

## Preliminary study on the spore-pollen assemblages found in the Cenozoic sedimentary rocks in Grove Mountains, east Antarctica and its climatic implications

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**Abstract** Glaciogene sedimentary rocks have been found in modern tills of the Grove Mountains, east Antarctica during the 1998 – 1999 Chinese National Antarctic Research Expedition (CHNARE). Based on the lithologic and sedimentary features, these sedimentary rocks are correlated with Cenozoic sedimentary strata of the Pagodroma Group in the neighboring Prince Charles Mountains and the Sorsdal Formation in Vestfold Hills. Sedimentary clasts contain sparsely Late Tertiary spores and pollens, including: *Toroisporis* (Lygodiaceae), *Osmunda*, *Granulatisporites* (Pteridaceae?), Polypodiaceae, *Podocarpus*, Araucariaceae, *Artemisia*, *Rhus*, *Nothofagidites*, *Proteacidites* (Proteaceae), *Quercus*, *Fraxinoipollenites* (Oleaceae), *Oleoidearumpollenites* (Oleaceae), *Operculumpollis*, and *Tricolpopollenites*. Most of the pollen and spores contained in these samples originate from local sources according to the conditions of their preservations as well as correlations with the microfossil assemblages found in the neighboring areas. The majority of the pollen assemblages, as represented by *Podocarpus* and *Nothofagus*, belong to the Weddellian biogeocenose, however some exotic components from the old sedimentary basement rocks may have been included during erosion of the proximal ice sheet. If the source areas of glaciogenic sedimentary rocks that bear the pollen and spores are assumed to be local, or in the up glacier areas, the pollen assemblages in these samples might represent an inland flora during a warmer period of the ice-sheet evolutionary history. The finding of the *Artemisia* and Chenopodiaceae in the pollen assemblages implies that they may belong to late Tertiary (most probably Pliocene). The absence of diatoms in the samples analyzed may indicate that there are no Cenozoic marine strata in the interior of the east Antarctica beyond the Grove Mountains. The significances of the finding of the *Nothofagus* in these pollen assemblages are discussed on the basis of current knowledge about the age, distribution and ecological conditions of this kind of fossils found in Sirius Group or other strata outcropped in Antarctica. As a preliminary conclusion, we think that the existence of the Cenozoic glaciogenetic rocks and their pollen assemblages present new evidence for a large scale glacial retreat history in Grove Mountains of east Antarctica, and thus support a dynamic East Antarctic Ice Sheet (EAIS). This is consistent with the interpretations of Webb *et al.* (1984).

**Key words** East Antarctica, Grove Mountains, Cenozoic sedimentary rocks, spore-

pollen, *Nothofagus*, *Artemisia*, Pliocene.

## 1 Introduction

The dynamic evolutionary histories of the Antarctic Ice Sheet during the Cenozoic era and the subsequent global climatic changes have always been the most important subjects in Antarctic research, while evidence to reveal these processes are mainly contained in the Cenozoic sediments and ice cores inside the Antarctic continent and its surrounding regions, among which the fossils that are preserved in the sedimentary sequences are of particular significance in determining the ages of the strata and inferring their paleo-environmental and paleoclimatic conditions. However, the fact that the evidence from the sedimentary strata, especially the fossils, are very scarce because of the extremely rigorous geographical situations in Antarctica resulted in great difficulties in building the biostratigraphic frameworks of the Cenozoic sedimentary units that are sporadically outcropped in Antarctica. Therefore, further studies on the glacial and climatic evolutions in Antarctica are greatly constrained.

The Chinese National Antarctic Research Expedition (CHNARE) team has made geological field survey in the Grove Mountains (Fig. 1) of the east Antarctica several times since 1998, and a certain quantity of Cenozoic sedimentary debris have been found in glacial moraine banks near the center of this area. These sedimentary rocks are of the characteristics of glaciogenic diamicton and can be correlated with Cenozoic sedimentary strata of the Pagodroma Group in the neighboring Prince Charles Mountains and the Sorsdal Formation in VestFold Hills based on their lithologic and sedimentary features (Fang *et al.* 2004a). By micropalaeontologica analyzing, these sedimentary clasts contain some Cenozoic spores and pollens, and especially, they contain some pollens of *Nothofagus* and *Artemisia*, which have very important significances in inferring their ages and paleoclimatic conditions. This paper is to give a short report on the preliminary results from the spore-pollen study on the samples collected during the 15th CHNARE geological field survey in Grove Mountains.

