A DIATOM REPORT ON DVDP CORES 3, 4A, 12, 14, 15 AND OTHER RELATED SURFACE SECTIONS

Howard T. BRADY

School of Biological Sciences, Macquarie University, North Ryde, 2113, Sydney, Australia

Abstract: This paper covers diverse topics. A glacial till in the western Ferrar Glacier area shows that glacial drainage patterns in southern Victoria Land changed during the Victoria Orogeny. A recently discovered section provides further evidence of a Miocene fjord in Wright Valley. Diatom analysis of DVDP 14 (Wright Valley) and DVDP 12 (Taylor Valley) shows that diatoms are not helpful in interpreting those sedimentary sections. Analysis of a newly discovered mirabilite deposit on the Ross Ice Shelf indicates that mirabilite can be formed by the injection of saline brines to the surface of ice shelves and that other mirabilite deposits in the McMurdo region may reflect ancient ice shelf thicknesses rather than former sea levels. Finally, there is some evidence that diatoms grew in freshwater pools during a hyaloclastite phase of Ross Island volcanism.

1. Introduction

Each sub-title in this paper covers an individual topic or problem relevant to the interpretation of the Dry Valley Drilling Project cores:

1) The present day dry valley glacial system and earlier glaciations.
2) The age of the Lake Vanda core (DVDP 4A) and related surface sections in Wright Valley.
3) The interpretation of DVDP 14, Wright Valley.
4) The interpretation of DVDP 12, Taylor Valley.
5) The presence of ice age freshwater moats in McMurdo Sound.

2. Earlier Glaciations That Predate the Present Dry Valley Glacial System

BRADY and MCKELVEY (1978, in preparation) have described an ancient tillite at 2750 m on Mt. Feather overlooking the Skelton Névé, the Ferrar Glacier and Beacon Valley (Figs. 1 and 2). The deposit has many features in common with Sirius tillites described by MERCER (1972), MAYWESKI (1972, 1975) and BARRETT (1979). BRADY and MCKELVEY mapped 57 directions on striated clasts and exposed two sections of striated pavement which show a glacial direction to the south-south east towards and parallel to the Skelton Glacier. This information does not agree

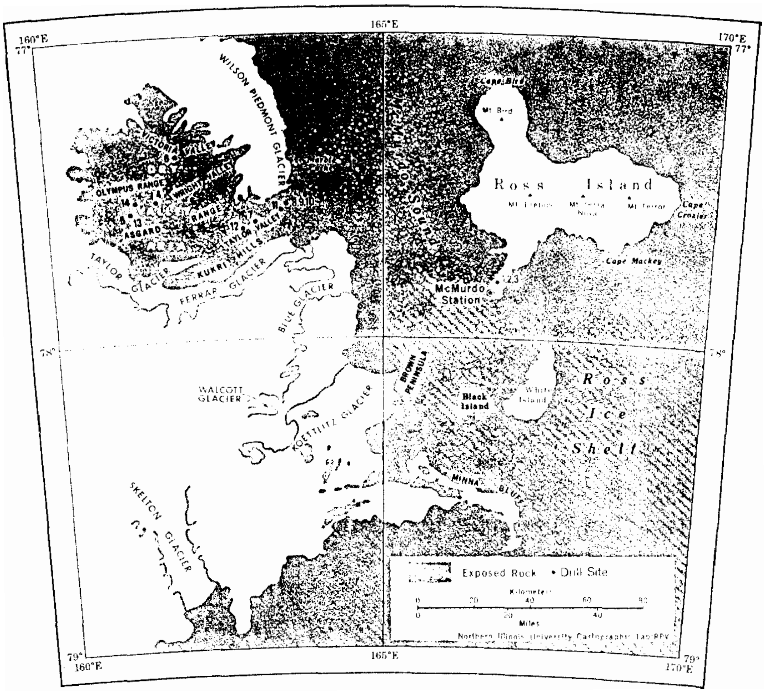

Fig. 1. Map of DVDP drill sites (courtesy L. McGINNIS).

