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Spectral analysis of physical properties of the Prydz Bay sediments, Antarctica for identifying cycles for the last five million years

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Abstract

The ODP Site 1165 is located 400km northwest of Prydz Bay, Antarctica and it contains a high-resolution Plio-Pleistocene sediment record of glacial history and related climate changes. The East Antarctic Ice Sheet (EAIS) has existed for more than 34 Ma. During that time it has fluctuated considerably and it has been one of the considerable driving forces of climate and global sea level throughout the late Cenozoic era. Evidence of the formation and development of the Antarctic ice sheets comes from variety of sources, including physical properties of the marine sediments. The waxing and waning of ice masses is associated with changes in terrigenous sediment supply. High quality record of physical properties from marine sediments is increasingly collected for paleoclimatic purposes. This study is an example of use of spectral analysis to physical properties including magnetic susceptibility and gamma-ray attenuation porosity/density evaluation (GRAPE) measurements during the last five million years of deposition. The studied interval was sampled every 10 cm and discrete samples were measured for magnetic susceptibility to obtain more prominent dataset with less noise. The results show record of the glacier ice dynamics and its cyclic behaviour due to external (i.e. orbital) forcing. The pronounced expression of the middle Pliocene warm period from 3.15 to 2.85 Ma ago is seen in discrete samples by the elevated magnetic susceptibility values by a factor of two compared to earlier record.

Key words: Antarctica, physical properties, ice sheet dynamics, climate change

1. Introduction

The East Antarctic Ice Sheet (EAIS) is presently the largest and longest-lived ice mass on Earth. Since its inception, it has played a central role in global climate and in higher order sea level change (*O'Brien et al.*, 2007). According to *Zachos et al.* (2001) a broad band of Antarctic glaciations are known which has fluctuated considerably throughout the late Cenozoic era. The history of the East Antarctic ice sheet in the Prydz Bay area was delineated by drilling on the Prydz Bay shelf during ODP Legs 119 and 188, with glaciation dating from late Eocene time (*Williams and Handwerger,* 2005). The middle Pliocene is though to be a time of global climate warmth and much evidence exist that enhanced oceanic heat transport played a significant role in sustaining high latitude warmth during this period (*Grützner et al.,* 2005). In this study a

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specific interest is to detect the middle part of the Pliocene epoch, approximately 3.2–2.7 million years ago, imprint in the sediments. During that time global climate was about 2°–3°C warmer globally than today (*Robinson, et al.,* 2008). Recent studies also show that during the Pliocene climate system response was dominated by the 41,000-year period of Earth's obliquity rather than by the 100,000-year period of eccentricity that has governed the more recent waxing and waning of Northern Hemisphere ice sheets. Southern Hemisphere records are sparse and also one focus of this study. Globally, the prolonged cooling transition is then recorded by the late Pleistocene intensification of glaciations.

High quality record of physical properties from marine sediments is increasingly collected for paleoclimatic purposes. The data collected requires a proper time series analysis in order to receive important information of possible cyclicities and to evaluate their causes. This study is an example of use of spectral analysis to physical properties including magnetic susceptibility and gamma-ray attenuation porosity/density evaluation (GRAPE) measurements for the Ocean Drilling Program (ODP) Site 1165 sediments deposited on the continental rise, proximal to the EAIS of the Prydz Bay during the last five million years. The physical properties of the sediments generally respond to major changes of the amount of terrestrial components as climate, ocean currents and melt water conditions changes in proximity of glacier ice (*Warnke,* 2004). Generally, climatic variations influence magnetic susceptibility through changes in glacial erosion and changes in terrigenous lithogenic input during glacial-interglacial periods (cf. *Ellwood et al.,* 2000). The first 50 meters below sea floor (mbsf) of Site 1165 sediments were of special interest consisting of five million years of deposition that possible record of glacier ice dynamics and its cyclic behaviour as well as possible expression of the middle Pliocene global warmth.

