$Fe^{2+}/(Fe^{2+} + Fe^{3+})$, Cr/Fe(T) and Fe^{3+}/Fe^{2+} values in Cr-spinels from the enclosing rocks to the chromitite layer are unlikely to be caused by serpentinization or metamorphism. These observations are consistent in all Cr-spinel analyses (Table 1). However, minor modification of Cr-spinel composition by these processes cannot be ruled out[17]. It may be concluded that the Kathpal part of the SUC represents a feeder zone for intrusion of Mg-rich boninitic magma which produced the layered chromite deposit in the SUC. The formation of chromitite zones within the ultramafic rocks in Kathpal is controlled mainly by fluctuation of fO_2, with minor influence of temperature and total pressure that existed in the magma chamber.

1. Irvine, T. N., *Can. J. Earth Sci.*, 1965, **2**, 648–672.
2. Cameron, E. N. and Desborough, G. A., *Econ. Geol.*, 1969, **75**, 845–871.
3. Duke, J. M., *Geosci. Can.*, 1983, **10**, 15–24.
4. Stowe, C. W., *Econ. Geol.*, 1994, **89**, 528–546.
5. Thyayer, T. P., Int. Geol. Cong. Report, 21st Session, 1960, vol. 13, pp. 247–259.
6. Ulmer, G. C., *Econ. Geol. Monogr.*, 1969, **4**, 114–131.
7. Banerji, P. K., *Mem. Geol. Surv. India*, 1972, **103**, 1–171.
8. Chakraborty, K. L., Chakroborty, T. L. and Majumder, T., *J. Geol. Soc. India*, 1980, **21**, 398–404.
9. Chakraborty, K. L. and Majumder, T., *Indian Miner.*, 1985, **36**, 1–13.
10. Sahoo, R. K. and Van der Kaaden, G., *Neues Jahrb. Mineral., Monatsh.*, 1976, **11**, 484–494.
11. Chakraborty, K. L. and Baidya, T., *J. Geol. Soc. India*, 1978, **19**, 303–309.
12. Chakraborty, K. L. and Chakroborty, T. L., *Miner. Deposita*, 1984, **19**, 256–265.
13. Murck, B. W. and Campbell, I. H., *Geochim. Cosmochim. Acta*, 1986, **50**, 1871–1887.
14. Dick, H. J. B. and Bullen, T., *Contrib. Mineral. Petrol.*, 1984, **86**, 54–76.
15. Jan, M. Q. and Windley, B. F., *J. Petrol.*, 1990, **31**, 667–715.
16. Arai, S., *Mineral. Mag.*, 1993, **56**, 173–184.
17. Sarkar, A., Mondal, S., Ripley, E. M. and Chusi, L. I., *Geol. Soc. Am. Abs with Programs*, 2003, **35**, 231.

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Recovery of airborne palynodebris from Continental Ice Sheet, Schirmacher Oasis, East Antarctica

Climate changes have a significant effect on the periglacial region in front of the large inland ice masses of Antarctica. They also affect the glaciers and permafrost soil. Information on environmental changes during the recent history of the earth is stored in the deposits found there, especially the huge continental ice sheet and polar lake bottom sediments which could be the important data archives of palaeoenvironmental condition. Glacier ice, like other accumulating sediment, incorporates fossil pollen and spores[1]. The potential for pollen analysis of polar ice was first tested by Fredskild and Wagner[2] on four melt water samples from Greenland ice core and dated back to 8800 and 14,390 yrs BP. The pollen count was not enough for suitable percentage calculation from low amount of water samples. Later, Lichti-Federovich[3] analysed large volumes of melt water for better results and proved the potentiality of palynological interpretation from polar ice samples. This is an attempt on the palynological study of glacial ice from huge east–west-oriented continental ice sheet in the Schirmacher Oasis, a group of low-lying hills and ice-free high-polar rock desert covering 34 km^2 in the eastern Dronning Maud Land, East Antarctica (70°45′39.4″S and 11°44′8.6″E; Figure 1). The climate is relatively mild due to the low altitude, with air temperature over the glacier ice between –7 and +8°C during mid-summer (December–January), when melt water is abundant. Ten bulk ice samples were taken from the exposed wall of the ice sheet (Figure 2) and allowed to melt up to at least 1 l. After centrifuging and proper sieving, the same was made up to 10 ml and stored with 50% glycerine in a vial. Then 100 ml of water samples from flowing glacial stream were directly centrifuged and stored in the same manner. Entire samples were studied under Olympus BX-50 microscope. Pollen–spore counts are not sufficient for formulating pollen spectra (15–30 per sample).