## 2 Regional backgrounds

The Grove Mountains (latitude 72°20'–73°10' S, longitude 73°50'–75°40' E), about 450 km inland from the Zhongshan Station of China, is located within the largest ice sheet drainage system of the Lambert-Amery ice shelf in east Antarctica (Fig. 1). It covers an area of about 3200 km<sup>2</sup>, and totally, 64 isolated nunataks are exposed over the blue ice within this region. These nunataks are distributed as 5 parallel island chains extending in a direction from SSW to NNE with a SE to NW dipping topographic outline. The East Antarctica Ice Sheet (EAIS) flows from the inland continent through this area in a direction of SE toward NW, and it is divided into several branches in this area because of the holdback of the nunataks and subglacial mountains, and then incorporated into the Lambert Rift which is formed in Mesozoic and extends into the East Antarctic Shield for about 800 km.

Geologically, the Grove Mountains is located between the largest ice-free area in the east Antarctica of the Prince Charles Mountains (PCM) and the ice-free areas of the Larse-

mann Hills and the Vestfold Hills exposed along the coastal line of the Prydz Bay, so it is one of the very few inland ice-free areas in East Antarctica. During its evolutionary process, the Lambert Glacier produced a lot of Cenozoic glacial deposits which are now discovered sporadically outcropped in those ice-free regions mentioned above and drilled by ODP in the ice-shelf of the Prydz Bay, and these discovery records provide direct evidence for revealing its developing history as well as that of the EAIS (Barker *et al.* 1998). As a result, in recent years, detailed investigations of the Cenozoic sedimentary rocks that were responsible for the reconstruction of regional ice sheet movements in the Prydz Bay and its inland basins have been carried out in this region, which greatly improved the understanding of the ice sheet evolutionary history of the Lambert Glacier as well as the EAIS (Labia and Pushina 1997; Quilty 1992; Harwood *et al.* 2000; Whitehead and McKelvey 2001; Hambrey and McKelvey 2000a,b; Hambrey *et al.* 1989; O'Brien *et al.* 2000). However, because of the geographic obscurity of its location, there had been no formal scientific investigations in the Grove Mountains until CHNARE's 1998-1999 first field trip, and it is still poorly known how the glaciers have evolved in this area.

Cenozoic sedimentary records that have been found in the Grove Mountains by CHNARE team in 1998 should also belong to products of the glacial movements of the Lambert ice-sheet, and therefore, they contain invaluable information about the glacial evolution in this region (Fang *et al.* 2004a,b; Fang *et al.* 2005). Furthermore, because of its special situation, the Cenozoic sedimentary rocks left by the ice sheet movements in Grove Mountains are very helpful to reflect the behavior of the EAIS, and they also provide good correlations between the Cenozoic sedimentary records found in the PCM and those in the Larsemann Hills and the Vestfold Hills.

### 3 Samples and their field outcroppings

All the samples analyzed in this paper were collected from the debris belt lying over the blue ice to the west of the Gale Escarpment and the Mt. Harding (Fig. 1), namely the "West-Dike Detritus Strip" in the 1:25000 geographic map of the center Grove Mountains. This debris belt is composed of different kinds of ice boulders left by the movements of the ice sheet in this area from the Last Glacial Period (Fang *et al.* 2004a). It looks like a large moraine bar in its geometrical shapes, while most of the debris belt is floating over the blue ice (Fig. 2a) instead of accumulating over the bedrocks as normal moraine banks. This debris belt extends for more than several kilometers, ranging in width from 50 to 300 meters and with a relative height of 40m above the blue ice surfaces. According to its geometric shape and the components of its ice boulders, this debris belt belongs to a floating ice-cored terminal moraine resulted from glacial activities of a paleo-ice sheet in this region, and it was most probably formed during an advancing event after the Last Glacial Maximum (Fang *et al.* 2004a).

