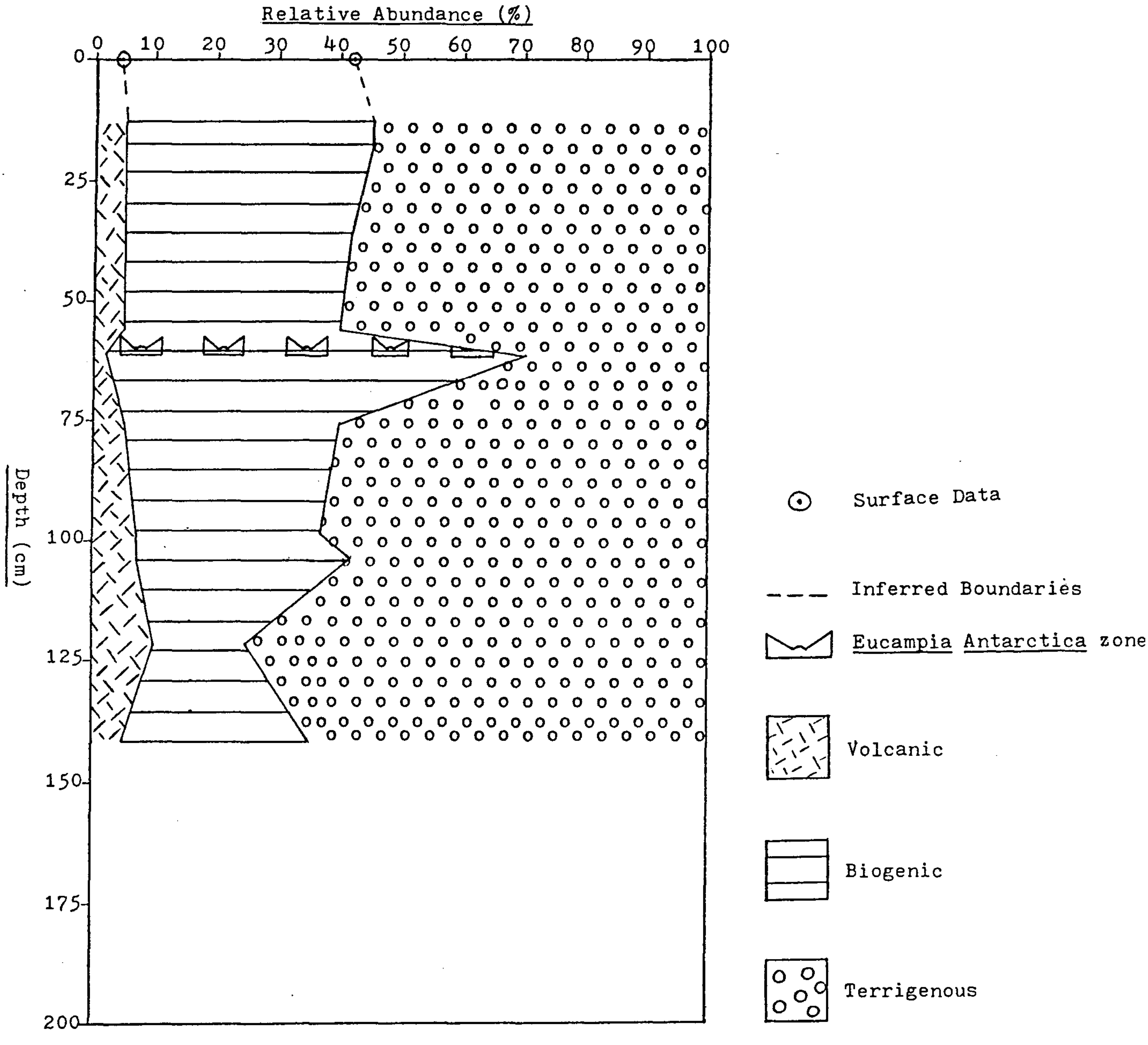


Figure 4. d. DF80 - 110

