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Palynology of Permian shale, clay and sandstone clasts from the Basen till in northern Vestfjella, Dronning Maud Land

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Abstract: The palynological content of randomly collected sedimentary rock clasts from the till on the south-east slope of the Basen nunatak in northern Vestfjella in western Dronning Maud Land indicate that these sedimentary rocks were derived from strata of Middle Permian age. The palynological content and preservation is similar to palynofloras described from the sedimentary rocks that crop out at the Fossilryggen nunatak to the south-east, therefore, it seems likely that the Fossilryggen area represents the source of the sedimentary rock samples in the Basen till. This is further supported by known ice flow directions obtained from striations and clast fabric measurements in the area.

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Key words: Middle Permian, pollen, provenance, reworked, spores

Introduction

The summits of the Vestfjella, Heimefrontfjella and Kirwanveggen mountain ranges are emergent through the modern ice sheet in western Dronning Maud Land (Fig. 1). The landscape of the region, with its typical alpine landforms such as cirques, glacial valleys and arêtes, is considered to have been formed by local wet-based mountain glaciers or by a locally wet-based ice sheet during a more temperate phase in early to middle Cenozoic times (Holmlund & Näslund 1994, Näslund 2001).

The presence of tills and glacial striations on nunataks of the Vestfjella mountain range indicates that these summits were once affected by higher levels of glaciation, and it has been suggested that the tills and striae were formed during the latest glacial maximum (Lintinen 1996, Lintinen & Nenonen 1997).

This paper deals with the palynology of sedimentary rock clasts collected from a till lodged on one of the nunataks in northern Vestfjella. The aim is to determine the age of the palynological assemblages from the rock samples and to compare them with palynofloras described from sedimentary outcrops in western Dronning Maud Land, in order to determine the likely provenance of the clasts.

There have been several studies on reworked palynomorphs in Antarctic sediments, but most have dealt with recycling into marine sediments (e.g. Wilson 1968, Kemp 1972, Truswell & Drewry 1984). This is the first report on the palynology of glacially deposited reworked sedimentary clasts from Dronning Maud Land.

Geological setting

The Vestfjella mountain range (73–74°S, 13–16°W) in western Dronning Maud Land consists of numerous scattered ridges and nunataks oriented parallel to, and some 120 km inland of, the ice shelf coast. The northernmost and southernmost nunataks are situated just a few kilometres away from the grounding line of the present ice sheet. The highest summits of the Vestfjella mountain range reach an altitude of 1100 m a.s.l. Nunatak peaks reach a maximum of 700 m above the ice sheet surface, but most are exposed to heights of ten to a few hundred metres. The Vestfjella mountain range is composed mainly of Jurassic basaltic rocks and dolerite intrusions, with olivine-gabbro dominating in its southern part, and Permian sedimentary rocks exposed at Fossilryggen in the north-eastern part (Fig. 1).

The Basen Nunatak is the northernmost peak in the Vestfjella mountain range. The western side of Basen consists of an approximately 400 m high vertical cliff, whereas the eastern side slopes gently so that the entire nunatak has the morphology of a huge roche moutonnée (Lintinen 1996, fig. 2). The summit of Basen consists of a flat-topped plateau. The main surficial cover on Basen consists of frost weathered basaltic regolith, varying from block fields to more fine-grained material (Lintinen 1996). Till cover is present mainly in an extensive field on the plateau and on the south-eastern slope of the nunatak, and its properties have been described by Lintinen (1996) and Lintinen & Nenonen (1997). The till is at least 0.8 m thick (Lintinen 1996).

During the Swedish Antarctic Research Programme (SWEDARP) expedition to western Dronning Maud Land in the austral summer of 1989/90 clast samples, primarily consisting of shales and sandstones, were collected for palynological processing from the till on the south-eastern slope of the Basen Nunatak in Vestfjella. A list of the palynomorph-taxa recorded from the clast samples is presented in Table I.

