Antarctica: Prospects for Palaeoclimatic studies

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Abstract

Despite the fact the greater part of the rocky foundation of Antarctica is hidden beneath the huge ice sheet, enough can be seen along the Transantarctic Mountains in the Antarctic Peninsula, and around the edges of the east Antarctic ice cap. The geologists and other associated scientists are very interested in the continent which forms one of the earth's seven major rock plates. whose margins are constantly changing and making it one of the best plates in the world to study the movement of earth's crust. It is one of the best climatic archives of the past with terrestrial sediments covering the last 2, 00, 000 years and marine sediments covering millions of years and even older areas of ancient continental rocks Coal beds, plant fossils *(Glossopteris Dicroidium* and other ancient ferns) and animal fossil like *Lystrosaurus* were reported from the Ohio range of Transantarctic Mountains 200 million years ago, clearly indicating that the Antarctic was not always covered with ice. After its final detachment from Australia, about 40 my ago, Antarctica settled into its present polar position and began to cool diamatically.

Climate changes have a significant effect on periglacial regions in front of the large inland ice masses of Antarctica and Greenland. As a consequence, information on environmental changes during the recent history of the earth is stored in the deposits found there. The deposits in the sediments at lake bottom and glacial clay varves are valuable source of palaeoenvironmental data. Long Antarctic ice core analysis may reflect climatic and environmental conditions which existed at the time of deposition. It also gives a unique access to the past concentration of a wide range of atmospheric parameters like trace gasses, soluble / insoluble aerosols, volcanic compounds trapped in the ice Study of stable isotopes is also useful fot various palaeoconditions, viz, ™ ^{18}O provides indication of palaeotemperature, ™ " B preserves palaeo pH, ™ ^{13} C derive dissolved inorganic caibon and Cd / Ca ratios provide palaeoproductivity.

Keywords

Transantarctic Mountains, Palaeoenvironments, Schirmacher

Introduction

Antarctica-a vast supercontinent is the coldest, windiest, driest (more than Sahara) and highest polar desert of all continents in the World. It covers an area of appx.14, 000,000 Sq km, with only *2%* of ice free area & contains 90% of the World's ice surrounded by Atlantic, Pacific & Indian oceans. Geographic South Pole is on an ice plateau at 2,843 in elevation with land below sea level. The Continent has active volcanoes and largest is the Mount Erebus (3,794 m) whereas, among mountains and glaciers, Vinson Massif (4,897 m) and Lambert (40 km) are the largest respectively. Discovery of fossil seed ferns in West Antarctica & Transantarctic Mountains strongly suggest its connection with other Gondwana lands. Occurrence of several trace fossils such as burrows preserved in sandstone, which indicate the life was abundant.

Antarctic ice sheet is a rich storehouse of meteorites. Continent has very low seismicily & largest Earthquake free area on the earth except lew volcanic regions (M.Erebus, Ross & Deception Islands) due to calving of ice shelves or fracturing of ice sheet. World's lowest natural temperature was recorded -89.2^{Q}C (Vostok) and high as *+ 6-C - 9"C* at summer. Wind speed exceeds upto 350 kmph in winter. The icy continent becomes double in winter as ice spreads over the surrounding oceans. In recent years models of present day atmospheric circulation in the higher Southern latitudes, stressing, for example, the importance of Antarctica and its apron of sea ice (Simmonds, 1981), illuminate our understanding of the climate system and warrant attention. Models applicable to the late Quaternary (Manabe and Broccoli, 1985; Kutzbach and Guetter, 1986), after testing by palaeo-ecological, glacial, and related data, can be the basis for palaeoclimatic theory (Kutzbach, 1985).