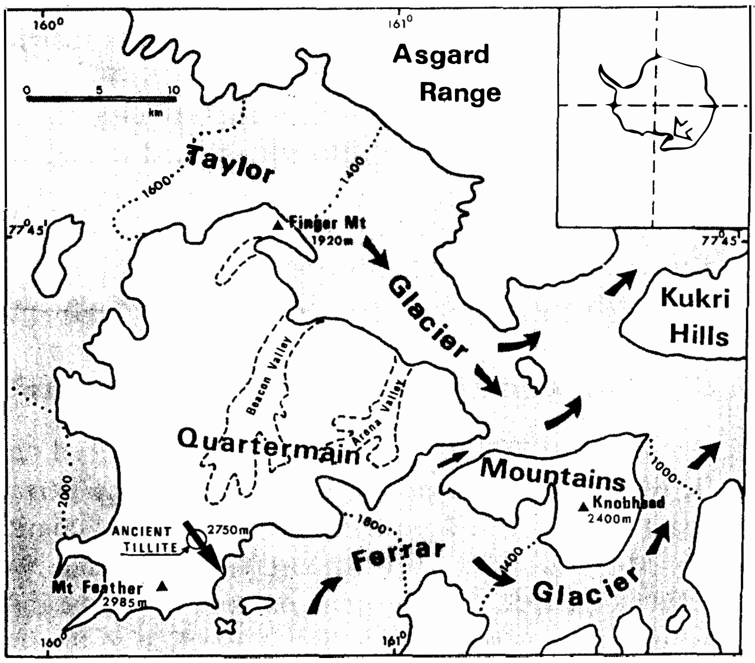

Fig. 2. Map of Mt. Feather locality adapted from U.S. Geological Survey Sheets 1: 250,000.

with Mayewski's diagrams which show a direction to the east parallel to the direction of the Ferrar Glacier. BRADY and McKELVEY consider that this deposit is a remnant of a paleoglacial floor which has been eroded by the subsequent cutting of Beacon Valley and the Ferrar Valley, which lie 1000 m and 700 m below the tillite. Since the cutting of Beacon Valley would seem to be contemporaneous with the cutting of Taylor Valley, it is suggested that this tillite predates the cutting of Taylor Valley and the adjacent dry valleys.

This suggestion is consistent with the pattern of uplift that has emerged from the DVDP papers on Taylor Valley and Wright Valley which confirm the existence of fjords suggested by WEBB (1972, 1974) which have been progressively uplifted above sea level. STUCKLESS (1975) has already pointed out from fission track dates in apatite from DVDP 6 (Victoria Valley) that the Vida granite was uplifted 50 m.y. ago. The data from Mt. Feather would suggest that glacial drainage patterns have been substantially modified during a long history of uplift in southern Victoria Land. This uplift is consistent with uplift along continental rift zones and a thinning of the crust over a lighter aesthenosphere. This suggestion agrees with Goldich's interpretation of the alkali basalts of the McMurdo region which he relates to continental rather than oceanic rifting (GOLDICH *et al.*, 1975).

3. The Lake Vanda Core (DVDP 4A) and Wright Valley Surface Sections (Fig. 3)

The marine sedimentary succession in DVDP 4A drilled in the floor of Lake Vanda is from 5.74 m–11.2 m sub-bottom (BRADY, 1979). A reinspection of this interval confirms the existence of late Miocene diatoms such as *Denticula dimorpha* SCHRADER and *Denticula hustedtii* SIMONSEN and KANAYA. The absence of *Thalassiosira torokina* BRADY and flat forms of *Antinocyclus ingens* RATTRAY which are