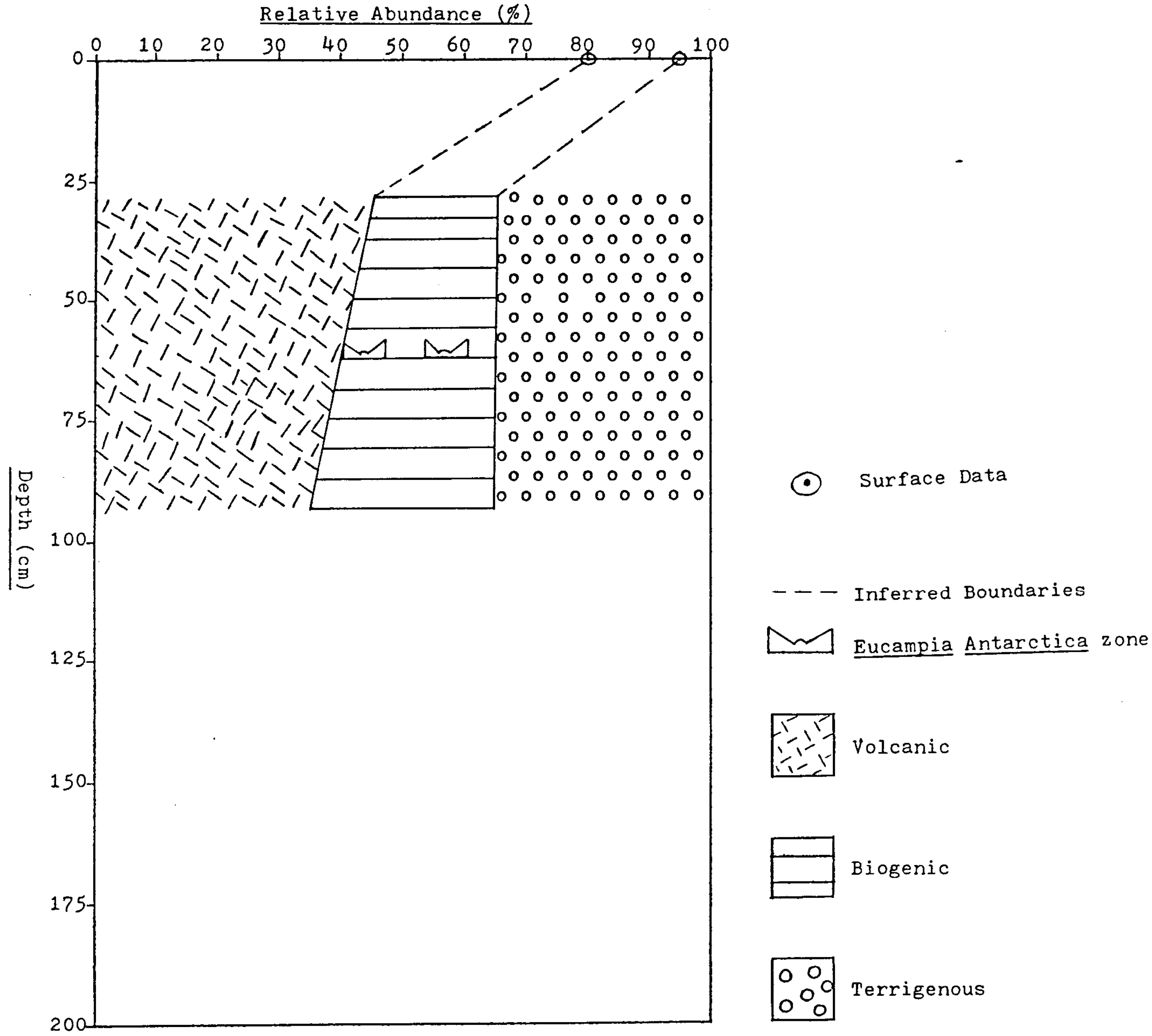


Figure 4. e. DF80 - 127

