Determination of and preliminary results from the high-resolution physical properties record of the AND-1B sediment core from beneath Ross Ice Shelf, Antarctica

D. Magens[1], F. Niessen[2] and the ANDRILL-MIS Science Team[3]

[1]Alfred Wegener Institute for Polar and Marine Research, Am Alten Hafen 26, 27568 Bremerhaven, Germany (diana.magens@awi.de)
[2]Alfred Wegener Institute for Polar and Marine Research, Am Alten Hafen 26, 27568 Bremerhaven, Germany (frank.niessen@awi.de)
[3]http://www.andrill.org/support/references/appendixc.html

Summary A more than 1200 m long sediment core was drilled beneath McMurdo Ice Shelf near Ross Island (Antarctica) in austral summer 2006/07 (ANDRILL-MIS Project). High-resolution whole-core physical properties were determined as one set of parameters to describe changes in the depositional system over the sedimentation period of about 12 myrs incorporated in the core. Four parameters were measured using a multi-sensor core logger: acoustic velocity, wet-bulk density, non-contact electrical resistivity and magnetic susceptibility. Data quality was routinely controlled by measurement of standards. Deviations from the reference values are minimal with regard to the whole spectrum of sediment data points and no offsets between core diameter intervals are obvious. Almost all boundaries between lithostratigraphic units are in good agreement with changes in the physical properties record. For the depth interval between 140-300 mbsf the physical properties indicate rhythmic changes in the environmental system with alternations of diatomite and diamictite sequences.

Citation: Magens, D., F. Niessen and the ANDRILL-MIS Science Team (2007), Determination of and preliminary results from the high-resolution physical properties record of the AND-1B sediment core from beneath Ross Ice Shelf, Antarctica, in Antarctica: A Keystone in a Changing World – Online Proceedings of the 10th ISAES X, edited by A. K. Cooper and C. R. Raymond et al., USGS Open-File Report 2007-xxx, Extended Abstract yyy, 1-4.

Introduction

Large ice sheets and ice shelves play a major role in the earth's system as they link cryosphere, ocean and climate. With respect to global warming it is therefore essential to know about possible responses, which may have larger than just regional effects. In this context the multi-national ANDRILL project has drilled a unique record of more than 1200 m of sedimentary rocks from a deep basin beneath the McMurdo Ice Shelf near Ross Island (Antarctica) in the austral summer season 2006/2007. A multi-proxy approach is followed in order to study the behavior of the Ross Ice Shelf /Ice Sheet under different climate conditions during the last 12 myrs (Naish et al., 2005).

By means of a multi-sensor core logger whole-core physical properties were measured on-site for the AND-1B sediment core in order to gain information about variations in the depositional system. The detected parameters cannot only be used for initial core characterization, but also provide a high-resolution tool for defining and interpreting stratigraphical patterns, such as a comparison between lithology and sequences which is especially interesting for rhythmic diatomite-diamictite intervals. Regular standard logging provided control over instrument performance over the whole working period.

Methods

General settings and data processing

Physical properties measurements at the drill-site laboratory included non-destructive, near-continuous determinations of wet-bulk density (WBD), P-wave velocity (Vp), non-contact electrical resistivity (NCR) and magnetic susceptibility (MS) at 1 to 4 cm intervals depending on type of core (mud or rock) and rate of core recovery. The Multi-Sensor Core Logger (MSCL, GEOTEK Ltd., UK) was used to measure core temperature, core diameter, P-wave travel time, gamma-ray attenuation, electrical conduction and MS. The cores were logged in liners or on plastic carriers (half-liners). The MSCL had two central sections holding Vp and gamma sensors. The orientation of the P-wave and gamma sensors was horizontal for cores logged in liners and vertical for cores logged on carriers. Except for shorter coring runs, data were logged in continuous intervals of 3 to 18 m (usually 6 m) long core sections.

For each of these runs calibration sections were logged to calibrate and/or monitor data quality of core diameter, density, Vp and NCR. Also an empty plastic tube of 0.2 m length was logged to obtain levels of drift of MS and NCR sensors at the end of a logging run. Prior to logging, cores on carriers were described with respect to occurrence of cracks, fractures, unconsolidated or crumbly materials, which influence physical property data.