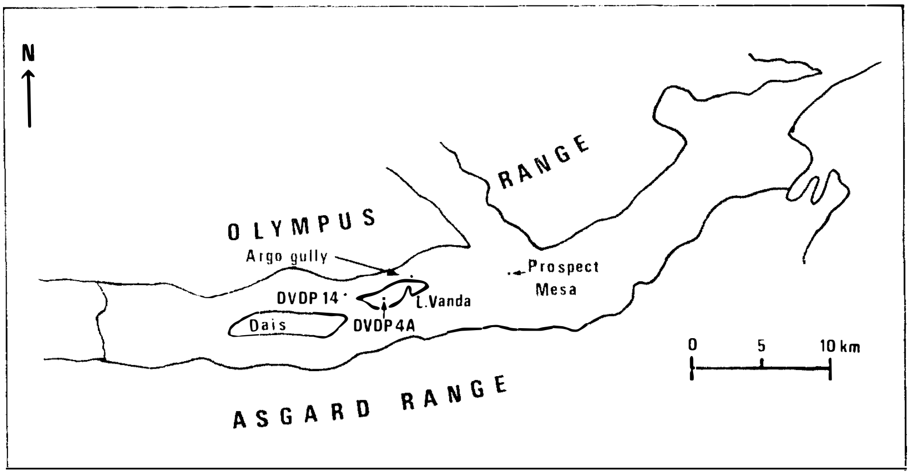

Fig. 3. Wright Valley sedimentary sections (Maps adapted from WEBB, 1975).

common in the late Miocene section in Taylor Valley (DVDP 11, 290 m) would seem to suggest that the two successions are not isochronous and that the Lake Vanda marine material is older. An alternative suggestion would be that uplift had so changed the parameters of the Wright Valley fjord that there were significant late Miocene ecological variations between the shallow Wright Valley fjord and

Depth (m)	Core bag intervals	Marine diatom fragments	Marine sponge spicules	Non-marine diatoms	Identifiable diatoms
0.16-17	16-17	R	R	A	I
	32-33	B	R	A	I
	48-49	R	R	A	I
	16-17	R	R	A	I
	32-33	R	R	C	I
	48-49	R	R	C	I
	10-11	R	R	A	I
	20-21	R	R	A	I
	7- 8	R	R	C	I
	7- 8	R	R	C	I
	14-15	R	R	F	I
	10-11	R	R	F	I
2.68-69	20-21	R	R	F	I
	-	R	R	C	I
	6- 7	R	R	C	I
	10-11	R	R	C	I
	20-21	R	R	C	I
3.38-39	30-31	R	R	C	I
	7- 8	R	R	C	I
	6- 7	R	R	R	I
3.51-2	4- 5	R	R	R	I
	16-17	B	R	B	
	32-33	B	R	B	
	48-49	B	R	B	
3.84-85	5- 6	B	R	B	
	6- 7	B	R	B	
	3- 4	B	R	B	
4.14-15	10-11	B	R	B	
	20-21	B	R	B	
	10-11	B	R	B	
	20-21	B	R	B	
4.80-81	7- 8	B	R	B	
	20-21	B	R	B	
	40-41	B	R	B	
	60-61	B	R	B	
	15-16	R	R	B	
	40-41	B	R	B	
	50-51	R	R	B	
5.74-75	15-16	R	R	B	
	30-31	R	R	B	
	10-11	R	R	B	
	20-21	R	R	B	
	30-31	R	R	B	
	5- 6	C	C	B	I

Depth (m)	Core bag intervals	Marine diatom fragments	Marine sponge spicules	Non-marine diatoms	Identifiable diatoms
	15-16	C	R	B	I
	7- 8	C	R	B	I
	14-15	R	R	B	
	5- 6	R	R	B	
	10-11	R	R	B	
	20-21	C	C	B	I
	30-31	R	R	B	I
	45-46	R	R	B	I
	10-11	A	F	B	I
	20-21	A	F	B	I
	35-36	R	R	B	
6.25-26	0- 1	R	R	B	
	10-11	F	R	B	
	20-21	R	R	B	
	30-31	R	R	B	
	0- 1	C	C	B	I
	10-11	R	R	B	I
	20-21	C	R	B	I
	35-36	F	F	B	I
7.65-66	10-11	R	R	B	I
	20-21	R	R	B	I
	10-11	R	R	B	
8.86-87	0- 1	R	R	B	I
	15-16	R	R	B	I
	35-36	R	R	B	
	15-16	F	F	B	
	30-31	F	R	B	
	0- 1	C	C	B	
	15-16	R	B	B	
	35-36	A	A	B	I
	50-51	A	A	B	I
9.88-89	5- 6	R	C	B	I
	15-16	C	C	B	I
10.03-04	3- 4	R	R	B	
	22-23	R	R	B	
	30-31	R	R	B	
	15-16	R	R	B	
	35-36	R	R	B	I
	50-51	R	R	B	I
	15-16	B	R	B	
	35-36	B	R	B	
	55-56	B	R	B	

Fig. 4. Abundance and distribution of diatoms in DVDP 4A, Lake Vanda, Wright Valley (Key at 1000 × : B-Barren; R-Rare; F-One fragments/5 fields of view; C-Fragments in each field of view; A-Abundant diatoms or fragments).

the deeper Taylor Valley fjord; this problem remains unresolved.