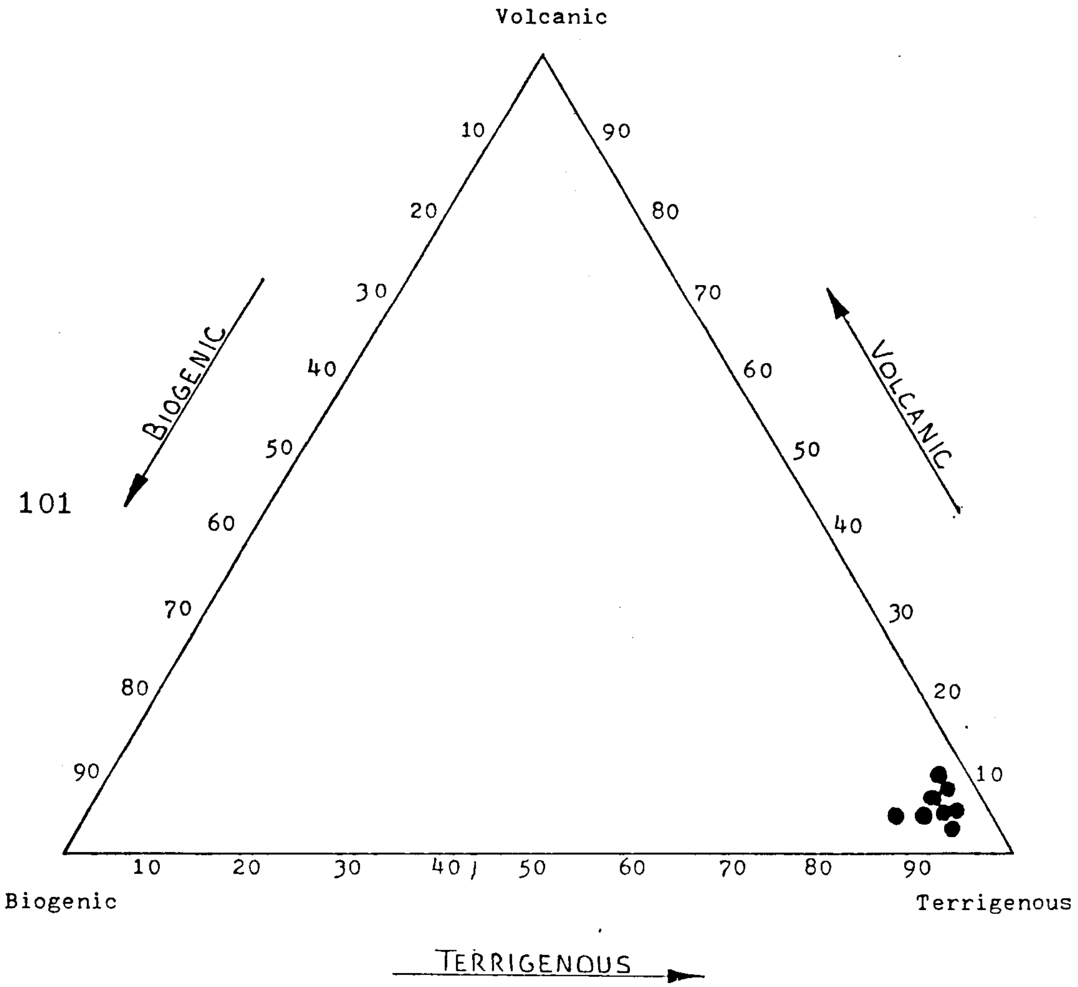


Figure 5. a.