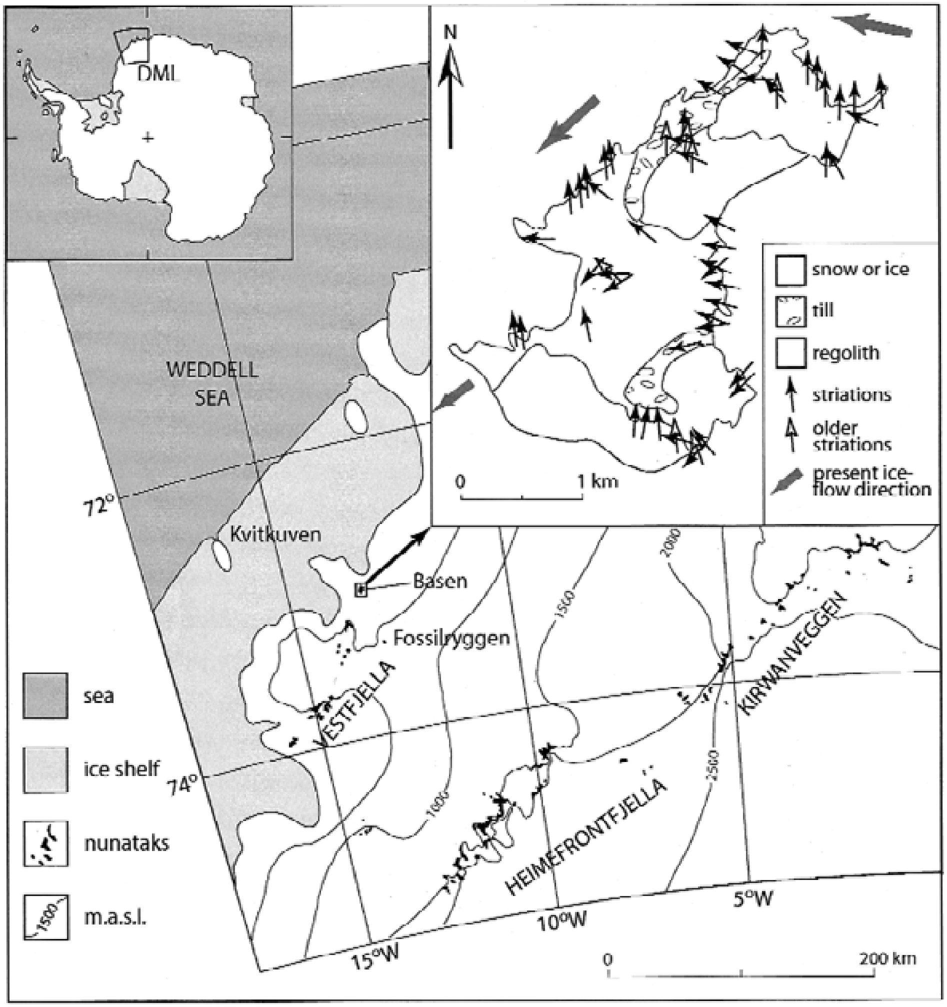

Fig. 1. Map showing the geographical setting of western Dronning Maud Land. Inserted close up map of the Basen nunatak after Lintinen (1996).

Previous palynofloral investigations of Dronning Maud Land

Palynologically productive samples have been obtained previously from two of the three main mountain ranges in Dronning Maud Land, namely Heimefrontfjella and Vestfjella. Details of the previously recovered palynofloras are given below and in Table II. All processed samples from the third mountain-range, Kirwanveggen, have been unproductive.

Heimefrontfjella

Early Permian palyno-assemblages have been reported from three localities in Heimefrontfjella, i.e. Locality A, Lidkvarvet and Locality C (Larsson *et al.* 1990, Lindström 1994, 1995b). The palynofloras from Locality A and Lidkvarvet are assigned to the *Pseudoreticulatispora confluens* Zone (Foster & Waterhouse 1988, Backhouse 1991), based on the co-occurrence of *P. confluens*, *Microbaculispora tentula*, *Converrucosisporites grandegranulata*, *Leiotriletes* spp., *Punctatisporites gretensis*, *Horriditriletes tereteangulatus*, *Jayantisporites pseudozonatus*, *Cycadopites cymbatus*, *Cannanoropollis* spp., *Plicatipollenites* spp., and *Protohaploxypinus* spp. (Table II). In Australia the *P. confluens* Zone has been dated as late Asselian to early Tastubian (Foster & Archbold 2001).

The very sparse palynoflora of Locality C contains a few specimens of *Microbaculispora trisina* and is, therefore, assigned to the mid-Artinskian *M. trisina* Zone or Stage 3b of Australia (Backhouse 1991, Foster & Archbold 2001).

Fossilryggen, Vestfjella

Permian palynoassemblages from Fossilryggen and the adjacent NW Nunatak (informal name), were reported by Lindström (1994, 1995a, 1996), and these are shown in Table II. The assemblages are dominated by taeniate bisaccate pollen, such as *Protohaploxypinus amplus*, *P. limpidus*, *Striatopodocarpidites cancellatus* and *S. fusus*, and non-taeniate forms such as *Scheuringipollenites maximus*, *S. ovatus* and *Alisporites* spp. Fern spores assigned to *Leiotriletes directus*, *Horriditriletes*

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Table I. Alphabetical list of the palynomorph taxa identified in this study, arranged under probable plant affinities.