MS was measured in terms of SI units, using Bartington MS-2 meter loop sensors of 80 mm or 100 mm internal diameter. A sensor-specific correction was applied to the data, which accounts for geometrical differences between the diameter of the core and the diameter of the loop sensor as outlined in the GEOTEK MSCL Manual (2000).

Velocity was measured using two different types of transducers. Cores in liners were logged with standard GEOTEK piston transducers in horizontal orientation. Acoustic coupling between transducers and liner was encouraged by water. For cores on carriers, Acoustic Rolling Contact Transducers (ARC, GEOTEK Ltd., UK) were used. These transducers were rolling along the top of the core (upper transducer) and the bottom outside of the carrier (lower transducer), respectively. Whole-core P-wave velocities were calculated from the core diameter and travel time after subtraction of the P-wave travel time through the core carrier (or core liner) wall, transducers, electronic delay, and detection offset between the first arrival and second zero-crossing of the received waveform (P-wave Travel Time Offset (PTO)), where the travel time can be best detected. This travel-time offset was determined using cylindrical plastic standards of PQ, NQ and HQ core size of known velocities (2330 ms^{-1} and 2382 ms^{-1} for PQ and HQ, NQ, respectively). For PQ-core in liner a liner filled with water was used to calibrate velocity. P-wave velocities (Vp) were normalized to 20°C using the temperature logs detected by a calibrated infrared sensor.

WBD was determined from attenuation of a gamma-ray beam transmitted from a radioactive source (^{137}Cs). A beam collimator of 2.5 mm was used and the beam was focused through the core-centre into a gamma detector. To calculate density from gamma counts, GEOTEK MSCL software was used (www.geotek.co.uk), which applies a 2nd order polynomial function to describe the relationship between the natural logarithm of gamma counts per second and the product of density and thickness of the measured material. For calibration the three constants of the equation are determined empirically for each run by logging a standard core consisting of different proportions of aluminum and water as described in Best & Gunn (1999). For PQ-liner a set of aluminum plates of different thickness was used placed in a liner filled with water. At the end of each PQ, HQ and NQ core-logging run, a whole plastic core-size cylinder and an aluminum cylinder were logged with an outside diameter of the core and two cylindrical chambers of different volume inside filled with water plus a whole aluminum cylinder. For cores logged on carriers this is the only way to ensure the different gamma-ray absorption coefficients of solid material (minerals or aluminum) and water (pore space) are considered for calibration (Weber et al., 1997). For data-quality control the same plastic cylinder as at the end of each run was logged as initial calibration piece at the beginning of the run. According to the formula given in the GEOTEK Manual (2000) fractional porosity was calculated from the WBD accounting for constant grain density (2.7 g cm^{-3}) and pore-water density (1.03 g cm^{-3}).

For the first time the AWI-MSCL was equipped with a GEOTEK non-contact electrical resistivity sensor (NCR). Since it is a relatively new product, work needs to be done to understand the behavior it. For this reason, no resistivity data will be presented in this abstract.

Density and velocity logs were processed from the raw data using GEOTEK software. From there the data were exported to a spreadsheet and corrected for depth below sea floor. WBD, Vp and MS data were cleaned for odd data points related to core destruction (naturally or coring induced, gaps on carriers or between carriers) or obvious malfunction of accurate MSCL data acquisition. At levels of low MS, sensor drift corrections were applied where appropriate in order to clean negative values from the data. Calculation of fractural porosity and correction of MS were carried out after cleaning the data.

Off-ice corrections and data quality control with regard to down-core behavior of standards

Vp and WBD data of all calibration and control pieces were compiled, divided into the different core diameters from PQ liner to NQ, statistically analyzed and compared to the known reference values. Generally, the standard deviation is low and the mean for the standards fits very well to the respective reference values. Minor corrections were applied to the Vp data due to differences in measured and corrected PTO and a larger correction to the density data of HQ core size due to the circumstance that air was sucked into the aluminum cylinder falsifying detected densities for the calibration standard (Niessen et al., in press).