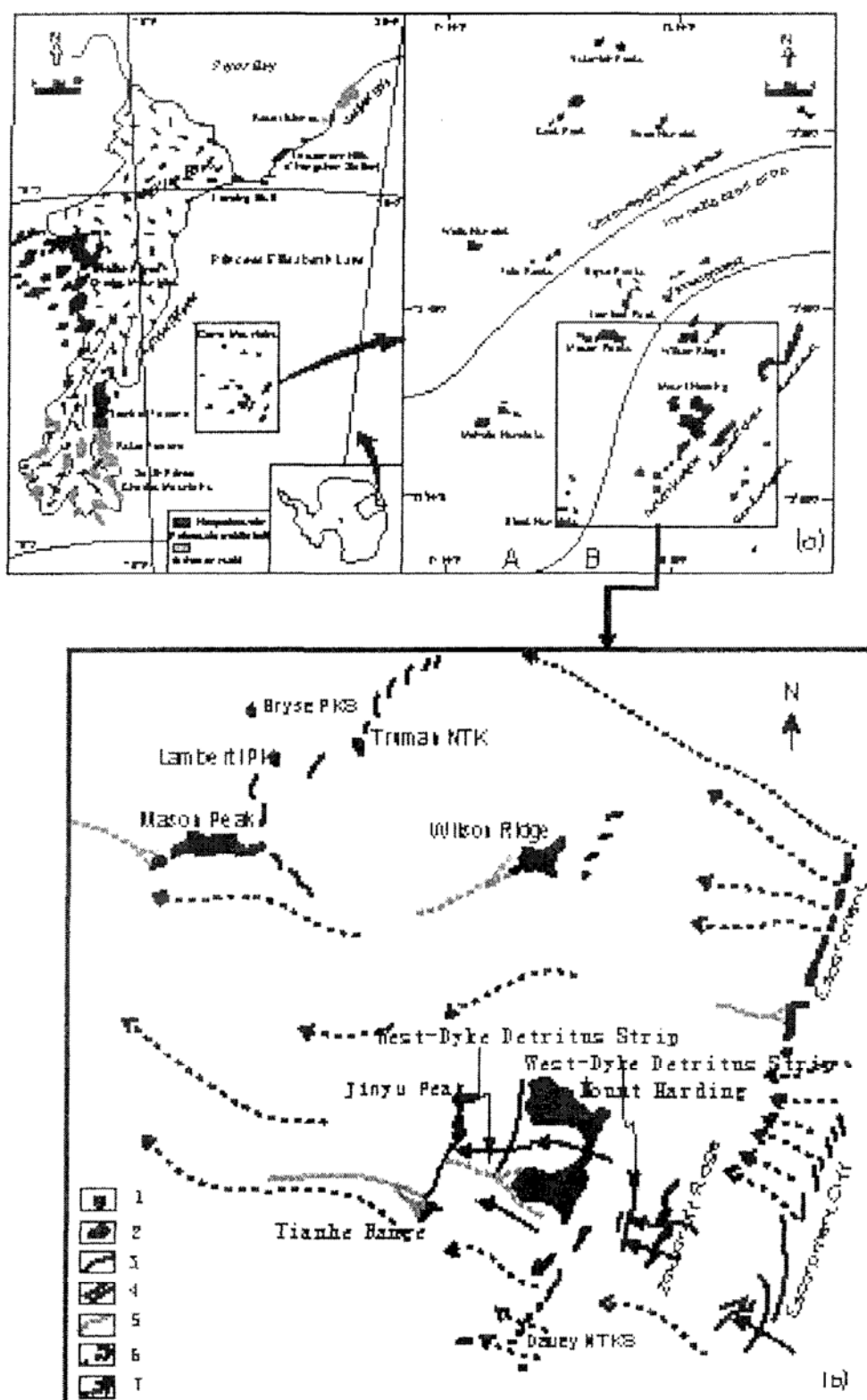


Fig. 1 The location of the Grove Mountains in the East Antarctica

(a) and sampling position (b) (modified after Liu *et al.* 2003 and Fang *et al.* 2004a)

1. sample location; 2. nunataks; 3. terminal moraines; 4. ice-cliff; 5. lateral moraines;
6. modern ice flows; 7. ice flows in the last glacial maximum.