Other problems associated with the Lake Vanda marine material are the state of diatom fragmentation and the absence of foraminifera. It is possible that the section is reworked but it is evident from the absolute abundance of siliceous microfossils (Fig. 4) that the marine material has not been transported any greater distance. There is no comparison between the abundant diatom fragments in the Lake Vanda section and the diluted assemblage of the Ross tills of Taylor Valley or the reworked lacustrine intervals in DVDP 11 (*e.g.* 0–17.20 m).

The relationship of the Lake Vanda core to surface sections in Wright Valley is also not perfectly clear (Fig. 3). During the 1977/78 season DENTON (personal communication) discovered shells overlying a bed of sediments on the north-eastern short of Lake Vanda (Argo gully). These were inspected by this author and found to be abundant in silicoflagellate and marine diatom fossils. Later in the same season, this author revisited the site and found additional shell material in other exposures of the same bed. A more complete report by DENTON and BRADY is yet to be published but the significant feature of the exposed beds is that shell material is only in the upper few centimeters of the massive three meter bed. It is possible that the waters of the shallow marine fjord represented by the pecten beds at Prospect Mesa (Fig. 3) reworked the older marine sediments of the Wright Valley fjord or that the Vanda section represents a glacially reworked sequence of older *in situ* fjord material.

The age of the pecten beds at Prospect Mesa (Fig. 1) is not clear. The foraminifera fauna is similar to WEBB and WRENN's Zone 2 fauna in DVDP 10, Taylor Valley (WEBB and WRENN, 1979). WEBB suggested that both horizons were mid-Pliocene (3.4–3.7 m.y.) but diatom evidence from DVDP 10 suggests that this fauna ranged back in time to the early Pliocene. It is therefore possible that the pecten beds at Prospect Mesa are slightly older than WEBB originally proposed in 1972, 1974 (*i.e.* between 3.97 and 4.59 m.y.). Additional glacial evidence and dating from DENTON's surface surveys in Wright Valley may clarify this problem. Unfortunately, no identifiable diatoms have been recovered from the Prospect Mesa section.

4. The Interpretation of DVDP 14

A sedimentary succession of 28 meters was recovered from DVDP 14 drilled in the north fork of Wright Valley (Fig. 3). Twenty two samples were processed for siliceous microfossils and all proved barren (Fig. 5). A comparison between the elevation of this succession (48.37–68.37 m above sea level) and other sections in Wright Valley raises problems connected with the history of Wright Valley (Fig. 6). The section is below the marine surface section on the shore of Wright Valley and the pecten deposit at Prospect Mesa further to the east. The pecten deposit is definitely *in situ* (WEBB, 1974) and the marine waters of this fjord should have been

Depth (m)	Marine diatom fragments	Marine sponge spicules	Non-marine diatoms	Identifiable diatoms	Depth (m)	Marine diatom fragments	Marine sponge spicules	Non-marine diatoms	Identifiable diatoms
0.18	B	B	B		12.25	B	B	B	
0.96	B	B	B		15.00	B	B	B	
1.96	B	B	B		18.80	B	B	B	
2.06	B	B	B		19.80	B	B	B	
3.01	B	B	B		20.50	B	B	B	
4.15	B	B	B		21.31	B	B	B	
5.60	B	B	B		25.38	B	B	B	
6.90	B	B	B		26.00	B	B	B	
9.02	B	B	B		26.30	B	B	B	
10.30	B	B	B		27.10	B	B	B	
11.85	B	B	B		27.81	B	B	B	

Fig. 5. Abundance and distribution of diatoms in DVDP 14, North Fork, Wright Valley (Key at 1000 × : B-Barren; R-Rare; F-One fragments/5 fields of view; C-Fragments in each field of view; A-Abundant diatoms or fragments).