The picture thus obtained from pollen spectra of ten bulk ice samples reflects overall dominance of algal elements (*Nostoc*, *Oscillatoria*, *Pediastrum*, dinocyst, etc.), desmids (*Cosmarium* spp.), diatoms like *Navicula*, *Pinnularia*, *Fragilaria*, *Nitzchia*, etc. The angiosperm nonarboreal pollen taxa comprise Poaceae (30–40 μm), Caryophyllaceae, Chenopodiaceae, Asteraceae (Tubuliflorae), etc. However, *Pinus*, *Larix*, *Betula*, *Ulmus*, Urticaceae–Moraceae, etc. are the only arboreal taxa recovered from the samples. The algal remains, including desmids, diatoms and Acritarchs are of local origin. Occurrence of only monolete fern in the 9th sample is interesting. The occurrence of reworked palynomorph (Figure 3) is significant, which indicates the nearness of Gondwana sedimentary rocks in Eastern Antarctica. Presence of fungal remains in good value is indicative of humid climatic condition, in which it might have travelled along with long-distance transported pollen and got incorporated in the sediment and may be saprophytic in nature. The pollen concentration in the flowing water samples does not cohere with that of ice sheet samples, which needs detailed investigation. The pollen concentration in Antarctic ice samples is low compared to other surface samples like moss turfs, frozen

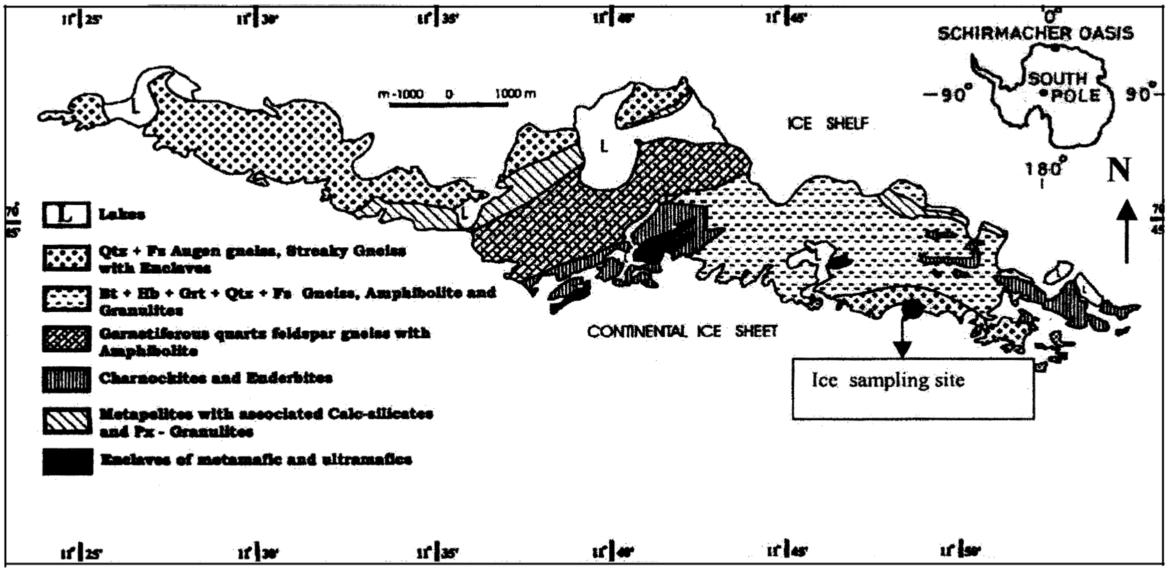

Figure 1. Geology of Schirmacher Oasis, East Antarctica (GSI, 1998).