The period after the end of the last ice coverage is usually documented in lake sediments. By virtue of the relatively high sedimentation rates, reconstruction with a high time resolution is possible. The data acquired can then be used to design model for predicting the reaction of the earth system to possible future changes in climate. Nevertheless based on the study of samples originating from the sea ice, sediment traps, surface deposits and sediment cores, a set of micropalaeontological indicators for past sea ice distributions could be derived for the Antarctic. The calcitic shells of planktonic foraminifera have proved to be one of the most important sources of information for reconstruction of palaeoenvironments.

Presently Indian scientists are drawing their attention on the various aspects of palaeo environmental science because of existence of a number of glacial lakes in and around Schirmacher oasis in East Antarctica. .The deep core sediments from lakes, fossil glacial valley, glacial clay varves occur in Schirmacher oasis & high mountain areas (Gruber massif, Orvin mountain range, etc.) could prove as most potential tools for reconstruction of palaeoclimate in polar region.

Plate Tectonics and Antarctica

Modern comprehensive theoretical concept of Continental drift, Subduction and Volcanism provides explanation for the break up of the supercontinent, Gondwana, and the formation of the present set up of Antarctic Continent (Fig. lb) which lies within a single lithospheric 'plate' with East Antarctica bounded only by passive continental margin and presently active margins occurring only off the Scotia Arc to the North East of Antarctic peninsula. Marine geo-magnetic measurements have made it possible, by extrapolation, to assign an age to much of the ocean floor around Antarctica, and to reconstruct the broad development of the Antarctic margin & Southern ocean during Gondwana break up. Some models suggest rifting between East & West Antarctica during early Tertiary times (60 my ago), and possibly convergence along the line of the modern Transanlarclic Mountains.

Plate tectonic history of Antarctic region gives timing of the opening of seaways between continental masses. Opening of the Drake passage between Antarctic peninsula & South America began about 29 my ago, and that between North Victoria Land & Tasmania at the same time. This allowed the eventual development of Antarctic Circumpolar Current. Thus the plate tectonic theory is relevant to the Palaeogeography, Palaeooceanography and Palaeoclimate of the polar region.

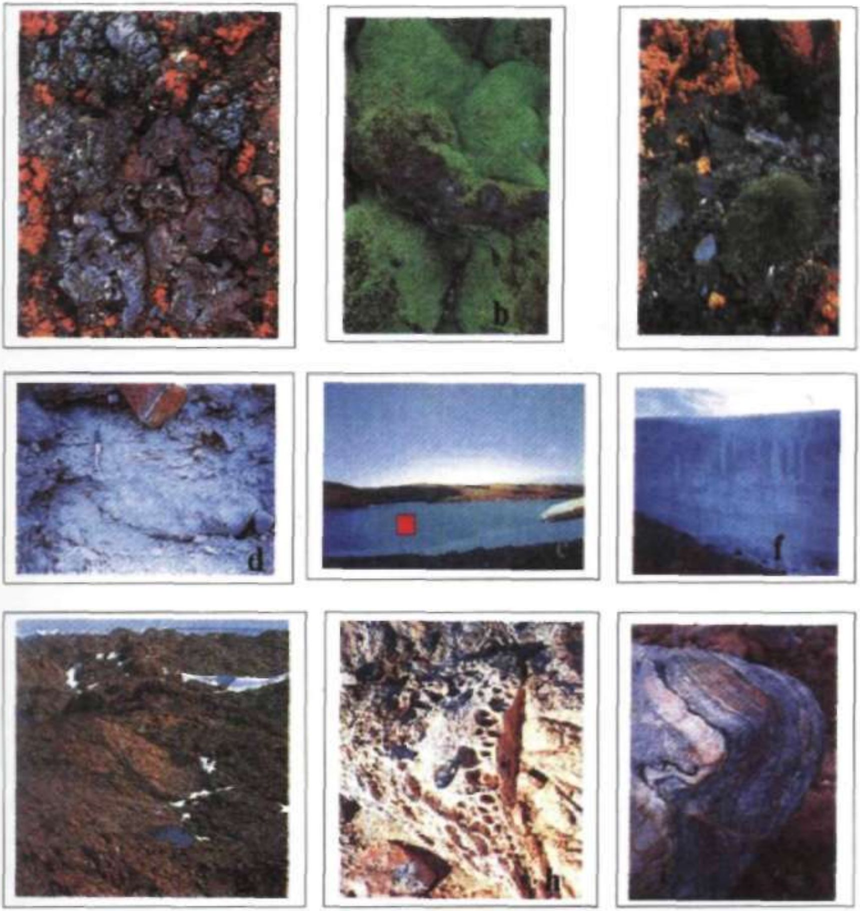
Schirmacher Oasis, East Antarctica: Terrestrial Deposits and Green Life