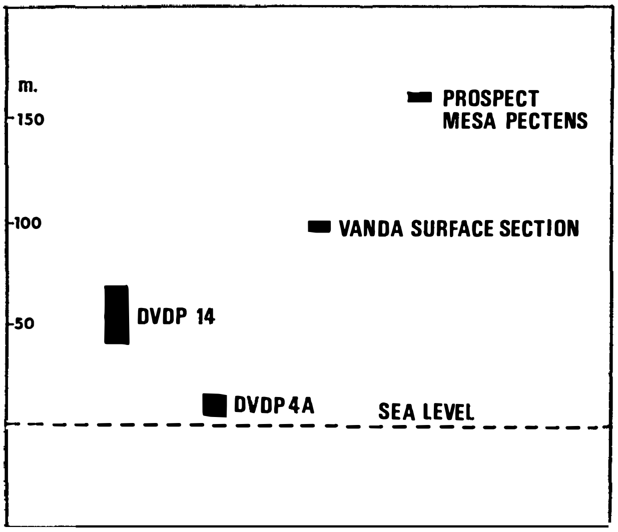

Fig. 6. Elevations of sedimentary sections, Wright Valley.

present at the DVDP 14 site unless it was overridden by a glacier at the time. This cannot be proved but the author considers that the barren nature of DVDP 14 rather suggests post-pecten glaciation or fluvial activity has removed evidence of fjord episodes in western most Wright Valley.

5. The Interpretation of DVDP 12, Taylor Valley (Fig. 1)

DVDP 12 was drilled in Taylor Valley near Lake Hoare. Drill collar elevation

Depth (m)	Marine diatom fragments	Marine sponge spicules	Non-marine diatoms	Identifiable diatoms	Depth (m)	Marine diatom fragments	Marine sponge spicules	Non-marine diatoms	Identifiable diatoms
5.58	B	B	B		100.45	B	B	B	
8.34	B	B	B		103.05	F	B	B	
11.65	F	B	B		109.20	B	B	B	
12.64	B	B	B		109.78	B	B	B	
25.08	B	B	B		113.17	B	B	B	
28.20	B	B	B		115.08	B	B	B	
28.90	R	R	B		116.85	B	B	B	
32.64	B	B	B		120.01	B	B	B	
36.59	B	B	B		120.67	B	B	B	
39.59	B	B	B		122.36	B	B	B	
47.84	B	B	B		125.42	B	R	B	
49.11	B	B	B		134.04	B	B	B	
52.80	B	B	B		134.96	R	B	B	
55.13	R	B	B		136.93	R	R	B	
57.43	B	B	B		137.64	B	B	B	
64.80	B	B	B		142.84	B	B	B	
68.54	B	B	B		147.22	B	B	B	
70.53	R	B	B		149.55	B	B	B	
75.06	B	B	B		155.76	B	B	B	
76.09	B	B	B		156.38	B	B	B	
80.70	B	B	B		158.25	R	B	B	
85.76	B	B	B		160.96	B	B	B	
88.13	B	B	B		161.78	B	B	B	
92.17	B	B	B		164.19	B	B	B	
96.62	B	B	B						

Fig. 7. Abundance and distribution of diatoms in DVDP 12, Taylor Valley (Key at 1000 × : B-Barren; R-Rare; F-One fragments/5 fields of view; C-Fragments in each field of view; A-Abundant diatoms or fragments).

was 75.07 m above sea level and basement was penetrated at 90 m below sea level. Even though non-marine diatoms have been recovered from DVDP 11 from 80 m above sea level to 20 m below sea level, non-marine diatoms were not recovered from any samples from the entire DVDP 12 sedimentary succession. Rare reworked marine diatoms and sponge spicules occur at sporadic intervals (Fig. 7) but it is clear that the main source of sedimentary material for DVDP 12 has not been reworked marine material introduced by Ross Glaciations The absence of non-marine diatoms is perplexing because other algal material is present throughout the succession especially just above the basement contact where complete unicellular algal cells occur. This author suggests that a study of organic/algal matter in DVDP 12 may assist interpretations of this succession.