Probable botanical affinity	Taxa
Arthrophyta	*Calamospora sp.*
Lycophyta	*Gondisporites raniganjensis* Bharadwaj 1962
	Indospora clara Bharadwaj 1962
	Jayantisporites sp.
	Lundbladispora sp. cf. *L. iphilegna* Foster 1979
Pterophyta	*Apiculiretusispora* sp. A
	Baculatisporites comaumensis (Cockson) Potonié 1956
	Brevitriletes levis (Balme & Hennelly) Bharadwaj & Srivastava 1969
	Cyclogranisporites spp.
	Didecitriletes ericianus (Balme & Hennelly) Venkatachala & Kar 1965
	Didecitriletes uncinatus (Balme & Hennelly) Venkatachala & Kar 1965
	Horriditriletes filiformis (Balme & Hennelly) Backhouse 1991
	Horriditriletes tereteangulatus (Balme & Hennelly) Backhouse 1991
	Laevigatosporites colliensis (Balme & Hennelly) Venkatachala & Kar 1968
	Leiotriletes directus Balme & Hennelly 1956
	Lophotriletes novicus Singh 1964
	Microbaculispora micronodosa (Balme & Hennelly) Anderson 1977
	Microbaculispora tentula Tiwari 1965
	Microbaculispora trisina (Balme & Hennelly) Anderson 1977
	Osmundacidites wellmanii Couper 1953
	Procoronaspora sp. cf. *P. spinosa* (Anderson) Backhouse 1991*
	Pseudoreticulatispora pseudoreticulata (Balme & Hennelly) Bharadwaj & Srivastava 1969
Gymnosperms	
Monocolpate grains	*Cycadopites cymbatus* (Balme & Hennelly) Segroves 1970
Praecolpate grains	*Marsupipollenites striatus* (Balme & Hennelly) Foster 1975
	Marsupipollenites triradiatus Balme & Hennelly 1956
	Praecolpatites sinuosus (Balme & Hennelly) Bharadwaj & Srivastava 1969
Monosaccate grains	*Barakarites rotatus* (Balme & Hennelly) Bharadwaj & Tiwari 1964
	Cannanoropollis janakii Potonié & Sah 1960
	Florinites eremus Balme & Hennelly 1955
	Plicatipollenites sp.
	Plicatipollenites malabarensis (Potonié & Sah) Foster 1979
Non-taeniate bisaccate grains	*Alisporites sp.*
	Alisporites splendens (Leschik) Foster 1979
	Alisporites tenuicorpus Balme 1970
	Chordasporites sp.
	Limitisporites rectus Leschik 1956
	Platysaccus leschikii Hart 1960
	Pteruchipollenites gracilis (Segroves) Foster 1979
	Scheuringipollenites maximus (Hart) Tiwari 1973
	Scheuringipollenites ovatus (Balme & Hennelly) Foster 1975
Taeniate bisaccate grains	*Guttulapollenites hannonicus* Goubin 1965
	Lueckisporites sp.
	Lunatisporites spp.
	Lunatisporites noviaulensis (Leschik) Foster 1979
	Protohaploxypinus amplus (Balme & Hennelly) Hart 1964
	Protohaploxypinus limpidus (Balme & Hennelly) Balme & Playford 1967
	Protohaploxypinus perexiguus (Bharadwaj & Salujha) Foster 1979
	Protohaploxypinus rugatus Segroves 1969
	Protohaploxypinus samoilovichii (Jansonius) Hart 1964
	Striatoabieites multistriatus (Balme & Hennelly) Hart 1964
	Striatopodocarpidites brevis Sinha 1972
	Striatopodocarpidites cancellatus (Balme & Hennelly) Hart 1963
	Striatopodocarpidites fusus (Balme & Hennelly) Potonié 1958
	Striatopodocarpidites phaleratus (Balme & Hennelly) Hart 1964
Costate grains	*Ephedripites* sp. (large)
	Vittatina sp.
	Weylandites lucifer (Bharadwaj & Salujha) Foster 1975
	Weylandites magmus (Bose & Kar) Backhouse 1991
Algae and probable algae	*Leiosphaeridia* sp. B
	Peltacysta monile Balme & Segroves 1966
	Peltacystia venosa Balme & Segroves 1966
	Quadrisporites horridus Hennelly ex Potonié & Lele 1961

*Specimens resembling *P. spinosa* are present only in sample MB90-23. The diameter ranges between 32–38 µm. The spores are proximally laevigate, and distally sculptured with short spines, about 2 µm in basal diameter and spaced 2–4 µm apart. The equatorial spines are 3-4 µm long. The specimens are similar to *D. uncinatus*, but have more sparsely spaced spines. They are, due to their high thermal maturity, only tentatively assigned to *P. spinosa*.

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Table II. Comparison of the palynoassemblages from the clasts from the Basen till with the previously reported palynofloras of western Dronning Maud Land (Lindström 1994, 1995a, 1995b, 1996).