Triangular plot of DF80 - 101

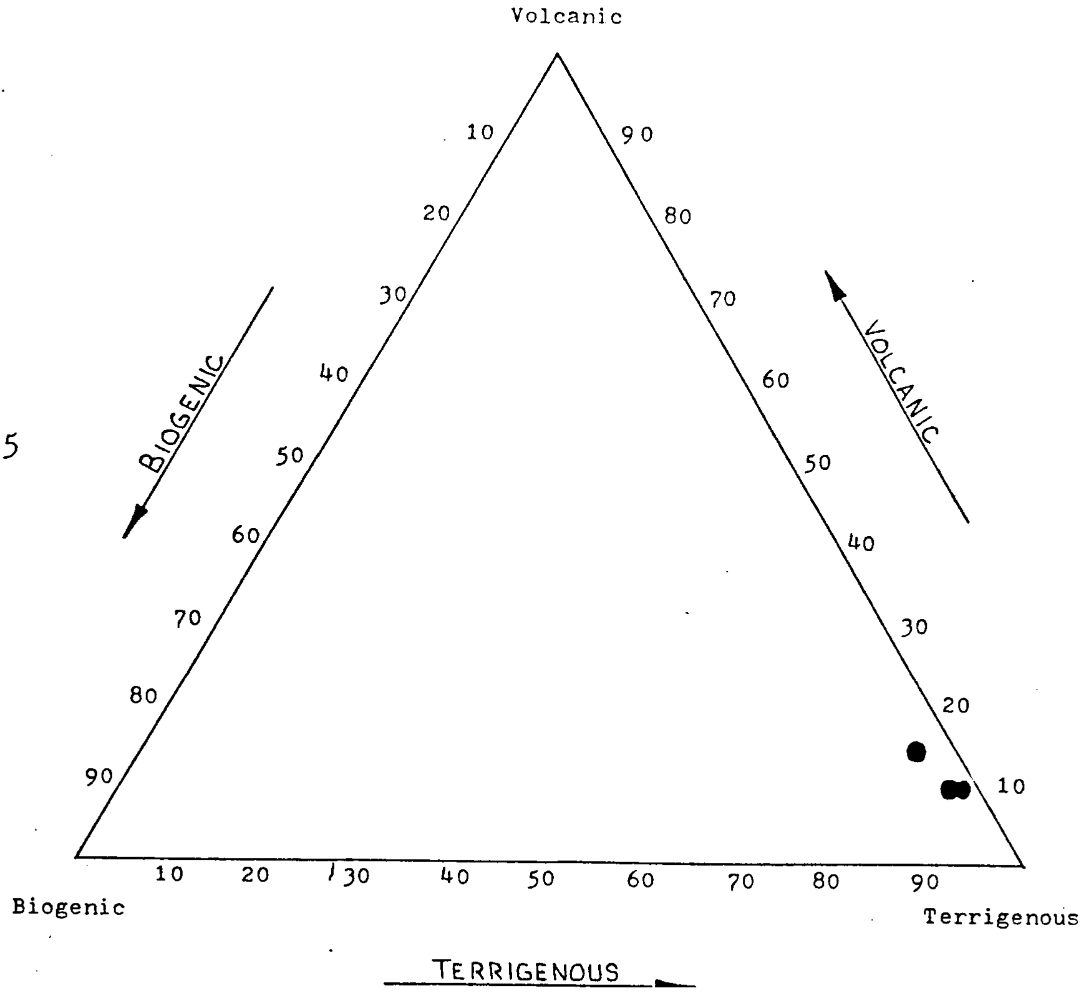