6. The Presence of Non-Marine Moats in McMurdo Sound (*c.f.* Fig. 8)

BRADY (1979) suggested that the DVDP 15 succession between 141 m–184 m

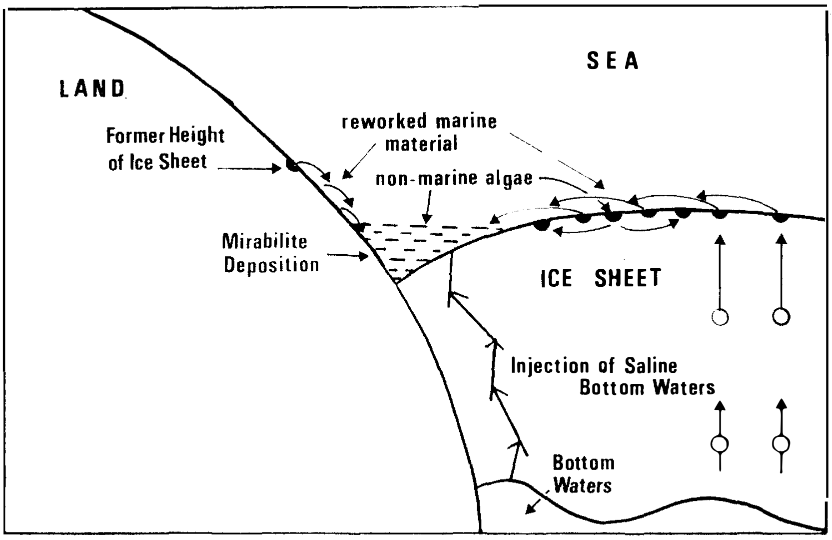

Fig. 8. Coastal Regional Moats formed between marine ice sheets and the land.

below sea level represented non-marine conditions in western McMurdo Sound (Fig. 1). The salinity logs of this interval (McGINNIS and OSBY, 1977; McGINNIS *et al.,* 1979) also confirm the non-marine nature of this interval. STUIVER and DENTON (1977) have also shown that lakes developed to the east of the moraines blocking the mouth of Taylor Valley as the Ross Ice Sheet retreated from western McMurdo Sound.

This author suggests that non-marine moats are a common feature associated with the presence of grounded marine ice sheets wedged against a coastline. These lakes may exist as isolated freshwater moats well above sea level or they may have some connection with the sea as an ice sheet thins and becomes a floating ice shelf. These moats can then become tidal and be related to the sea level while still being non-marine in nature (*e.g.* Beaver Lake wedged between the Amery Ice Shelf and the coast—W. BUDD, personal communication).

These non-marine moats provide an environment above sea level in which marine material which has been pushed landwards by ice sheets can be resorted and rebedded. BRADY (1979) suggested that the presence of non-marine diatoms in the elevated marine deposits at Cape Barne supports this interpretation. These non-marine moats may also become areas of mirabilite deposition. DORT and DORT (1972) have already suggested that a fractional crystallisation of mirabilite can occur beneath the freezing subsurface of ice shelves as the underlying solution increases in salinity but they associated mirabilite deposits above sea level with higher sea levels (up to 200 m above present day levels). This author suggests that such an interpretation is not correct and that saline brines from under an ice shelf may be injected above the surface as the ice shelf grounds. These solutions would then be deposited on the surface of the ice shelf or would find their way into non-marine moats wedged between the ice shelf and the coast. This may explain the massive mirabilite deposit at Cape Barne which lies 2–3 meters stratigraphically below bedded marine deposits which BRADY interprets as being reworked in non-marine moats (BRADY, 1979).

The mirabilite deposit discovered by BRADY during the 1977/78 season on the McMurdo Ice Shelf to the east of Black Island provides more information. One mirabilite bed is one meter thick and up to two meters wide and occurs along a 1 km line parallel to the Black Island coast. Underneath the friable mirabilite is pure ice. Dried non-marine algal mat (up to 20 cm thick) rests conformably on the surface of the deposit. The mirabilite occurs on a long pressure ridge and individual blocks have been faulted and displaced. It is difficult to explain how huge blocks of mirabilite could be uplifted from the sea floor and remain intact. This author suggests that the mirabilite was, in fact, deposited on ice when highly saline solutions from beneath the McMurdo Ice Shelf were injected to the surface as the shelf grounded. Deposition would have occurred both on the surface and in crevasses. The presence of non-marine algal mats resting conformably on the mirabilite beds suggests the non-marine nature of the final environment of deposition. It is not clear, even though the algal mats are stratigraphically above the mirabilite, whether they predate or post-date the deposit. They could have been floated by highly saline solutions at the time of injection and been redeposited; C_{14} dating of these mats is in progress.