2. Regional settings of Site 1165 record

The Prydz Bay is in the seaward end of the Lambert Graben between 66°E and 79°E, which hosts the Lambert Glacier – Amery Ice Shelf system, the largest single glacier in Antarctica. This large fault-bounded graben is at least 700 km long and 100 km wide and is located between the Princess Elizabeth Land and Mac Robertson Land in East Antarctica (Fig. 1). The broad pattern of glacier ice and sediment movement in the region is controlled by the Lambert Graben. Most of the basement rocks of the Lambert Glacier drainage area are high-grade Precambrian metamorphic and intrusive rocks with isolated onshore exposures of Paleozoic granite, mafic dykes, Permian sediments, Paleogene volcanics, and Oligocene and younger age glacial sediments (*Mikhalsky et al.,* 2001).

Site 1165 is situated on the continental rise offshore from Prydz Bay (64°22.77'S, 67°13.14'E) at 3537 m of water depth. Drilling at Site 1165 yielded a relatively continuous 999 meter-thick sedimentary section of Early Miocene to Pleistocene age of terrigenous and hemipelagic deposits. The cyclic variations in lithology are recorded well as magnetic susceptibility according to *Warnke et al.,* (2004). The sediments mostly consist of quartz, calcite, plagioclase, K-feldspar, and a mixture of clay minerals. The presently studied interval 0–50 m below sea floor is characterized by structureless brown diatom-bearing silty clay and clay with minor diatom-bearing greenish grey clay with dispersed sand grains and lonestones, minor laminated silt, and minor brown foraminifer-bearing clay which are interpreted as hemipelagic sediments (*Shipboard Scientific Party,* 2001).

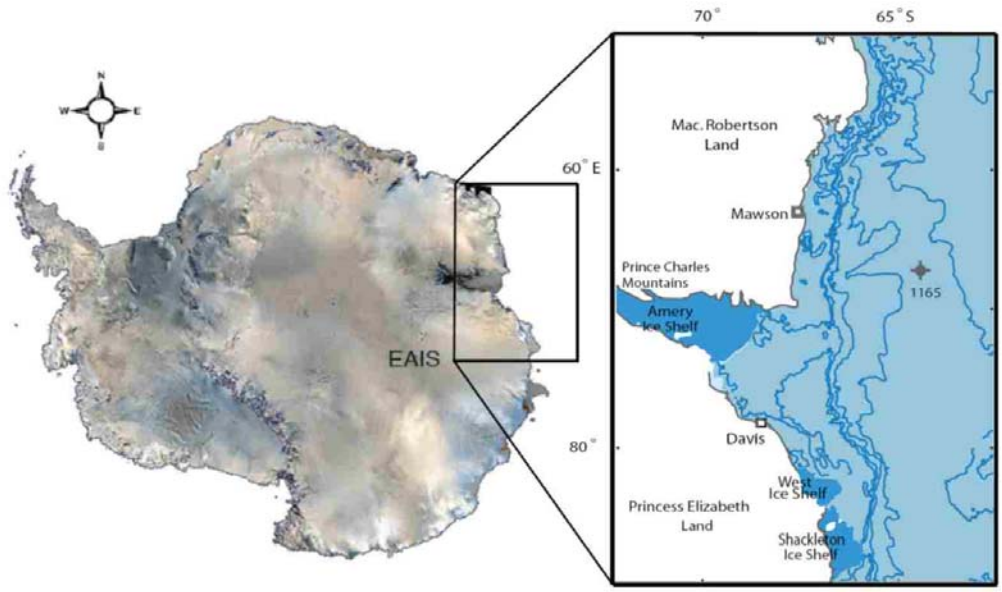

Fig. 1. Location of the Ocean Drilling Program Site 1165 at the Prydz Bay continental rise, Antarctica.

3. Methods and Measurements

This study examines existing data on the sediment column, the first 50 metres of Site 1165 drilling which consist of a high-resolution and well-preserved section of Pliocene- to Pleistocene-age (~5Ma) sediments (*Warnke,* 2004). The time series for these sediments (Table 1) were calculated by linear interpolation between age control points based on microfossil biostratigraphy (*Florindo et al.,* 2003).