Coldest desert having Prccambrian Crystalline basement of East Antarctic Platform exposed over an 14 sq km length & 3 km breadth in Queen Maud Land. Polymetamorphic rock sequence consist of biotite garnet gneiss & pyroxene (Fig. la) bearing granulites with minor intercalation of marbles & calc silicate rocks, ultramafics, amphibolites & other metabasites is traversed by dolerite (Ravindra et al. 2001; Sengupta, 1986). Excepting glacial moraine matrix & frozen soil, the thick moss turfs, lichen patches, algal mats are only the terrestrial substrates for accumulating surface deposits (Bera, 2003, XXIX & XX IAE Report: In press). Vast Antarctic ice sheet ranging from 3000-4000 m thick towards polar plateau could be a most vital thrust area for palaeoclimatic studies.

Fig. 1(a). *Geology of Schirmacher Oasis, East Antarctica Arrow mark indicates four major lake sites under study.*

Fig. 1(b). *Present day setup of Gondwana lands.*

Among plant gioups algae lichen and moss (Figs 2 a c) are the major elements in Antarctic environment Only two higher groups of plants (*Deschampsia antarctica* a grass sp and *Colobanthus quitensis* a heib sp) however occur m peninsula The palaeoglacial valley is interspersed with a number of lakes catagonsed as inland lakes epishelf lakes and high mountain frozen lakes (Ravindra et al 2002) Zub Lake, Long Lake Lake 91 and Dakshin Gangotn (Fig la) lake are better sites in the Oasis for palaeochmatic research



Tig2 a Folwse lichen (Umb hcana sp) b Thick moil turf (Bryam sp) c Antatctc peninsular grass (Deschampna antarctica) d ulty clay exposure e Coring site m Long lake f Thick Antatctic ice cap g Inland lakes m Palaeoglacial valley Sch rmacher oasis h Honey comb ock feature i raiding in granitic rock

Palaeoclimate and Palaeoenvironmental Studies

Climate changes have a significant effect on the periglacial region in front of the large inland ice masses of Antarctica & Greenland that manifests itself within a short period of time & also affect glaciers & permafrost soil (Johnsen et al. 1972). As a consequence, information on environmental changes during recent history of the earth is stored in the deposits in Antarctica. The periglacial lake bottom sediments and dry glacial clay varves are valuable source of environmental data as documented after the end of the last ice coverage. The data acquired from older ice cores, deep lake sediments, characteristic rocks can then be used to design models for forecasting the reaction of the earth system to possible future changes in climate. A long term record of environmental change in the South polar regions, from late Mesozoic times until the present day, will result from a judicious interfacing of a variety of data from geological sections on land and beneath the sea including micropalaeontological studies.

A 2000 year period spans atleast two intervals of important large scale climatic changes, i.e., 'European Little Ice Age' and Medieval warm period'. Effort should be made to validate past environments from lake sediment & peat accumulation, and assess if these mirror changes recorded in ice cores.