Locality:	Heimefrontfjella		Vestfjella																		
	P. confluens Zone	Locality C	Fossilryggen area Southern section							"NW Nunatak"		Basen Till samples									
Samples/assemblages: Taxa			A	B	C	D	E	F	G	I	J	23	17	16	19	32	20	11	44	3	4
Acritarch sp. A	x																				
Acritarch with forked processes													x	x							
Alisporites sp.																				x	
Alisporites splendens									x					x							
Alisporites tenuicorpus												x	x	x		x	x				cf
Apiculiretusispora sp. A				x	x	x	x	x		x		x									
Baculatisporites comaumensis				x	x	x	x	x								cf					
Barakarites rotatus	x					x										x					
Bascanisporites undosus								x								x					
Botryococcus braunii	x																				
Brazilea scissa	x	x			x		x	x	x	x											
Brevitriletes cornutus	x																				
Brevitriletes levis	x			x	x	x	x	x	x	x				x							
Caheniasaccites ovatus	x																				
Caheniasaccites sp.					x																
Calamospora sp. cf. *C. microrugosa*	x																				
Calamospora sp. cf. *C. ubischii*	x																				
Calamospora sp.								x	x			x	x			x					
Camptotriletes warchianus														x							
Cannanoropollis bilateralis	x																				
Cannanoropollis janakii	x					x						x	x								
Chordasporites sp.																	x				
Circulisporites parvus								x													
Converrucosisporites grandegranulatus	x																				
Converrucosisporites sp. cf. *C. naumoviae*	x																				
Corisaccites alutas							x														
Cycadopites cymbatus	x	x					x	x			x		x								
Cycadopites nevesi	x																				
Cyclogranisporites spp.	x			x	x	x	x	x								x					
Cymatiosphaera gondwanensis							x	x						x							
Densoisporites solidus	x																				
Densosporites rotundidentatus	x																				
Dictyotidium sp. A	x																				
Dictyotriletes labyrinthicus							x	x		x	x										
Didecitriletes sp. A	x																				
Didecitriletes ericianus							x	x	x				x	x	x						
Didecitriletes uncinatus								x	x						?	x	x				
Distriatites dettmannae								c													
Ephedripites sp. cf. *E. stevesii*							x														
Ephedripites sp. (large)												x	x								
Falcisporites australis/stabilis			x	x	x	x	x	x													
Florinites eremus	x				x	x										x					x
Gondisporites raniganjensis	x						x	x		x		cf	cf		cf	cf	cf				
Guttulapollenites hannonicus							x	x				x	x				x				
Horriditriletes filiformis						x	x	x	x			cf		x	x						
Horriditriletes ramosus	x																				
Horriditriletes tereteangulatus	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x					
Indospora clara															x						
Indospora laevigata							x	x													
Indotriradites niger	x	x		x	x		x			x											
Indotriradites splendens	x	x					x														
Interradispora robusta	x																				
Jayantisporites sp.				x		x	x	x		x		x				x	x				
Jayantisporites conatus	x																				
Jayantisporites pseudoreticulatus	x																				
Laevigatosporites colliensis	x							x	x	x	x	x			x						
Leiosphaeridia sp. A	x																				

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Table II. (continued) Comparison of the palynoassemblages from the clasts from the Basen till with the previously reported palynofloras of western Dronning Maud Land (Lindström 1994, 1995a, 1995b, 1996).