Monitoring the behavior of the standards over the whole logging period down-core is essential to insure that the data of the standards are free from any systematic offset between the four different drilling diameters as such offset would also be present in the core data. Standard values vary in a certain range down-core but do not show a general trend, which indicates that the core data have no offset in the record related to core diameter. By comparison with the total range in sediment parameter values of both Vp and density it becomes evident that the fluctuation of standard data points is negligibly small (less than +/- 1.5 % from mean value in both density and Vp).

Preliminary Results & Discussion

Overview description of the AND-1B physical properties record

In order to give an overview of the physical properties of the entire core, density, velocity and MS data were smoothed over 50 data points. In this data the effect of clasts causing higher density and velocity is included but, due to smoothing, single clasts are no longer visible in the graphs (Figure 1), unlike the original data.

Vp ranges from about 1460 ms^{-1} in mud and some mudstones to more than 7000 ms^{-1} in large single clasts. The distribution of Vp is slightly negative-skewed and bimodal. The former effect is mostly due to very high Vp measured in clasts of core size or bigger, which do not occur very frequently in the record. Some high velocities may also be related to cementation. The bimodality is related to the cyclic behavior of the core between mudstones and diatomites (low Vp) and the rest of the core including thick diamictites (higher velocities). There is an overall linear down-core gradient in Vp from about 1800 ms^{-1} at the top to 3200 ms^{-1} at the bottom of the core (Fig. 1). WBD ranges from about

1.4 g cm^{-3} and less in mudstones, diatomites and pumice to up to about 3.7 g cm^{-3} in large clasts. The distribution is bimodal for similar reasons as described for Vp. The positive tail is not so distinct as in Vp data. There is an overall down-core gradient in WBD from about 1.8 g cm^{-3} at the top to 2.3 g cm^{-3} at the bottom of the core (Fig. 1). MS resolved significant variability over four orders of magnitude. MS below 10 (10^{-5} SI) is frequently observed in diatomites and some large clasts (e.g. granite). MS data is mostly below 2000 (10^{-5} SI) but in volcanic clasts and volcanic rocks values can reach up to about 9000 (10^{-5} SI). Thus, the distribution is strongly negative-skewed and down-core data are plotted on a logarithmic scale. There are large MS fluctuations in the core but no significant overall down-core trend in the data (Fig. 1).

In most cases the changes in pattern of physical properties is in good agreement with the boundaries of the major stratigraphic units (LSU-1 to LSU-8, as defined in Krissek et al., in press). Remarkable features of LSU-1 are a steep down-core gradient to high densities of 2.2 g cm^{-3} at the bottom of the unit and relatively high velocities up to 3000 ms^{-1}. The unusual high values in these relatively young and shallow rocks suggest a combination of both subglacial overconsolidation and cementation. LSU-2 is very variable and shows densities, which are generally lower than those of the previous unit. Velocities, however, frequently reach very high values up to almost 3500 ms^{-1} in well-cemented units.