Polar Lake Sediments

Three folds climatic oscillations (arid-warm and humid- warm & more humid) are recorded from one meter polar lake sediments (Zub and Long lakes) during late Holocene (8,000 years Bp) as evidenced by the fluctuation of the values of long distance transported microbiota along with local moss spores and algal assemblage (Bera, 2004). Trace occurrence of Antarctic grass *(Deschampsia Antarctica ?)* and herb (*Colobanthus quitensis?)* in sediment indicates the presence of the species during the time of deposition (Fig. 4). Although more detailed study is required to confirm the fact, pollen-spore deposition model, well corroborated with air study suggest that reconstruction of pollen diagram is possible to elucidate the past climatic oscillation in polar region through palynostratigraphy (Bera and Khandelwal, 2003). Palynological investigations of various polar surface deposits and lake core sediments from Schirmacher oasis have generated quite inspiring pollen data in order to depict past polar climatic events & episodes. The information on the biogeographical distribution of species in the Circum-Antarctic region is incomplete, and the plant species at Marion Island - tree less vegetation consisting mainly of mire & bog communities dominated by Bryophytes & Grasses (Bakker, 1973) show strong affinities with those of Kerguelen Province (Upland wind deserts dominated by cushion plants), the Sub-Antarctic phytogeographical province to which the Island belong (Scott & V Z Bakker, 1985; Young et al. 1973). Still the scientific data is not adequate to support long distance transport of various microbiota through any means for accurate interpretation of polar palaeoclimate

Figure 4

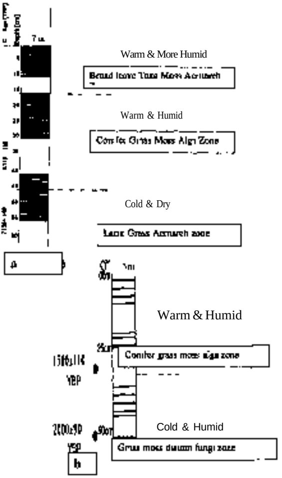


Fig. 4. *Climatic Oscillations recorded from two Polar Lakes East Antarctica a, Zub Lake; b, Long Lake.*

Despite the poverty of Antarctic vascular plant flora having only two species may have discouraged the pollen analysis but the pollen diagram can be made through the study of polar lake sediments & palynomorphs encountered can be divided into a strictly local and a long distance transported, extra-regional component. Therefore, explanation of changes in past local vegetation should first be attempted in terms of changes in past local factors such as hydrology, slope processes and peat development, snow cover and nutrient status, since past climatic changes often plays an indirect role by influencing these factors.

Marine Sediments around antarctica

During major glaciation, the Antarctic ice expands across the continental shelf, reaching the shelf break and deposits sediments on the continental slopes, building up a record of each glaciation. Sedimentary record is truncated & discontinuous because of unstable slope deposits in most of the parts of Antarctic margins. An important exception appears to be the 'submarine Fan' built by the Lambert glacier on the continental slope offshore from Prydz Bay and Parts of this submarine fan exhibit minimal slumping and may preserve a near continuous record of the advance and retreat of the ice shelf and the largest glacial system in east Antarctica. Efforts must be made for a better understanding of global climate change by providing statements of the Antarctic & Southern ocean palaeoenvironments over the time scales of Holocene-Post glacial warming (0-10,000 yrs) to Pliocene warming of Antarctica (0-5,00,000 yrs BP). Based on the study of samples originating from sea ice, sediment traps, surface sediments and deep lake sediment cores, a set of micropalaeontological indicators for past sea ice distributions could be derived for the Antarctic.

The calcitic shells of planktonic foraminifera have proved to be one of the most important sources of informations for the reconstruction of palaeoenvironments. For example ^{18}O provides indication of palaeotemperature, " B preserves palaeo-pH and ^{13}C of dissolved inorganic carbon and Cd/Ca ratios in their tests may tell about palaeoproductivity.