For this study cyclicity was pursued by using core magnetic susceptibility, core GRAPE density and measured discrete magnetic susceptibility. The first 50 metres of the core were sampled every 10 cm and total number of 500 samples was measured for magnetic susceptibility following the procedure introduced by *Korja* (2008). Magnetic susceptibility is a rapid and non-destructive measurement that depends primarily on the amount of ferromagnetic minerals, such as magnetite generally confined to the terrigenous fraction of the sediment in Prydz Bay area (*Williams and Handwerger,* 2005).

Table 1. Age model for Site 1165 based on combination of biostratigraphic data after *Florindo et al.* (2003).

Average depth (mbsf)	Age(Ma)-	Age(Ma)+	Sample
3.95	0.6	0.7	1165B-1H-5, 20-21
7.73	1.2	1.5	1165B-2H-2, 95-96
13.25	1.8	2	1165B-3H-1, 95-96
17.52	2.1	2.5	1165B-3H-1, 127-129.5
17.92	2.5	2.7	1165B-3H-2, 17-20
18.42	2.5	2.7	1165B-3H-2, 67-70
25.51	2.7	3.2	1165B-5H-CC
38.01	3.7	3.8	1165B-5H-2, 117-119.5
38.02	4.2	4.2	1165B-5H-2, 127-129.5
41.84	4.2	4.3	1165B-5H-5, 47-50
49.62	4.8	5	1165B-6H-, 27-30

Data sets of magnetic susceptibility and GRAPE density measured with the shipboard multisensor track (*Shipboard Scientific Party,* 2001) have been edited for erroneous measurements resulting from section breaks and voids. Dataset was then converted from depth to time domain.

In order to investigate the cyclicities in the high resolution time series of physical properties of Site 1165 sediments the Singular Spectrum Analysis (SSA, *Vautard et al.,* 1992) was used to pre-process data. Spectral analyses algorithms (Program AnalySeries, *Paillard et al,* 1996) were then applied to this data. SSA is a method based on the principal component analysis to decompose the obtained time series into a trend, oscillatory components and noise. Each principal component analysis contains significant parts of the spectrum and convolution of two or more of them with their corresponding empirical orthogonal functions can be used to reconstruct a specific bandwidth of the original signal (*Vautard et al.,* 1992). The resulting outputs are data adaptive filters but unlike band pass filtering SSA provides an independent spectral estimation (*Grützner et al.,* 2005). AnalySeries is designed specially to facilitate the study of paleoclimatic records using the approach and some of the methods defined by the SPECMAP group (*Martinson et al.,* 1987; *Imbrie et al., 1984,* 1989). It provides a set of classical spectral analysis methods that are often complementary in terms of robustness versus resolution. We used The Blackman-Tukey algorithm to pre-processed data. The algorithm computes first the autocovariance of the data, then applies a window, and finally Fourier-transforms it to compute the spectrum (*Paillard et al.,* 1996).

4. Results

4.1 Physical properties

Sediment density and magnetic susceptibility (discrete and MST) seems to have general increasing alignment along the age. Three different phases (1-3) were observed altering in depths 30 mbsf and 14 mbsf (Fig. 2). Within phase 1 magnetic susceptibility values are altering slightly, mainly staying in lower level when compared to other phases. In phase 2 the pronounced rise of magnetic susceptibility values up to a factor of two is observed after 30 mbsf compared to the interval below. In phase 3 magnetic susceptibility values get significantly higher than in previous phases. There is also prominent variation pattern throughout the phase 3. Same three phases and patterns are observed also in GRAPE density record. Difference in appearance between discrete and MST results from the used measuring methods. A discrete sample represents better the material measured due to whole magnetic content of sample being analysed when MST measurement is preformed in a single point. Discrete magnetic susceptibility and density values show a good correlation in relation to each other.