	Heimefrontfjella											Vestfjella									
Locality:	*P. confluens*	Locality C		Fossilryggen area Southern section						"NW Nunatak"		Basen Till samples									
Samples/assemblages: Taxa	Zone		A	B	C	D	E	F	G	I	J	23	17	16	19	32	20	11	44	3	4
Leiosphaeridia sp. B	x			x	x	x	x	x		x	x	x	x			x					
Leiotriletes directus	x	x		x	x	x	x	x	x	x	x	x	x	x		x	x				x
Leiotriletes virkkii	x	x										x		x		x					
Limitisporites rectus	x			x	x									x			cf				
Lophosphaeridium spp.	x																				
Lophotriletes novicus														x							x
Lueckisporites spp.	x						x				x		x				x				
Lunatisporites spp.	x											x	x	x			x				
Lunatisporites noviaulensis																	cf				
Lundbladispora sp. cf. *L. iphilegna*												x	x	x							
Marsupipollenites triradiatus				x			x	x				x	x			x	x				x
Marsupipollenites striatus	x	x		x			x			x		x			x	x					x
Mehlisphaeridium regulare						x					x										
Microbaculispora sp. A						x	x		x												
Microbaculispora micronodosa	x													x	cf						
Microbaculispora tentula	x	x	x	x	x	x	x	x	x	x		x	x		x	x					x
Microbaculispora trisina		x			x	x	x	x		x		x	x	x							
Microbaculispora villosa							x					x	x								
Osmundacidites wellmanii						x	x	x				x	x			x					x
Pachytriletes densus	x																				
Peltacystia monile							x			x	x		x	x							
Peltacystia venosa							x	x							x						
Pilasporites calculus	x																				
Platysaccus leschikii	x			x									x	x	x	x	x				
Plicatipollenites sp.								x													
Plicatipollenites densus	x																				
Plicatipollenites gondwanensis	x																				
Plicatipollenites malabarensis	x												x				x				
Potonieisporites balmei	x																				
Potonieisporites novicus	x																				
Praecolpatites sinuosus				x	x	x	x	x				x	x		x	x	x				x
Procoronaspora sp. cf. *P. spinosa*												x									
Protohaploxypinus amplus	x			x	x	x	x					x		x	x	x	x				x
Protohaploxypinus bharadwaji							x														
Protohaploxypinus goraiensis	x																				
Protohaploxypinus limpidus	x			x	x	x	x	x	x	x	x	x	x	x	x	x	x				x
Protohaploxypinus perexiguus								x				x	x				x				
Protohaploxypinus rugatus							x	x				x	x			x	x		x		
Protohaploxypinus samoilovichii												cf	cf	cf			cf				cf
Pseudoreticulatispora confluens	x																				
Pseudoreticulatispora pseudoreticulata												x	cf								
Psomospora detecta	x																				
Pteruchipollenites gracilis	x	x			x	x	x	x				x				x		x			
Punctatisporites gretensis	x											x									
Punctatisporites lucidulus	x																				
Quadrisporites horridus	x											x									
Rattiganispora minor	x																				
Retusotriletes spp.	x																				
Retusotriletes nigritellus	x			x				x		x	x										
Sahnites sp. A	x																				
Scheuringipollenites maximus	x			x	x	x	x	x	x				x	x		x					
Scheuringipollenites ovatus	x	x	x	x	x	x	x	x	x	x	x	x	x	x		x	x				x
Striatoabieites multistriatus	x						x	x			x	x	x				x				x
Striatopodocarpidites brevis													x								
Striatopodocarpidites cancellatus					x	x	x	x	x	x	x	x	x	x	x	x	x				x
Striatopodocarpidites fusus	x	x	x	x	x	x	x	x	x	x	x	x		x	x	x	x		x		x
Striatopodocarpidites phaleratus				x								x									

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Table II. (concluded) Comparison of the palynoassemblages from the clasts from the Basen till with the previously reported palynofloras of western Dronning Maud Land (Lindström 1994, 1995a, 1995b, 1996).

	Heimefrontfjella		Vestfjella																		
Locality:	*P. confluens*	Locality C	Fossilryggen area Southern section							NW Nunatak		Basen Till samples									
Samples/assemblages: Taxa	Zone		A	B	C	D	E	F	G	I	J	23	17	16	19	32	20	11	44	3	4
Tasmanites sp.	x																				
Tetraporina sp. A	x																				
Tetraporina gigantea	x																				
Tetraporina tetragona	x																				
Tiwariasporites simplex	x																				
Verrucosisporites andersonii	x																				
Vestigisporites sp. A	x																				
Weylandites lucifer			x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x			x
Weylandites magmus	x				x		x					x	x			x					
Vitreisporites pallidus				x	x	x	x	x	x	x											
Vittatina sp.												x									
Vittatina fasciolata	x																				

tereteangulatus, *H. filiformis* and *Osmundacidites wellmanii*, are common constituents. In the upper part of the southern section at Fossilryggen *Didecitriletes ericianus*, *D. uncinatus*, *Microbaculispora villosa*, appear for the first time, together with *Indospora laevigata*, *Dictyotriletes labyrinthicus*, *Guttulapollenites hannonicus* and *Protohaploxypinus rugatus* (Lindström 1996).