Ice Cores

Antarctic ice sheet contains 'fossilized atmospheres' and are storehouse of informations.Antarctic 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 meter long Ice core of Vostok provides a direct measure of global temperature changes over the past 1,50,000 years BP. Important features are that climate has been up to 10°C colder than at present for most of the past 1,50,000 years, with large periodic variations (Jouzel et al. 1987; Lorius et al. 1985) in temperature both within cold intervals (ice ages) and the shorter, warm intervals (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 numbers of dust particles carried to Antarctica and deposited in the ice (fig. 3 a & b). Ice core study gives a unique access to the past concentrations of a wide range of atmospheric parameters, i.e., trace gases, soluble/insoluble aerosols and volcanic compounds, etc.

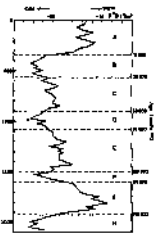


Fig. 3(a). *Climatic fluctuations since last 1,50,000 years BP as depicted from Vostok Ice cores (B,D,F,H showing cold phases). (After JouZel et al, 1987).*

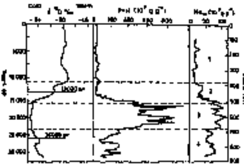


Fig .3(b). *Concentration of dust and other elements recorded in Ice cores since past 30,000 years BP. (After Lorius et al, 1979).*

Concluding Remarks

Antarctica is an open research platform where various research programmes could be successfully carried out without hampering ecological balance. Late Quaternary palaeoecological & glacial evidence from the higher latitudes of the Southern Hemisphere implies overall uniformity of large-scale glacial & interglacial climatic fluctuations for the past 40,000 years BP (Burrows, 1975; Pittock, 1978; Poter, 1981). Climate of the LGM, variously dated between 30,000 and 11,000 yrs BP, was relatively cold and dry compared with the wanner, more humid climate of the Holocene and the inte-stade preceding LGM. Conditions were apparently coldest during millennia centered around 20,000 yrs BP & the wannest in the early Holocene. A cold late glacial episode, estimated as occurring between ca. 13,000 & 11,000 yrs BP. in Antarctica, possibly was coeval with the Younger Dryas in NW Europe and may be correlative with a climatic episode in Southern South America & perhaps in New Zealand and South Georgia, however there is no evidence for the event in Tasmania (Fig. 3 c).

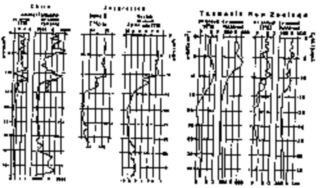


Fig. 3(c). *Temperature and precipition in Chile, New Zealand and Tasmania compared with ^{18}0 variations at Dome C and Tetnperatue at Vostok in Antartica Over 40 thousand yean (Aftet Petit et al, 1987).*

The results of dating of two lake sediment cores (Zub and Long lakes) of Schirmacher oasis (Bera, 2004) was between 7,000 to 8,000 years BP indicate the presence of these lakes in Holocene times. Our study also corroborates with the data of German workers (Richter and Stranch, 1983).

General atmospheric circulation models for the polar latitudes at the time of LGM show an intensification of the Southern westerlies, apparently a result of the expansion of ice cover in Antarctica and of sea ice in the Southern ocean. Significant in the connection among the climatic anomalies observed in Southern south America and the Southern oscillation, changes in atmospheric carbon dioxide with regard to growth and decay of the Antarctic Ice Sheet and deep water circulation between North Atlantic & the Southern ocean & for testing these & future concepts of late Quaternary climate, gathering of data in the Southern Hemisphere requires greater emphasis. Besides these, Limnology, Palynostratigraphy coupled with Geomorphology & Geochemical studies on deep lake core sediments, glacial varves in higher mountains and deep ice cores from Antarctic ice sheet can provide better understanding of polar climate for which a beginning is already made. BSIP has initiated palaeoclimatic studies on polar sediments by participating in two consecutive Antarctic expeditions(XIX & XX). An ongoing collaborative project (ILTP) with Arctic and Antarctic Research Institute, St. Petersburg, Russia, National Center For Antarctic and Ocean Research, Goa & Antarctic Division, Geological Survey of India, Fandabad is finalized by DST, Govt. of India.