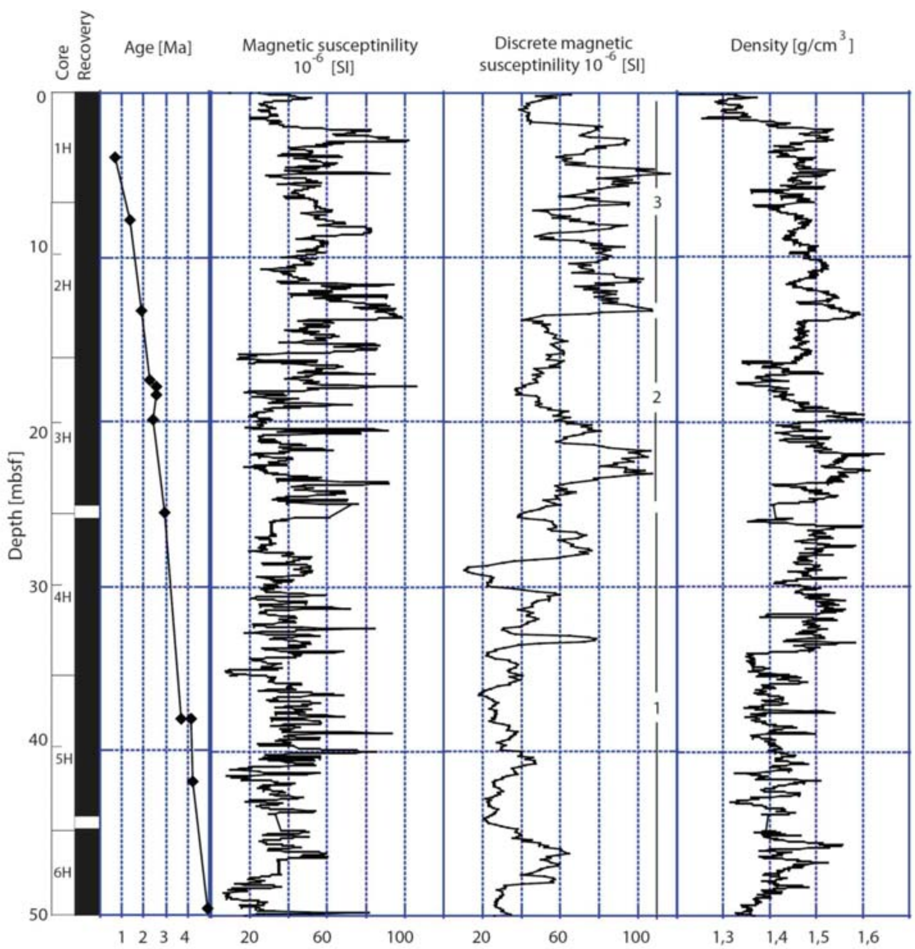

Fig. 2. Core recovery, age, magnetic susceptibility (MST and discrete) and density plotted against depth for Site 1165 Plio-Pliocene sediments (0–50 mbsf).

4.2 Cyclicity

Spectral analysis performed on depth series of GRAPE density and magnetic susceptibility (MST and discrete) show cyclicity (Fig. 3A and 3B). Discrete magnetic susceptibility is well concentrated at orbital frequencies eccentricity (~100 ka), obliquity (~41 ka) and precession (~23 ka). MST magnetic susceptibility power spectrum shows cyclicity at 100 ka and also a weak 41 ka cycle can be detected. Eccentricity can be also identified from the GRAPE density power spectrum although other cyclicities are not seen (Fig. 3C).