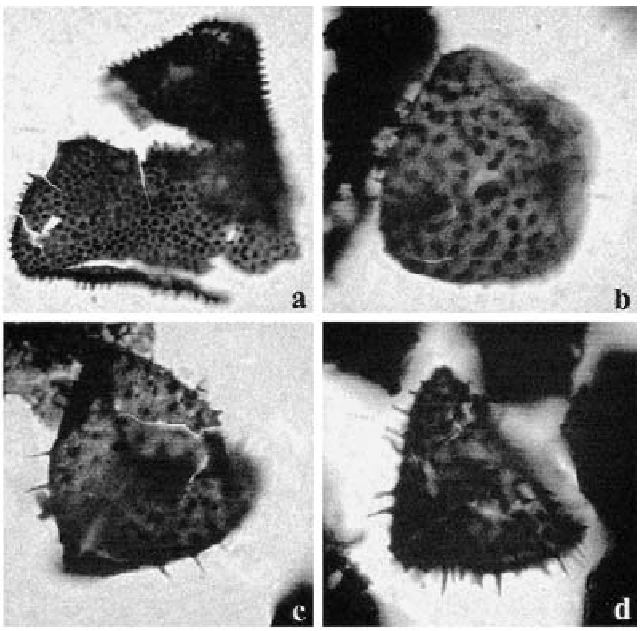

Fig. 2. Selected spores from the Basen till slabs (all x1250). Species name followed by sample number and slide number with England Finder coordinates, and specimen number (LO). **a.** *Microbaculispora villosa*, MB90-17:1, P40/3, LO 9424t, **b.** *Didecitriletes ericianus*, MB90-16:1, U44/4, LO 9425t, **c.** *Procoronaspora* sp. cf. *P. spinosa*, MB90-23:1, H27/4, LO 9426t, **d.** *Didecitriletes uncinatus*, MB90-32:1, U30/4, LO 9427t.

Lindström (1996) suggested that the successive first appearances of different taxa within the southern section of Fossilryggen was more related to preservational factors than age differences, and correlated the palynofloras from the southern section at Fossilryggen and the "NW Nunatak" with Australian Upper Stage 5 microfloras. According to McLoughlin *et al.* (2005) it is possible that the successive first appearances of taxa actually reflects age differences within the southern section, and that the upper part of the section is equivalent to Australian Lower Stage 5b/c microfloras as originally suggested by Lindström (1995a), while the lower part is somewhat older.

Palynology of the Basen till samples

Twenty-nine clast samples were randomly collected from the till on the south-east slope of Basen. The samples consist mainly of sandstones, claystones and shales. The samples were processed according to standard palynological methods. Two strew slides were prepared from each sample residue, one after treatment in nitric acid, and one after subsequent treatment with Schulze's solution.

Ten of the twenty-nine till samples from Basen contained identifiable palynomorphs. The palynomorphs are commonly fragmentary, and of high thermal maturity, black to brownish-black even after treatment with Schulze's solution. The taxa identified in the samples from the Basen till are listed alphabetically under probable plant affinity in Table I. Some of the remaining samples were totally barren of palynomorphs and contained black phytoclasts only, while others yielded abundant but unidentifiable black ”ghost images” of spores and pollen. The four specimens illustrated in Fig. 2 (prefixed LO) are lodged in the collections of the Geology Department, GeoBiosphere Science Centre, Lund University.

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Comparisons within Dronning Maud Land

Table II shows the palynological content of the productive samples from the Basen till compared to palynofloras described from other parts of western Dronning Maud Land. None of the samples from the till at Basen corresponds to the Early Permian microfloras of Heimefrontfjella, but all the productive till samples are similar to the palynofloras of Fossilryggen and the "NW Nunatak". The high thermal maturity of the Basen till clast samples indicate that they too were subjected to thermal metamorphism, of the same degree as the Permian sedimentary rocks in the Fossilryggen area where several dolerite dykes intruded the strata during the Jurassic.

Several taxa identified in the Basen till samples have only been found previously in the upper part of the southern section at Fosssilryggen. These are *Microbaculispora villosa*, *Peltacystia monile*, *P. venosa*, *Protohaploxypinus perexiguus*, *P. rugatus*, *Guttulapollenites hannonicus*, *Didecitriletes ericianus* and *D. uncinatus.*

Among the taxa not previously identified in assemblages from Dronning Maud Land are *Alisporites tenuicorpus*, *Indospora clara*, *Lunatisporites noviaulensis*, *Lundbladispora* sp. cf. *L. iphilegna*, *Procoronaspora* sp. cf. *P. spinosa*, *Protohaploxypinus samoilovichii*, *Striatopodocarpidites brevis* and *Pseudoreticulatispora pseudoreticulata.*

Comparison within Gondwana

The assemblages from the till clasts at Basen all appear to be of Middle Permian age. They are very similar to the palynofloras previously reported from the Fossilryggen area by Lindström (1995a, 1996), and just like those they differ in some respects from contemporaneous assemblages in other parts of Gondwana. *Densipollenites* species are common constituents of Middle to Late Permian assemblages from India (Tiwari & Tripathi 1992), Pakistan (Balme 1970), Prince Charles Mountains in Antarctica (Balme & Playford 1967, McLoughlin *et al.* 1997, Lindström unpublished data), and Australia (Foster 1979, Backhouse 1993), but so far these have not been registered in assemblages from western Dronning Maud Land. Apparently, *Densipollenites* species are also missing from Middle to Late Permian palynofloras of the Karoo Basin, South Africa (Anderson 1977), although they have been reported from other parts of Africa; e.g. Zambia (Utting 1979), Rhodesia (Falcon 1973), Nigeria (Broutin *et al.* 1990), and Madagascar (Wright & Askin 1987).