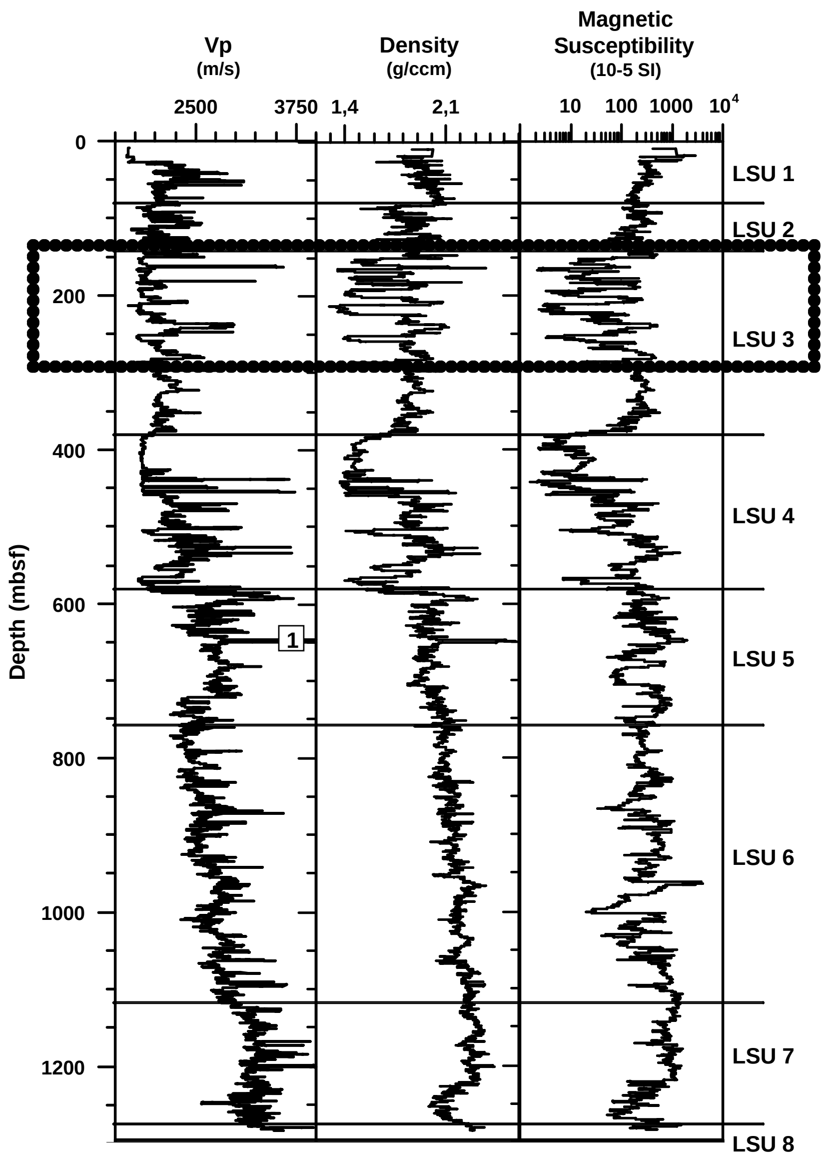

Figure 1. Summary logs of velocity, density and magnetic susceptibility (original data smoothed over 50 data points) over the whole length of the AND-1B core, subdivided into lithostratigraphic units (LSU) (see Krissek et al., in press, for details). Dashed box indicates interval of rhythmic diatomite-diamictite alternations as described in the text. Annotation (1) indicates that values are cut off for purposes of visualization. Original data reach peak velocities up to 5200 ms^{-1}.

The units LSU-3 and LSU-4 are remarkably cyclic. LSU-3 exhibits very low densities down to about 1.4 g cm^{-3} in the diatomites alternating with units of higher density of up to 2.4 g cm^{-3}, most of which are diamictites. In general, velocity is quite low, in particular in diatomites, with the exception of a few diamictes reaching velocities of up to 3500 ms^{-1}. The latter is likely to be related to cementation. MS is lower on average mostly caused by very low content of magnetic particles in diatomites. LSU-4 remains cyclic in density, velocity and MS with some spikes of increased density and velocity superimposed on the cycles. Since the spikes are most pronounced in velocity, once again cementation could have altered the rocks in some intervals more than in other intervals. MS exhibits a general trend from about 10 (10^{-5} SI) to 1000 (10^{-5} SI) towards the bottom of the unit.

At the top of LSU-5 the largest change in the general pattern of physical properties of the entire core is observed. One feature changing down-core is the much smaller amplitude in fluctuations or cycles in both density and velocity whereas MS maintains a more cyclic pattern down to the bottom of the core. The other feature is a sharp down-core onset to higher densities and velocities at the top of LSU-5. Also remarkable in LSU-5 is the phonolithic lava (646.49-649.3 mbsf), which is characterized by very high densities of 2.5 to 2.7 g cm^{-3} and velocities up to 5500 ms^{-1}. MS also increases in the lava to more than 4000 (10^{-5} SI). The boundary between LSU-5 and -6 is not correlated with major changes in the physical properties. A major decrease in density and MS and a small decrease in velocity are observed a few meters below the boundary between LSU-6 and LSU-7. A return to higher MS as well as velocities and densities is observed at the onset of LSU-8.