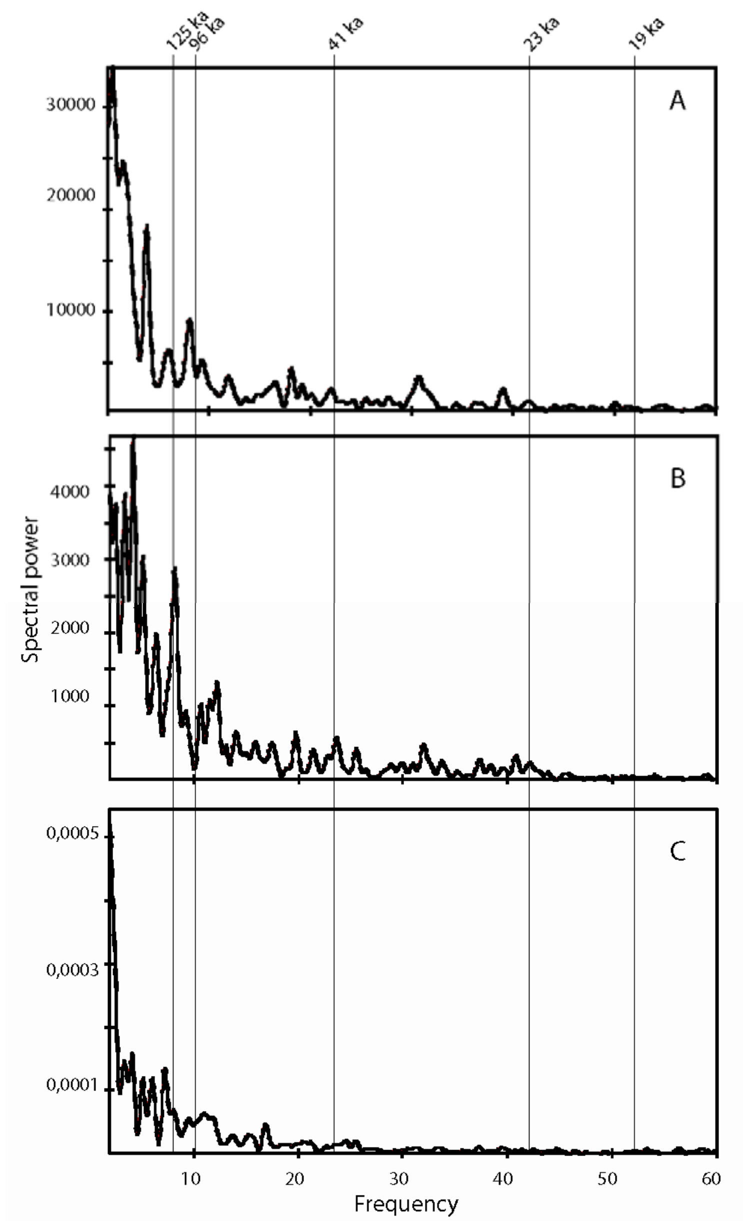

Fig. 3. Power spectrums of MST magnetic susceptibility (A) and discrete magnetic susceptibility (B) and GRAPE density (C).

5. *Discussion and conclusion*

It is well established that there is cyclicity in early and late Miocene record of 1165 sediments (*Grützner et al.,* 2005; *Williams and Handwerger,* 2005). The specific aim in this study is to show the possible cycles of sedimentation related to extent and retreat of the continental ice sheet across the continental shelf off Prydz Bay, East Antarctica and possible expression of the middle Pliocene warm period *(Ravelo et al,* 2004) that prevailed from 3.15 to 2.85 Ma ago within the well-preserved sediment column between 0 and 50 mbsf from the Ocean Drilling Program Site 1165.

Stable isotope analysis from the same samples show at least four glacial-interglacial cycles between 7.7 and 16 mbsf, and the $\delta^{18}O$ values show a general increase through the late Pliocene to Pleistocene (*Warnke et al.,* 2004). It may be the case that the processes, including the formation of clays, the transportation and the sedimentation, may be too slow in the Prydz Bay area to show the kind of glacial-interglacial cycles shown by the stable isotopes, however, the physical properties including susceptibility and GRAPE density seem to show these interglacial-glacial cycles prominent of 100 ka and 41 ka years of duration according to performed spectral analysis of the collected data. Physical properties of the sediments are indicative for glacial-interglacial dynamics and changes in terrestrial sediment input. In Prydz Bay, the Plio-Pleistocene sediment material is always included as glacigenic debris but seems to be controlled by intensity of melt water activity during interglacials. As an outcome of that magnetic susceptibility through changes in erosion and changes in terrigenous lithogenic input is a prominent proxy for glacial-interglacial cycles in Antarctica. The detected cyclicity in Site 1165 sediments shows clear connection in behaviour of the East Antarctic ice sheet in consistence with the global climate evolution (cf. *Zachos et al*., 2001).

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