In the Karoo Basin, South Africa, *Microbaculispora villosa* and *Didecitriletes ericianus* co-appear at the same level (Anderson 1977), and this is also the case in the southern section at Fossilryggen (Lindström 1996). According to palaeogeographic reconstructions (Torsvik & Van der Voo 2002) the Karoo Basin was juxtaposed to Dronning Maud Land during the Permian. In the Prince Charles Mountains *M. villosa* first appears at a slightly lower level than *D. ericianus* (Lindström unpublished data). This is also the pattern in India (Tiwari & Tripathi 1992) and in Australia where *M. villosa* is the index-taxon of the early Roadian *M. villosa* Zone or upper Stage 4b, whereas *D. ericianus* first appears at the base of the late Roadian to

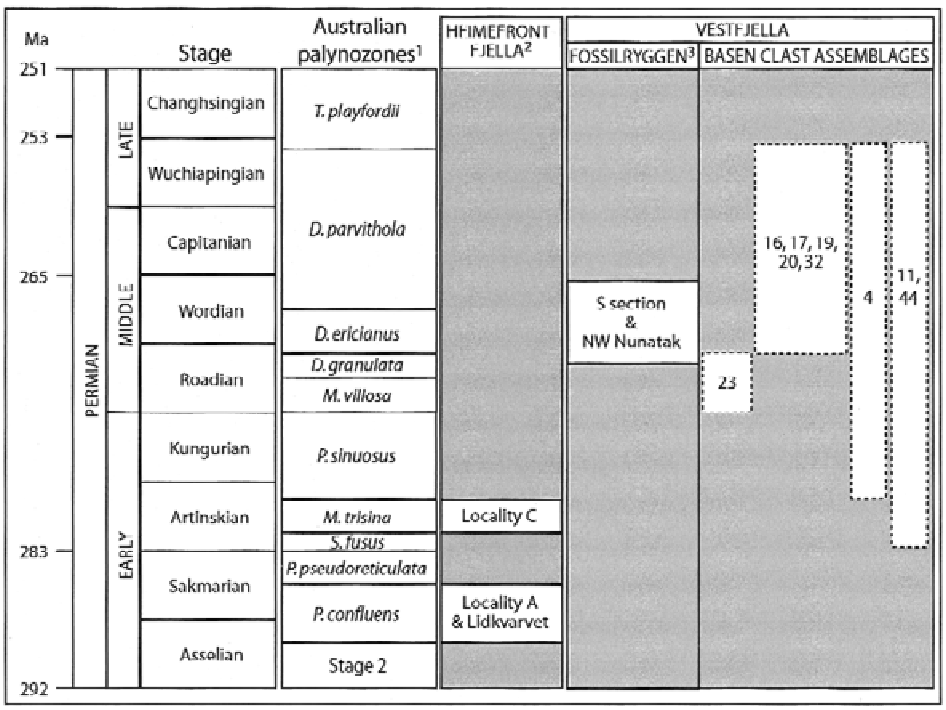

Fig. 3. Palynostratigraphical correlation between Australian palynozonation, the known palynofloras of western Dronning Maud Land and the assemblages from the Basen till. The numbers refer to the different clast samples/assemblages listed in Table II (Sample MB-90:3 is not included as it only contained a single speciment of *Alisporites* sp.). [1]Composite of western and eastern Australian palynozones, mainly after Foster & Archbold (2001), [2]After Lindström (1995b), [3]After Lindström (1995a).

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early Wordian *D. ericianus* Zone or lower Stage 5b (Backhouse 1991, Foster & Archbold 2001).

Figure 3 shows the correlation between the previously described Permian palynofloras of Dronning Maud Land, and the assemblages from the till at Basen. The assemblages from samples MB90: 11 and 44 are very sparse. Based on the respective presence of *Weylandites lucifer* and *Striatopodocarpidites fusus* in these assemblages they are probably no older than Artinskian, but may be as young as latest Permian. Similarly the fact that *Praecolpatites sinuosus* is recorded in sample MB90-04 indicates an age no older than latest Artinskian.