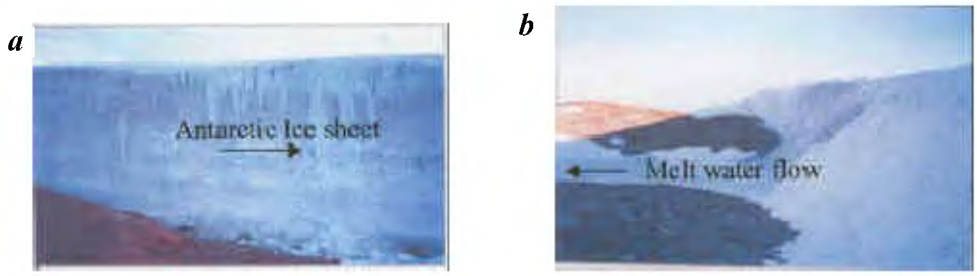

Figure 2. ***a***, Bulk ice samples collected along the arrow. ***b***, Melt water sample collected from glacial stream joining Zub lake.

soil and lichen patches. The overall palynological study also depicts different degrees of productivity in different samples, and rankwise they are moss tufts, frozen soil, lichen patches and glacial ice.

The encounter with different pollen and spore types reflects their long-distance transport ranging from tropical to temperate floristic regions of distant islands and surrounding continents. Palynological work done in Marian, King George and Kerguelen Islands has indicated that there is a regular transport of pollen and spores to sub-Antarctic Islands by the prevailing westerly wind across the circum Antarctic Ocean[4,5]. Likewise, other workers have also supported pollen–spore transport and colonization in Antarctica through palynological studies[6–10]. Data depict that Antarctic ice sheet contains 'fossilized atmospheres' and are a storehouse of information. The ice sheet is composed of layers of ice derived from snow sequentially deposited on the surface over many thousands of years and the properties of the materials embedded in it reflect climatic and environmental conditions that existed at the time of deposition. Data from 2000 m long ice core of Vostok provide a direct measure of global temperature changes over the past 150,000 yrs BP. The climate was up to 10°C colder than that at present for most of the past 150,000 yrs, with large periodic variations in temperature both within cold intervals (ice ages) and the shorter, warm intervals[11,12] (interglacials).

Compared with the interglacials, the glacial maximum was not only 10°C colder, but was also drier and experienced strong winds, as shown by the large number of dust particles carried to the Antarctica and deposited in the ice. Ice-core study gives unique access to the past concentrations of a wide range of atmospheric parameters, i.e. trace gases, soluble-insoluble aerosols, pollen–spores and volcanic compounds, etc.

Pollen analysis of bulk ice samples depicts the occurrence of airborne pollen and spores, although in low profile. The study indicates that continental ice sheet would also incorporate pollen and other microbiota that would be transported by ice flow until released by ice melt during glacier retreat. More detailed study is required on deep ice core samples to understand depositional environment and the nature of palaeowind current across the polar region. Two lake sediment profiles, one each from Zub lake (8000 yrs BP) and Long lake (2000 yrs BP) have predicted climatic oscillations from East Antarctica. Although present palynodata from ice samples is preliminary, combination and permutation of the database with other multiproxy databases from limnology,