Figure 5. b. DF80 - 105

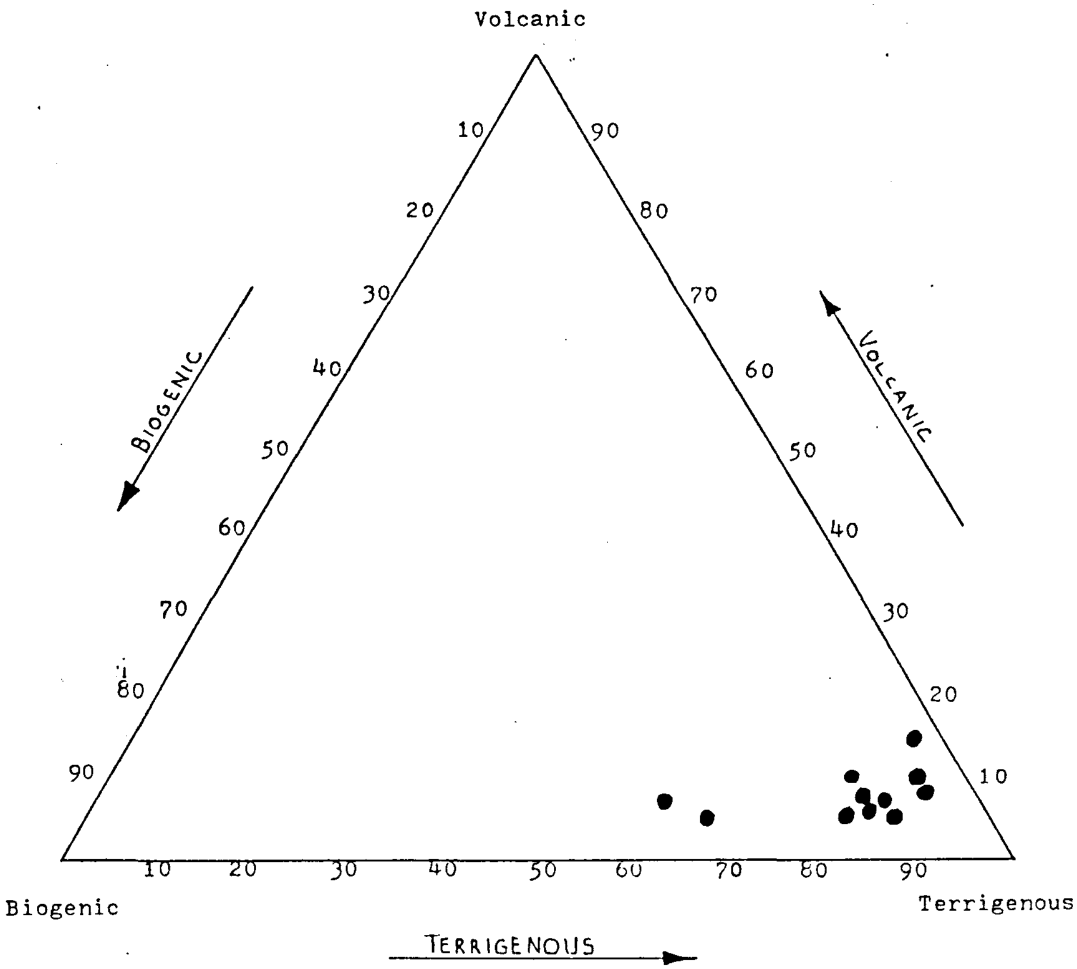


Figure 5. c. DF80 - 107