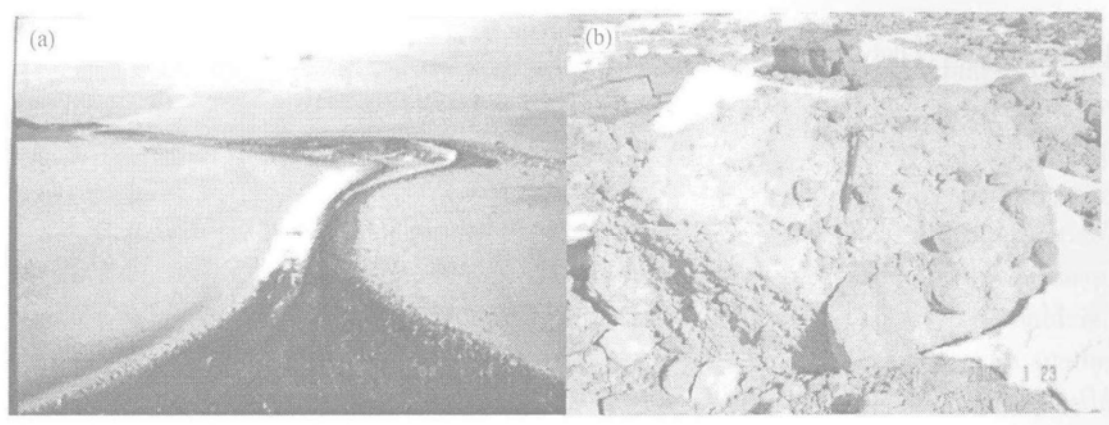


Fig. 2 The floating terminal moraine bars (a) and the glaciogenic sedimentary debris(b).

The iceboulders in debris belts of this group are mainly composed of the blocks of bed-rocks that were scratched out from the basement by the ice sheet movements as well as those dropped from surrounding nunataks, together with some Cenozoic sedimentary rocks and ultramafic rocks which have not been found outcropped in this area. The sedimentary ice-boulders found in the moraines are distributed sparsely among different kinds of metamorphic and/or igneous debris, varying in size from several centimeters to several meters in diameters (Fig. 2b). According to different extent of lithification and consolidation, they can be subdivided into three kinds (Fang *et al.* 2005): the well to half cemented hard sedimentary rocks; the weakly consolidated sediments and the loosely unconsolidated diamictons. All of these samples are of chaotic characteristics, showing typical features out of ice sheet reactions, and belonging to glaciogenic diamicts (Fang *et al.* 2004a,b). From their distributions and preservation conditions and the components of their surrounding iceboulders, these glaciogenic diamicton sediments were transported here in a short distance, and their primitive outcropping strata must exist in the upstream area of the glacier, probably near the Gale Escarpment (Fang *et al.* 2004a).

At the first time, 4 samples (Table 1) collected at the 1998–1999 CHNARE summer season field investigation have been chosen to do the spore-pollen analyzing in Nanjing Institute of Geology and Palaeontology, and 12 more samples have been conducted diatom and other microfossil analyzing subsequently in the Korea Ocean and Research and Development Institute, however, no such kinds of microfossils have been found in them.

Table 1. Characteristics of the samples for spore-pollen analysis

Sample no.	consolidation	Main characteristics	Lithologies
S1501	Solitude block	Grey massive block, with about 10% pebble-size particles, which range in sizes from 0.2–2 cm with angular shapes, without sorting; and about 60% sand-size particles, cemented by mud and calcite cements. The surface with wind weathered marks	Pebbly sandstones
S1507	Half-cemented block	Dark grey half-cemented blocks, mainly composed of sand-size particles, with certain amount of mud cements. The surface with wind weathered marks	Muddy sandstones
S1509	Loosen particles	Dark grey loosen sediments (mainly mud), contained some metamorphic rock blocks	Fine sediments
S1514	Loosen particles	Dark grey loosen sediment matrix filled between the metamorphic rock pebbles	Sediment matrix

Table 2. Results of the pollen – spore analysis of the 4 sedimentary samples in Grove Mountains.