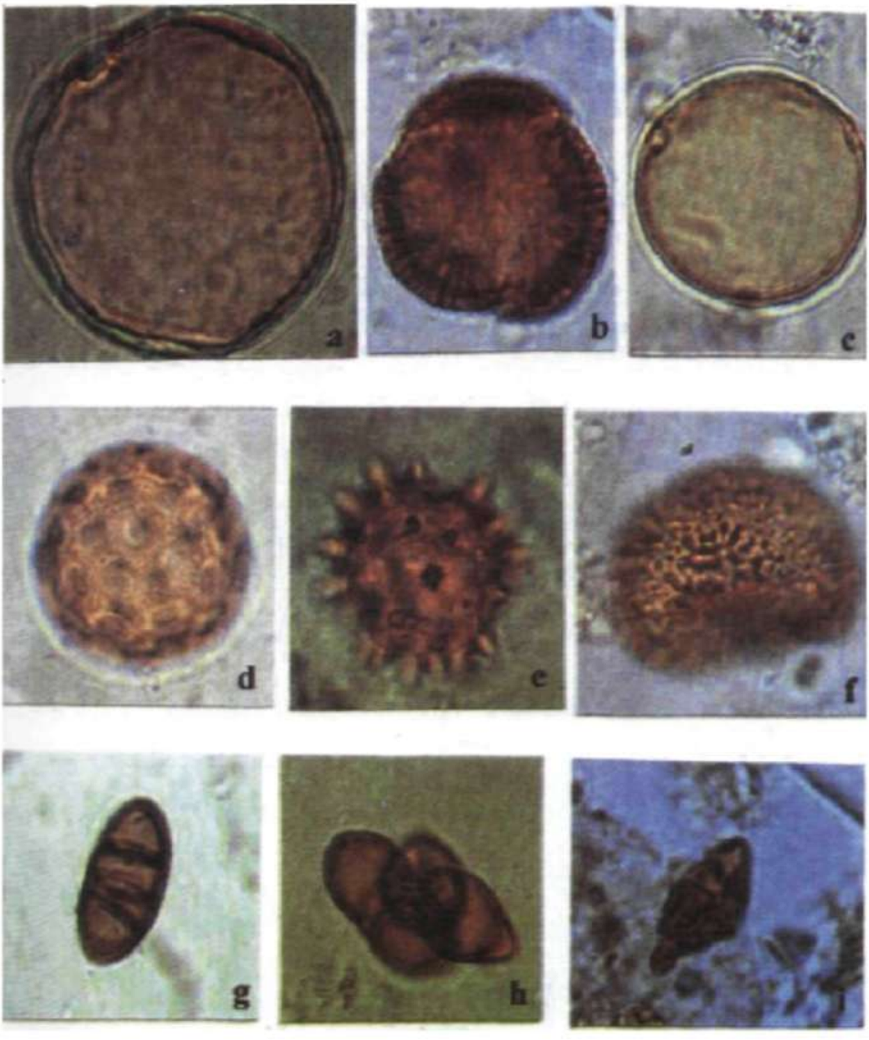


Fig 5(a). *Deschampsia Antarctica ?; b: Pollen of Oleaceae c: Pollen of Moraceae Urticaceae; d: Colobanthus quitensis ?; e: Pollen of Asteraceae; f :Monolete Fern spore; g, h, i: Fungal spores. All Palynomorpls X 1000.*

Acknowledgement

The authors are grateful to Dr. P .C. Pandey Director NCAOR Goa for inviting Prof. A. K Sinha to make the presentation of paper at the National seminar on the Antarctic Geoscience Ocean Atmosphere interaction and palaeoclimatology held at NCAOR Goa in November 2003.

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