One other form of non-marine moat may have existed in the McMurdo region due to volcanic activity in a glaciated area. CAMERON and MORELLI prepared smear slides from the upper section of the hyaloclastite sequence beneath 193.55 m in DVDP 3 drilled on Ross Island (Fig. 1). The intervals were never marked on these slides which are now in this author's possession. In six of the slides non-

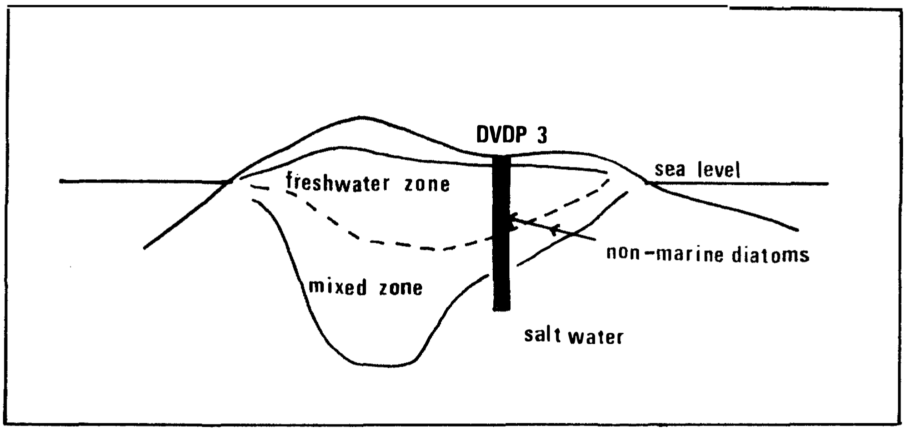

Fig. 9. DVDP 3 and location of non-marine diatoms on salinity diagram, Jackson (TREVES, 1975).

marine diatoms occur. Only one species has been noted related to the genus *Fragilaria* and attempts by BRADY and SCHRADER in 1977 to relate this species to any known species were unsuccessful, although there was a close affinity to *Fragilaria bidens* HEIBERG. The specimens observed in the smear slides were well preserved and sometimes in perfect colonies suggesting *in situ* deposition in freshwater. This agrees with interpretations about the upper section of the hyaloclastite sequence by TREVES (1975).

7. Summary

The main conclusions of this paper are:

1. Glaciations in southern Victoria Land occurred before the main axial cutting of the dry valleys and the flow directions of early glaciations were changed as uplift occurred.
2. The Lake Vanda core material (DVDP 4A) contains a marine succession which may have been partly reworked but which contains fossil material older than the pecten deposits at Prospect mesa. The diatom fossils in the DVDP 4A marine succession can be correlated to a surface section on the northeastern shore of Lake Vanda.
3. The Pecten Beds at Prospect mesa may be early Pliocene and slightly older than suggested by WEBB (1974).
4. DVDP 14 is barren of siliceous microfossils. This suggests removal of fjord deposits from North Fork by subsequent glacio-fluvial activity.
5. Siliceous microfossils can make little contribution to interpretations of the DVDP 12 sedimentary succession in Taylor Valley but an analysis of other algal material in this core is warranted.
6. Non-marine moats occur when grounded marine ice sheets wedge against coastal rocks; they form an environment in which uplifted marine material may be reworked and may be important sites for mirabilite deposition. This salt can be precipitated above sea level when ice shelves ground and force saline solutions to the surface. Mirabilite can be deposited on the surface of an Ice Shelf and also in crevasses and tidal cracks.
7. Non-marine diatoms from the upper section of the hyaloclastite sequence in DVDP 3 indicate the possibility of freshwater moats rimming volcanoes on Ross Island as volcanic material was ejected through a grounded ice sheet.

References

BARRETT, P. J. (1979): Mid Cenozoic glacial beds at Table Mountain, southern Victoria Land. To be published in Antarctic Geoscience, ed. by C. CRADDOCK. University of Wisconsin Press.

BRADY, H. T. (1979): Late Neogene history of Taylor and Wright Valleys and McMurdo Sound, derived from diatom biostratigraphy and paleoecology of DVDP cores. To be published in Antarctic Geoscience, ed. by C. CRADDOCK. Madison, University of Wisconsin Press.