Spore and pollen types	S1501	S1507	S1509	S1514
<i>Toroisporis</i> (Lygodiaceae)	4		1	
<i>Granulatisporites</i> (Pteridaceae?)	1		1	
<i>Osmunda</i>	5	1	4	
Polypodiaceae	1			
Araucardiaceae	3	1	2	
<i>Podocarpus</i>	9		3	1
Chenopodiaceae			2	2
<i>Artemisia</i>		2	2	
<i>Fraxinoipollenites</i> (Oleaceae)	2			
<i>Oleoidearumpollenites</i> (Oleaceae)			1	
<i>Operculumpollis</i>	1			
<i>Nothofagidites</i> (Nothofagus)	2	1	1	1
<i>Rhus</i>	2			
<i>Quercus</i>	1	1		
<i>Proteacidites</i> (Proteaceae)	1			
<i>Tricolpopollenites</i>	1			
Total spore-pollen number	33	6	17	4

#### 4 The results of the sporo-pollen analyses

By using routine spore-pollen analyzing method to deal with the four samples we chose, totally 60 particles of pollen and spore have been obtained. By further identification, they are subdivided into 15 types of pollen and spore, which belong to 12 species of plant and 3 kinds of pollen by their shapes (Table 2).

Generally, the numbers of the pollen and spores contained in the four samples are so sparse that they are not adequate to the statistic analysis although almost all the pollen and spores have been picked out. As for the pollen assemblages in the sample S1501 and S1509, which is relatively richer in pollen and spores than the other two samples, they have the following common characteristics: (1) contents of pollens of arbor or ligneous plants are superior, which is up to 80% of the total spore and pollens found. Among the pollens of arbor or ligneous plants, those of the *Podocarpus* are the majority, and there are also some pollens of the gymnosperm with broad leaves, such as *Proteacidites* (Proteaceae), *Quercus*, *Nothofagidites* (Nothofagus), *Rhus* and *Fraxinoipollenites* (Oleaceae). (2) Content of spores of ferns is the subordinate, which is up to 33% of the total assemblages, including *Toroisporis* (Lygodiaceae), *Osmunda*, Polypodiaceae, and *Granulatisporites* (Pteridaceae?). (3) Content of pollens of herbs and shrubs is very low, there are only some of the Chenopodiaceae and *Artemisia* occurring in S1509. Besides these common characteristics, however, there are also some distinct differences between the spore-pollen assemblages found in sample S1501 and S1509 and S1507, respectively, of which the most distinct one is that pollens occurred in sample S1501 does not contain those of herbs, while in the lat-

ter, there some Chenopodiaceae and Artemisia whose widely occurrence is supposed to be starting at the Pliocene (Wang 2004). As a result, the spore-pollen assemblages occurred in S1509 and S1507 and that in S1501 might represent different ages, the former as the Pliocene, while the latter as the earlier stages. According to the differences of cementation types, consolidation degrees and geochemical compositions among different samples, there might be existed different sedimentary units that formed at different stages after the initiation of the ice sheet in this region (Fang *et al.* 2004a), which is correspondent to the results obtained from the current pollen and spore analysis upon these sedimentary ice-boulders.