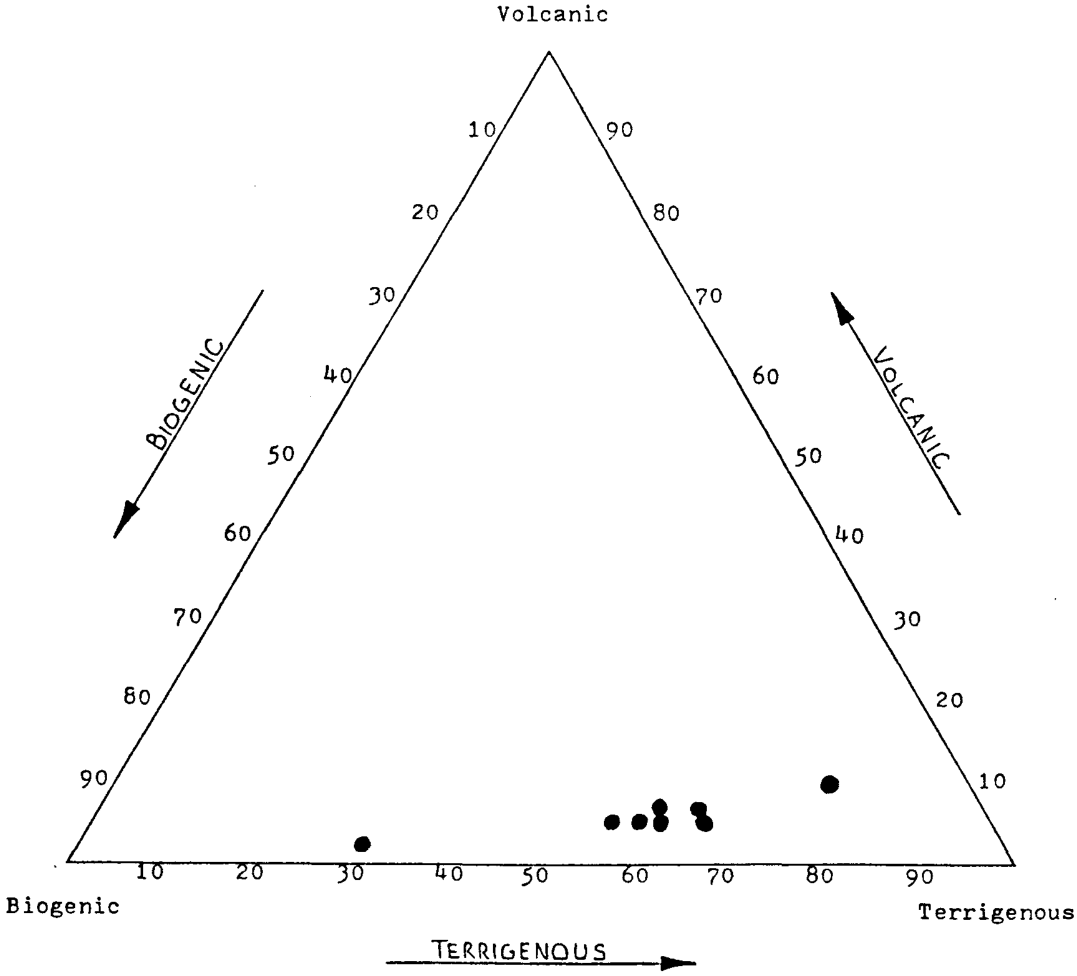
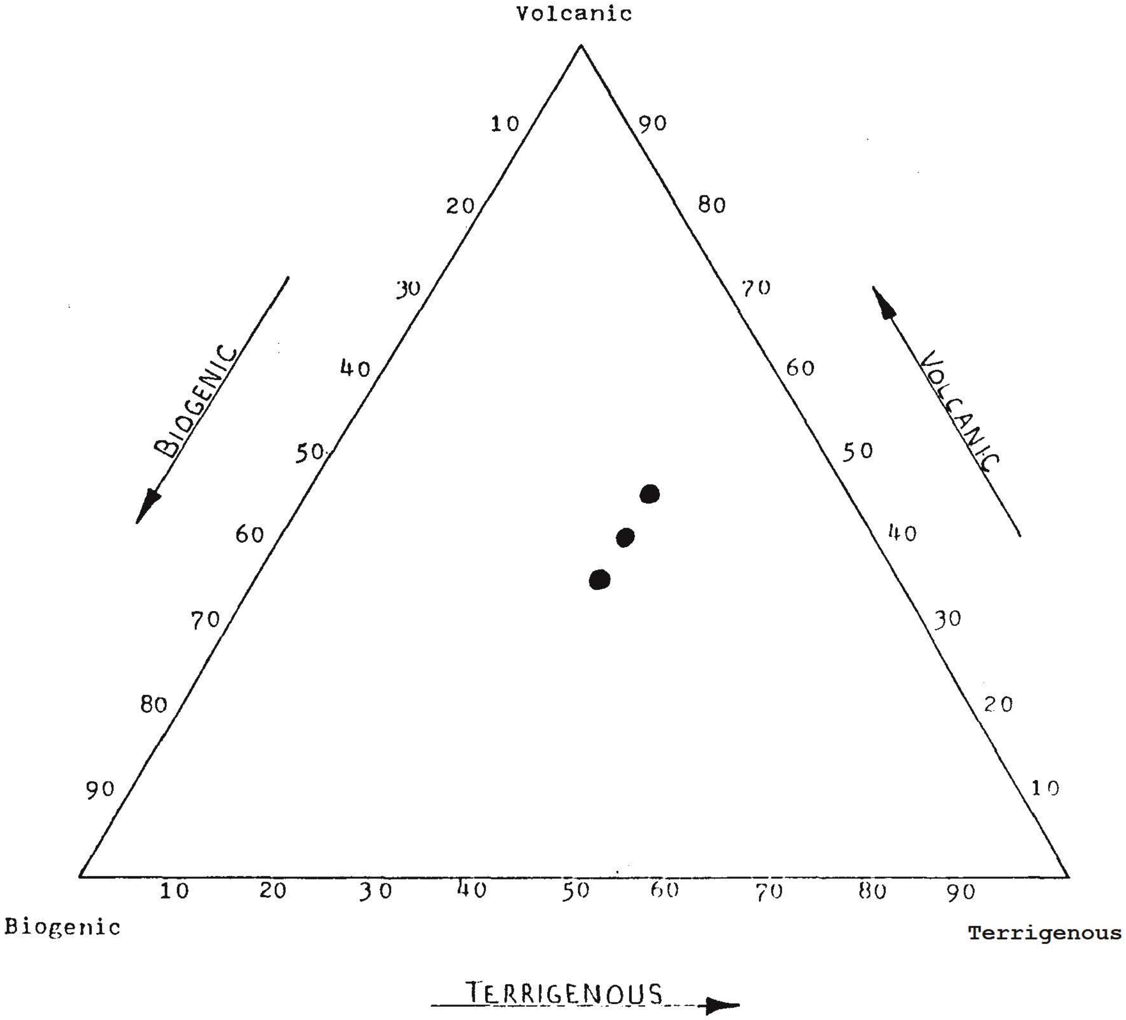