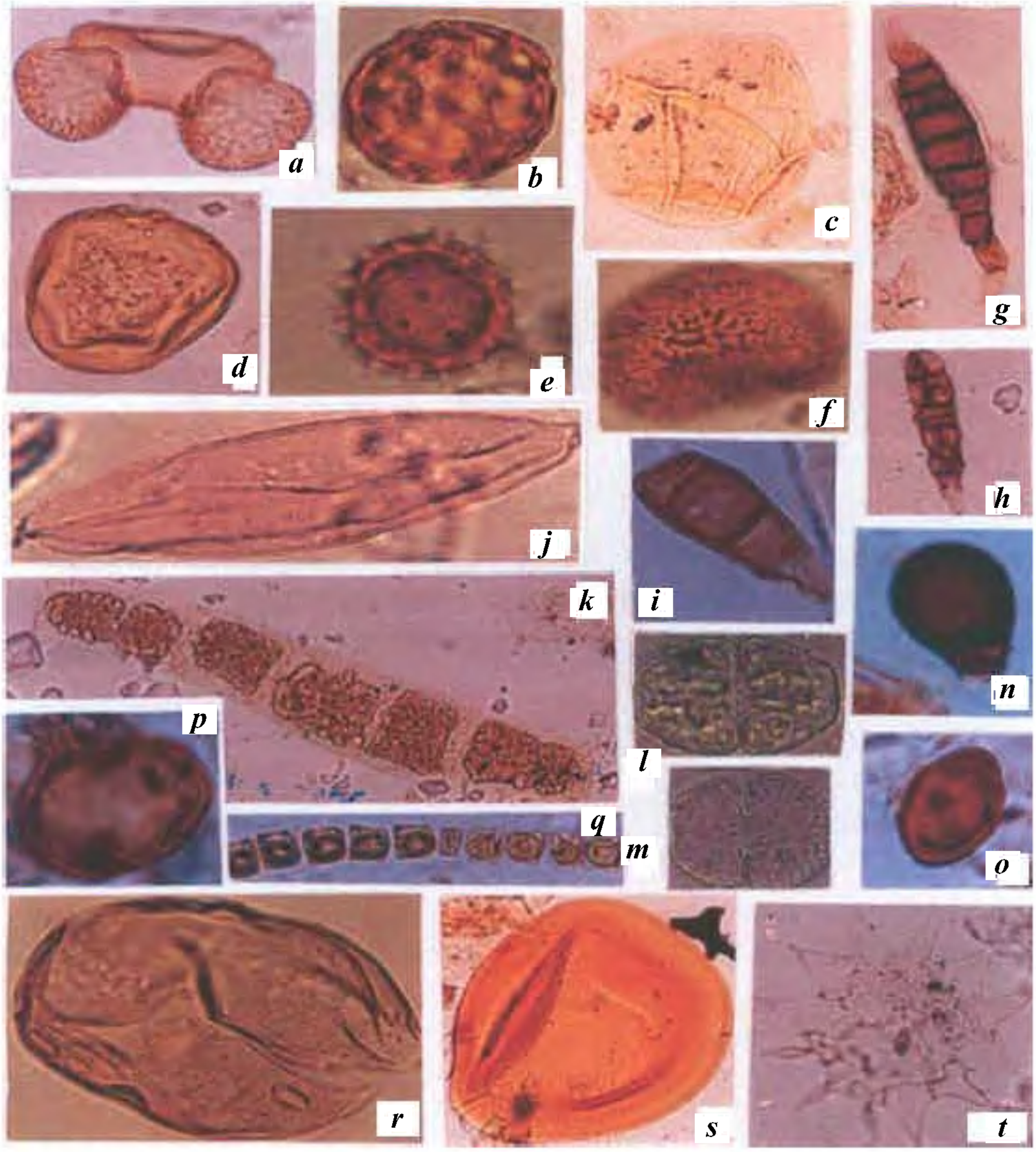

Figure 3. ***a***, *Pinus*; ***b***, Chenopodiaceae; ***c***, *Larix*; ***d***, Poaceae; ***e***, Asteraceae; ***f***, Monolete fern; ***g***, ***i***, ***n***, ***o***, Unknown fungal spores; ***h***, *Alternaria*; ***j***, Unknown animal cyst; ***k***, ***q***, Algal filament; ***l***, ***m***, *Cosmarium*; ***p***, Fungal fruiting body; ***r***, Unknown; ***s***, Reworked spore; ***t***, *Pediastrum*. All figures × 1000.

sedimentology, glaciology and more fine resolution palynostratigraphy, would be of immense value for accurate interpretation of palaeoclimate in the polar region.

1. Faegri, K. and Iversen, J., *Textbook of Pollen Analysis*, Munksgaard, Copenhagen, 1975.
2. Fredskild, B. and Wagner, P., *Boreas*, 1974, **3**, 105–108.
3. Lichti-Federovich, S., In *Report of Activities, Part A*, Geological Survey of Canada, 1975, Paper 75-1, Part A, pp. 441–444.
4. Kappen, L. and Straka, H., *Polar Biol.*, 1988, **8**, 173–180.
5. Young, S. B. and Schofield, E. K., *Nature*, 1973, **245**, 311–312.
6. Scott, L. and Van Zinderen Bakker Sr., E. M., *Grana*, 1985, **24**, 45–54.
7. Smith, R. I. L., *Grana*, 1991, **30**, 313–324.
8. Wynn–Williams, D. D., *Grana*, 1991, **30**, 380–393.
9. Bera, S. K. and Khandelwal, A., *Curr. Sci.*, 2003, **85**, 137–140.
10. Bera, S. K., *Curr. Sci.*, 2004, **86**, 1485–1488.
11. JouZel, J., Lorius, C., Petit, J. R., Gentheon, C., Barkov, N. I., Kotlyakov, V. M. and Petrov, V. M., *Nature*, 1987, **329**, 403–408.
12. Lorius, C., JouZel, J., Ritz, C., Merlivat, L., Barkov, N. I., Korotkevich, Y. S. and Kotlyakov, V. M., *Nature*, 1985, **316**, 591–596.

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