As for the composition of the pollen assemblage we studied, it is similar to a southern hemisphere Neogene flora since most species inside this assemblage lived in the Weddellian biogeocenose since Neogene, and the major pollen types, such as the Chenopodiaceae, the Artemisia, the Podocarpus and the Araucariaceae, are common components of a Neogene flora in Gondwana continent (Li 1994; Cao 1994; Duan and Cao 1998; Song 1997). It should also be noted that the occurrence of the Nothofagidites in all the 4 samples we studied provide some special evidence to discuss the nature and age of the spore-pollen assemblage in sedimentary rocks of the ice boulders in Grove Mountains since the Nothofagus is a typical component of the Weddellian biogeocenose and regarded as the major species in the plant communities so far reported in the Cenozoic strata outcropped in Antarctic continent (Askin and Markgraf 1986; Webb *et al.* 1986; Harwood 1986; Carlquist 1987; Webb 1991; Webb and Harwood 1987, 1993; Hill and Truswell 1993; Hill *et al.* 1996; Fleming and Barron 1996).

## 5 Climatic implications

During its long history, the Antarctic Ice Sheet has experienced a dynamic evolutionary process, especially in Pliocene. However, most of the relics formed by the glacial activities during this stage have been modified or covered by glacial activities at later stages, which resulted in the great disputes on the reconstruction of glacial and environmental evolution in this era. Generally, there are two completely different opinions on the evolution of the Antarctic Ice Sheet during Pliocene, namely the stablists and dynamicists, respectively. The former is represented by the Clapperton and Sugden who considered that the Antarctic Ice Sheet was kept in its present scale ever since the Miocene when the large scale of the initiated ice sheet had been formed (Clapperton and Sugden 1990; Kennett and Hodell 1993; Sugden *et al.* 1993; Marchant *et al.* 1996). While the latter, as represented by Webb and Harwood, regarded the evolution of the Antarctic Ice Sheet is a dynamic one, and during its evolutionary history, the ice sheet is kept on changing its scales and volumes, especially in Pliocene, it has experienced large scale of expansions and retreats (Hambrey and McKelvey 2000a,b; Webb and Harwood 1987, 1993; Webb 1991; Webb *et al.* 1984; Wilson *et al.* 1999; Pickard *et al.* 1986; Barrett *et al.* 1992). Besides these two opinions, some researchers stucked to a medium opinion, who considered that the evolution of the Antarctic Ice Sheet is a dynamic one, while its changes in volume and scale are not so large as the dynamists thought (Prentice *et al.* 1986; Denton *et al.* 1984, 1991; Bart and Anderson 2000).



The glaciogenic sedimentary rocks of the ice boulders found in Grove Mountains are formed in glacial front areas by melting down of a former expanded glacier during a warm climatic event (Fang *et al.* 2004a,b). By synthetic analyses and comparison, it can be correlated with those famous Pliocene strata of the Pagodroma Group (Whitehead and McKelvey 2001; McKelvey *et al.* 2001), the Sørødal Formation (Quilty 1992; Quilty *et al.* 2000) and the Sirius Group (Webb and Harwood 1987, 1991) that outcropped in the Charles Mountains, the Vestfold Hills and the Transantarctic Mountains, respectively, therefore, they might be deposited at a same glacial retreat or climatic warm event during Pliocene.

Although the age and origination of the pollen assemblage contained in the sedimentary ice boulders are not well constrained by the data so far we obtained since geological surveys in Grove Mountains have been started just recently, i. e. , much more works are needed to be conducted in the future, the finding of such a large amount of sedimentary ice boulders with pollen assemblage inside them does provide very useful evidence to discuss the climatic and glacial evolution in the inland Antarctica. In preliminary conclusions, the significance of the finding of the sedimentary rocks in Grove Mountains and the pollen assemblage inside them lies in the followings: (1) it confirmed that Pliocene glaciogenic sedimentary strata do exist in the inland of the Antarctic continent, and furthermore, the wide distribution of this kind of glaciogenic sedimentary rocks indicates that they are products of a large-scale ice sheet instead of the local alpine glaciers, therefore, they can reflect the evolutionary history of the whole ice sheet; (2) the microfossil assemblages found in these strata provided not only some definite constraints on the depositional time of these strata, but also provide very helpful materials for the analysis on its sedimentary environments; and (3) the palaeoclimate reflected by the fossil of *Nathofagus* found in this strata shows that the temperature at that time is much higher than that of today (Kennett and Hodell 1993), which presented a warm climatic event and a large-scale ice sheet retreat.

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