BRADY, H. and MCKELVEY, B. (1979): The interpretation of a Tertiary tillite at Mt. Feather, Southern Victoria Land, Antarctica. J. Glaciol., **22** (86), 189–193.

DENTON, G., ARMSTRONG, R. and STUIVER, M. (1970): Late Cenozoic glaciation in Antarctica: The record in the McMurdo Sound region. Antarct. J. U. S., **5** (1), 15–21.

DENTON, F. and BORNES, H., Jr. (1974): Former grounded ice sheets in the Ross Sea. Antarct. J. U. S., **9** (4), 167.

DORT, W. and DORT, D. (1972): Marine origin of sodium sulphate deposits in Antarctica. Antarctic Geology and Geophysics, ed. by R. J. ADIE. Oslo, Universitetsforlaget, 659–661.

GOLDICH, S. S., TREVES, S. B., SUHR, N. H. and STUCKLESS, J. S. (1975): Geochemistry of the Cenozoic volcanic rocks of Ross Island and the vicinity Antarctica. J. Geol., **83** (4), 415–436.

MAYEWSKI, P. A. (1972): Glacial geology near McMurdo Sound and comparison with the Central Transantarctic Mountains. Antarct. J. U. S., **7** (4), 103–106.

MAYEWSKI, P. A. (1975): Glacial geology and late Cenozoic history of the Transantarctic Mountains, Antarctica. Report 56, Institute of Polar Studies, The Ohio State University, Columbus, Ohio.

MERCER, J. H. (1972): Some observations on the glacial geology of the Beardmore Glacier area. Antarctic Geology and Geophysics, ed. by R. J. ADIE. Oslo, Universitetsforlaget, 427–433.

MCGINNIS, L. D. and OSBY, D. R. (1977): Logging summary of the Dry Valley Drilling Project. Antarct. J. U. S., **12** (4), 115–117.

MCGINNIS, L. D., OSBY, D. R. and KOHOUT, F. A. (1979): Paleohydrology inferred from salinity measurements on the Dry Valley Drilling Project (DVDP) core in Taylor Valley. To be published in Antarctic Geoscience, ed. by C. CRADDOCK. Madison, University of Wisconsin Press.

STUCKLESS, J. S. (1975): Geochronology of core samples recovered from DVDP 6, Lake Vida, Antarctica. DVDP Bull., **6**, 27.

STUIVER, M., YANG, E. and DENTON, G. (1976): Permafrost oxygen isotope ratios and chronology of three cores from Antarctica. Nature, **261**, 547–550.

STUIVER, M. and DENTON, G. (1977): Glacial history of the McMurdo region. Antarct. J. U. S., **12** (4), 128–130.

TREVES, S. B. (1975): Hyaloclastite of DVDP 3, Hut Point Peninsula, Ross Island, Antarctica. DVDP Bull., **5**, 32.

WASHBURN, A. L. (1977): Analysis of permafrost cores from Antarctic dry valleys. Antarct. J. U. S., **12** (4), 113–115.

WEBB, P. N. (1972): Wright fjord, Pliocene marine invasion of an Antarctic dry valley. Antarct. J. U. S., **7** (6), 227–234.

WEBB, P. N. (1974): Micropaleontology, paleoecology and correlations of the Pecten Gravels, Wright Valley, Antarctica, and description of *Trochoelphidiella onyxi*, n. gen., n. sp. J. Foraminiferal Res., **4** (4), 184–199.

WEBB, P. N. and WRENN, J. H. (1976): Foraminifera from DVDP holes 8, 9, 10, 11 and 12, Taylor Valley. Antarct. J. U. S., **11** (2), 85–86.

WEBB, P. N. and WRENN, J. H. (1979): Late Cenozoic micropaleontology and biostratigraphy of eastern Taylor Valley, Antarctica. To be published in Antarctic Geoscience, ed. by C. CRADDOCK. Madison, University of Wisconsin Press.

WRENN, J. H. (1977): Cenozoic and subsurface micropaleontology and geology of eastern Taylor Valley, Antarctica. Master's Thesis, Department of Geology, Northern Illinois University.

(*Received September 18, 1978*)