High-resolution analysis of fast-alternating sedimentary sequences from the upper part of the core

A distinct feature of the AND-1B core is the repeating sequences of diatomites and diamtictites in the upper half of the core (LSU3-4). This is especially prominent between 140-300 mbsf (see box with dashed line in Fig. 1) where about 8-9 rhythmic sequences of diatomite-diamictite packages can be identified in the physical properties (smoothed data considered in the following). Diatomite intervals are characterized by low Vp values around 1800 ms^{-1}, WBD minima around 1.4 g cm^{-3} and very low MS values up to 20 (10^{-5} SI). In contrast, diamictites represent the other end of the data range with very high Vp up to over 3500 ms^{-1} in single clasts and about 2500 ms^{-1} on average. WBD shows as well distinct broad peaks around 1.8-2.2 g cm^{-3} and MS displays values higher than one magnitude greater than the diatomites. An understanding of the pattern of the single sequences as well as the whole-core interval in conjunction with detailed lithological logs is necessary for drawing conclusions about environmental changes with regard to ice-shelf/ice-sheet extent. So far the data suggest Milankovich and sub-Milankovich forcing as possible control on system dynamics. However, there are difficulties in analyzing the cyclicity preserved in the record due to the occurrence of numerous glacial surfaces of erosion throughout the core.

Summary

In this extended abstract preliminary results of the physical properties data of the AND-1B sediment core are presented. Standard measurements prove the good quality of the collected data. Changes in the physical properties record meet almost all lithostratigraphic boundaries. The depth interval between 140-300 mbsf provides good possibilities for analyses of rhythmic changes in the environmental system.

Acknowledgements. I want to thank Catalina Gebhardt, Frank Rack, Gavin Dunbar and Trevor Williams for good collaboration at the drill site and for great responsibility during data collection assistance. Acknowledgements. The ANDRILL project is a multinational collaboration between the Antarctic Programmes of Germany, Italy, New Zealand and the United States. Antarctica New Zealand is the project operator, and has developed the drilling system in collaboration with Alex Pyne at Victoria University of Wellington and Webster Drilling and Enterprises Ltd. Antarctica New Zealand supported the drilling team at Scott Base and Raytheon Polar Services supported the Science team at McMurdo Station and the Crary Science and Engineering Laboratory. Scientific studies are jointly supported by the US National Science Foundation, NZ Foundation for Research, the Italian Antarctic Research Program, the German Science Foundation and the Alfred-Wegener-Institute.

References

Best, A. I. and D. E. Gunn (1999), Calibration of marine sediment core loggers for quantitative acoustic impedance studies, Marine Geology, 160, 137-146.

GEOTEK Manual (2000), Multi-Sensor Core Logger, Daventry, United Kingdom, www.geotek.co.uk.

Krissek, L.A., G. Browne, L. Carter, E. Cowan, G. Dunbar, R. McKay, T. Naish, R. Powell, J. Reed, and T. Wilch (in press), Sedimentology and Stratigraphy of the AND 001-001B Core, in Naish, T., et al. eds. Studies from the ANDRILL, McMurdo Ice Shelf Project, Antarctica. Initial Science Report on AND-1B. Terra Antarctica.

Naish, T., R. Powell, P. Barrett, H. Horgan, G. Dunbar, G. Wilson, R. Levy, N. Robinson, L. Carter, A. Pyne, F. Niessen, S. Bannister, N. Balfour, D. Damaske, S. Henrys, P. Kyle, and T. Wilson (2005), ANDRILL McMurdo Ice Shelf Project, Scientific Prospectus, ANDRILL Science Management Office, ANDRILL Contribution 4, University of Nebraska – Lincoln. Lincoln, NE.

Niessen, F., D. Magens, and A.C. Gebhardt (in press), Physical properties of the AND-1B core, ANDRILL McMurdo Ice Shelf Project, Antarctica, in Naish, T., et al. eds. Studies from the ANDRILL, McMurdo Ice Shelf Project, Antarctica. Initial Science Report on AND-1B, Terra Antarctica.

Weber, M. E., F. Niessen, G. Kuhn, and M. Wiedicke (1997), Calibration and application of marine sedimentary physical properties using a multi-sensor core logger, Marine Geology, 136, 151-172.