Figure 5. d. DF80 - 110

Figure 5. e. DF80 - 127



References

Anderson, J.B., C.F. Brake, and N.C. Myers, Sedimentation on the Ross Sea continental shelf, Antarctica, Mar. Geol., 57, 295-333, 1984.

Bromwich, D.H., and D.D. Kurtz, 1982, Experiences of Scott's Northern Party: Evidence for a relationship between winter katabatic winds and the Terra Nova Bay polynya, Polar Rec., 21, 137-146.

Burckle, Lloyd H., 1984, Ecology and paleoecology of the marine diatom *Eucampia antarctica* (castr.) mangin, Mar. Micropal., 9, 77-86.

Bromwich, D.H., and D.D. Kurtz, 1984, Katabatic wind forcing of the Terra Nova Bay polynya, J. Geophysical Res., 89, 3561-3572.

Dunbar, Robert B., Anderson, John B., and Eugene W. Domack, 1985 Oceanographic influences on sedimentation along the Antarctic continental shelf, Antarctic Res. Series, 43, 291-310.

Fisher, R.V., and H.-U. Schmincke, 1984, Pyroclastic Rocks, Springer-Verlag, Berlin, Heidelberg, New York, Tokyo, pp. 1-10, 89-106, 116-124, 231-242, 312-345.

Haq, Bilal U., and Anne Boersma, 1978, Introduction to Marine Micropaleontology, Elsevier - New York.

Heiken, Grant, 1974, An Atlas of Volcanic Ash, in Smithsonian Contrbutions to the Earth Sciences, Smith. Inst. Press.

Heiken, Grant, and Kenneth Wohletz, 1985, Volcanic Ash, Univ. of California Press.

Kurtz, D.D., and D.H. Bromwich, 1983, Satellite observed behavior of the Terra Nova Bay polynya, J. Geophysical Res., 88, 9717-9722.

Moore, Raymond C.(editor), 1955, Treatise on Invertebrate Paleontology, Part E, Archeocyatha and Porifera, Geol. Soc. Am. and Univ. of Kansas Press.

Rogers, Austin F., and Paul F. Kerr, 1933, Thin Section Mineralogy, McGraw-Hill Inc.