The presence of *Didecitriletes ericianus* in the assemblages from MB90: 16, 17 and 19, and that of a closely comparable form *D. uncinatus* in MB90: 20 and 32, shows that those rock clasts are no older than late Roadian (Foster & Archbold 2001). The co-occurrence of *M. villosa* and *Procoronaspora* sp. cf. *P. spinosa* in sample MB90-23 is intriguing, especially since *D. ericianus* appears to be absent from that assemblage. In the Karoo Basin *P. spinosa* is present only in Microfloral Zones 3a–d, which can be correlated to the upper Stage 3b to lower Upper Stage 4b (upper *M. trisina* Zone to lower *M. villosa* Zone) of Australia (Backhouse 1991, Foster & Archbold 2001). In Australia *P. spinosa* has a known stratigraphical occurrence from the uppermost Stage 3a to lowermost Lower Stage 5a [uppermost *S. fusus* to lowermost *D. granulata* zones (Backhouse 1991)]. This indicates, based on the absence of *D. ericianus* and the co-occurrence of *M. villosa* and *P.* sp. cf. *P. spinosa*, that the assemblage from MB90-23 might be correlated with the *M. villosa* to *D. granulata* zones of Australia (upper Stage 4b to Lower Stage 5a), suggesting an early Roadian age for that rock slab.

Discussion

Studying unweathered rock surfaces on Basen, Lintinen (1996) determined evidence for two major ice-flow directions, one from 90°–110° and the other from 150°–170°. On the plateau many cross striation relationships show that the easterly (90°–110°) direction is the younger one (Lintinen 1996). The Basen till is classified as a lodgement till based on its massive structure and prominent fabric (Lintinen 1996). Clast fabric measurements from the south-east plain were found to be consistent with the striations on nearby rock surfaces, showing preferred orientations of 150–190° (Lintinen 1996). Clast fabric measurements from the plateau are also found to be consistent with striations in the area, showing variations between a clear preferred orientation of 70° and a bimodal orientation with a more prominent maximum at 120–130° and a weaker maximum 150–170° (Lintinen 1996).

Jonsson (1988) suggested that the striations on Basen might have been eroded by a local glacier, but Lintinen (1996) argued that the striations and the lodgement till must have been formed by an ice mass that was at least locally warm-based, and that this is an improbable condition for local glaciers in Antarctica. Lintinen (1996) suggested that at least the northern part, but probably the entire Vestfjella mountain range was covered by ice during the last glacial maximum. In a pilot shallow drilling on the continental shelf to the west of Vestfjella Kristoffersen *et al.* (2000b) found evidence of a latest readvance of the Antarctic ice sheet during the Late Wisconsin Glacial Maximum (LGM). According to Antarctic deep ice core records the LGM occurred from 25–15 ka BP (Jouzel *et al.* 1989). Based on an uncorrected radiocarbon age of about 19 ka BP from a core north of the ice rise Kvitkuven (Fig. 1) Kristoffersen *et al.* (2000a) concluded that grounded ice must have either reached its maximum position there during the LGM, or retreated to that position at that time.

In western Dronning Maud Land Permian sedimentary rocks crop out at Fossilryggen in northern Vestfjella, and in Heimefrontfjella and Kirwanveggen. This entire area was perhaps in part continuous with the then juxtaposed Karoo Basin of South Africa (Torsvik & Van der Voo 2002), at least during the late Early to Middle Permian when a large inland sea is believed to have covered the area (Veevers *et al.* 1994, Visser 1995). The palynofloras from Heimefrontfjella are Early Permian in age and are generally less affected by the Jurassic volcanic intrusions in the area, which have thermally altered the palynofloras of Fossilryggen. The sedimentary rocks at Kirwanveggen have, despite major efforts, been palynologically unproductive. As Permian strata are only known from these relatively minor outcrops in western Dronning Maud Land, it is not possible to assess the previous lateral extent of the Permian strata in the area.

Nevertheless, the palynological content of the sedimentary clasts from the Basen till suggests that these rocks were derived from strata of comparable age to those at Fossilryggen to the southeast. Clast provenance from that area is supported by the evidence of ice flow directions derived from clast fabric measurements, 150°–190°, and striae, 150°–170° (Lintinen 1996). However, the present results do not contribute to the understanding of when and how the till was deposited.

Conclusions

Ten palynologically productive sedimentary rock clasts from the till at Basen all yielded Permian terrestrial palynomorphs. The assemblages are comparable in general composition and preservation to those previously reported from Middle Permian outcrops at Fossilryggen (Lindström 1995a, 1996), but differ substantially from the Early Permian palynofloras reported from the more distant Heimefrontfjella mountain range (Lindström 1995b). Three of the clast assemblages can be correlated with the microflora from the upper part of the southern section at Fossilryggen, and may represent the *D. ericianus* Zone of late Roadian to early Wordian age. One assemblage possibly correlates with the Roadian *M. villosa* to *D. granulata* zones, and thus may be derived from a part of the sedimentary sequence which is no longer exposed in the area. Indicating ice movements from 150°–190°, i.e. from the south or south-east (Lintinen 1996), clast fabric measurements from the till on the south-east slope of Basen and striations in its vicinity further support the Fossilryggen area as the source for sedimentary clasts in the till.

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