Magnetostratigraphy as a Tool to Date and Correlate Drilling Hole Sediments: Lake Baikal Essay

Vadim Kravchinsky*
University of Alberta, Edmonton, AB
vkrav@phys.ualberta.ca

Summary

Various magnetostratigraphic techniques were applied to date and correlate deep drilling sedimentary cores of the Lake Baikal with ages of 0.64 to 6.7 Ma. Geomagnetic polarity and excursion defining and correlation, magnetic susceptibility and relative paleointensity dating methods were used as independent tools and demonstrated substantial success. The result was compared between different cores and used to refine the age models of particular time intervals. Sediments with different sedimentation rates and limited absolute dating availability were correlated through the distances of a few meters to a few hundred kilometers. The techniques demonstrate enormous potential for the magnetostratigraphy use in various sedimentary sequences.

Introduction

Although magnetostratigraphy is a very useful tool to date and correlate sedimentary sequences and has been around for a few last decades, it is still not enough frequently used in the deep drilling exploration projects. At the same time any oceanic and continental drilling research project uses magnetostratigraphy as a leading method especially after new techniques have been progressively developed in the last decades. New reference continuous paleointensity curve was developed for last 2 Ma and a number of discontinues curves for older time periods additionally to the traditionally used polarity scale. Studying geomagnetic field excursions was applied to correlate sediments inside of the longer polarity intervals. Paleoclimatic studies proved a strong connection between earth orbital parameters (eccentricity, obliquity and precession) and petromagnetic parameter changes. The method was already used to date the sedimentary sequences.

Lake Baikal is the oldest and largest fresh water lake in the world with ~25 million year history. The sedimentary record of Baikal is also extremely long (up to 8 km) and continuous with sedimentation rates varying from 1 to 100 cm/kyr and therefore offers exciting opportunities to study magnetostratigraphy on a variety of temporal scales and resolutions.

All mentioned above magnetostratigraphic techniques were applied to date and correlate five different deep drilling cores (from 100 to 600 meters) for the Lake Baikal Deep Drilling Project (BDP) (Kravchinsky et al., 2003; Kravchinsky et al., 2007) and the results are extended and summarized in the present paper. Some cores were drilled close to each other, others separated for a few hundred km. The cores were various in ages and had different sedimentation rates.

Methods

More than 7200 samples were taken in small plastic boxes throughout the cores. The natural remanent magnetization (NRM) of all the samples was measured with a spinner magnetometer (JR-4) or a three-axis 2-G cryogenic magnetometer in the paleomagnetic laboratories of countries participated in the project (Canada, Russia, USA, Japan). Step-wise alternating field (AF) demagnetization of samples, up to 100 mT, was done to evaluate the primary remnant magnetization.

Low-field, whole-core magnetic susceptibility was measured at 3 cm intervals with a Bartington Instruments susceptibility meter generating an alternating field of 8 μT. A pass-through loop sensor operating at a frequency of 0.565 kHz allowed entire sections of core to be measured rapidly and nondestructively. In addition to the analysis of the natural remanence of the samples, anhysteretic (ARM) and isothermal (IRM) remanences for representative samples were also determined for mineral magnetic purposes and for estimating relative paleointensities.

Results

Chronological control was established by means of a few independent correlations. Matching the stable remanence directions to the standard geomagnetic polarity timescale (GPTS) provides a robust chronology from the present back to ~6.7 Ma. Excellent agreement in the magnetic inclination pattern enabled us to build the age model and establish the inter core correlation. Several short polarity zones were also observed (e.g. Jaramillo, Reunion etc.) in the record.

Matching the magnetic susceptibility and biogenic silica fluctuations to the oceanic oxygen isotope record (Shackleton et al., 1990) was used to date the last 2.5 million years. As shown in several earlier Lake Baikal studies, magnetic susceptibility has a strong inverse correlation with biogenic silica variations (Peck et al., 1994; Kravchinsky et al., 2003). Diatomaceous organisms that produce biogenic silica are more productive during warmer climatic conditions and the concentration of biogenic silica is thus higher in interglacial intervals than in the intervening colder glacial intervals. Because silica is diamagnetic it decreases the observed susceptibility values during relatively warm intervals and leads to the climate signal visible in Figure 1. A correlation is therefore expected between Lake Baikal magnetic susceptibility and oceanic oxygen isotope records. The BDP-96 and BDP-98 magnetic and biosilica data (Williams et al, 1997; Kravchinsky et al., 2003) and the ODP-677 (Shackleton et al., 1990) indicate that this is indeed the case. The magnetic susceptibility signal appears to be more detailed than the biogenic silica record because the dilution by biogenic silica is not the only factor able to affect the magnetic susceptibility variations. Peck et al. (1994) demonstrated that relatively cold intervals in the Lake Baikal sediments are characterized by higher concentrations of clay and magnetic minerals, high coercivity minerals and larger magnetic grain size, higher density and sedimentation rates and lower biogenic silica accumulation. Although magnetic susceptibility mirrors the biogenic silica content for the main features (when sedimentary sequences have high resolution), details of the drilling sections are still slightly better pronounced in the susceptibility record.

The relative paleointensity profiles were compared to the SINT-800 global reference intensity curve of Guyodo and Valet (1999) in order to independentely verify the magnetic susceptibility age model (Kravchinsky et al., 2007). The paleointensity record, although less detailed, correlates also well with known records from the Lake Baikal in terms of the main features.

Geomagnetic excursion correlation for the better-known Brunhes chron was also used as another independent dating tool (Kravchinsky et al., 2007). Stable remanence vectors were almost all of normal polarity. The few exceptions comprise brief intervals of low and/or negative inclinations which represent geomagnetic excursions. But these are far less numerous than the high sedimentation rate would lead one to expect. Four of them that can be promptly matched to the global pattern are the Laschamp, the Albuquerque, the Iceland Basin, and perhaps the West Eifel excursions which occurred at ~38,000, ~146,000, at 180,000 to 190,000, and at 480,000 to 495,000 years ago, respectively.

Spectral analysis of the resulting susceptibility and biosilica time series reveals the presence of Milankovitch signals at ~100 kyr (eccentrisity), ~41 kyr (obliquity) and ~20 kyr (precession) that gives one an independent validation of the age model and correlation in the different drilling cores.

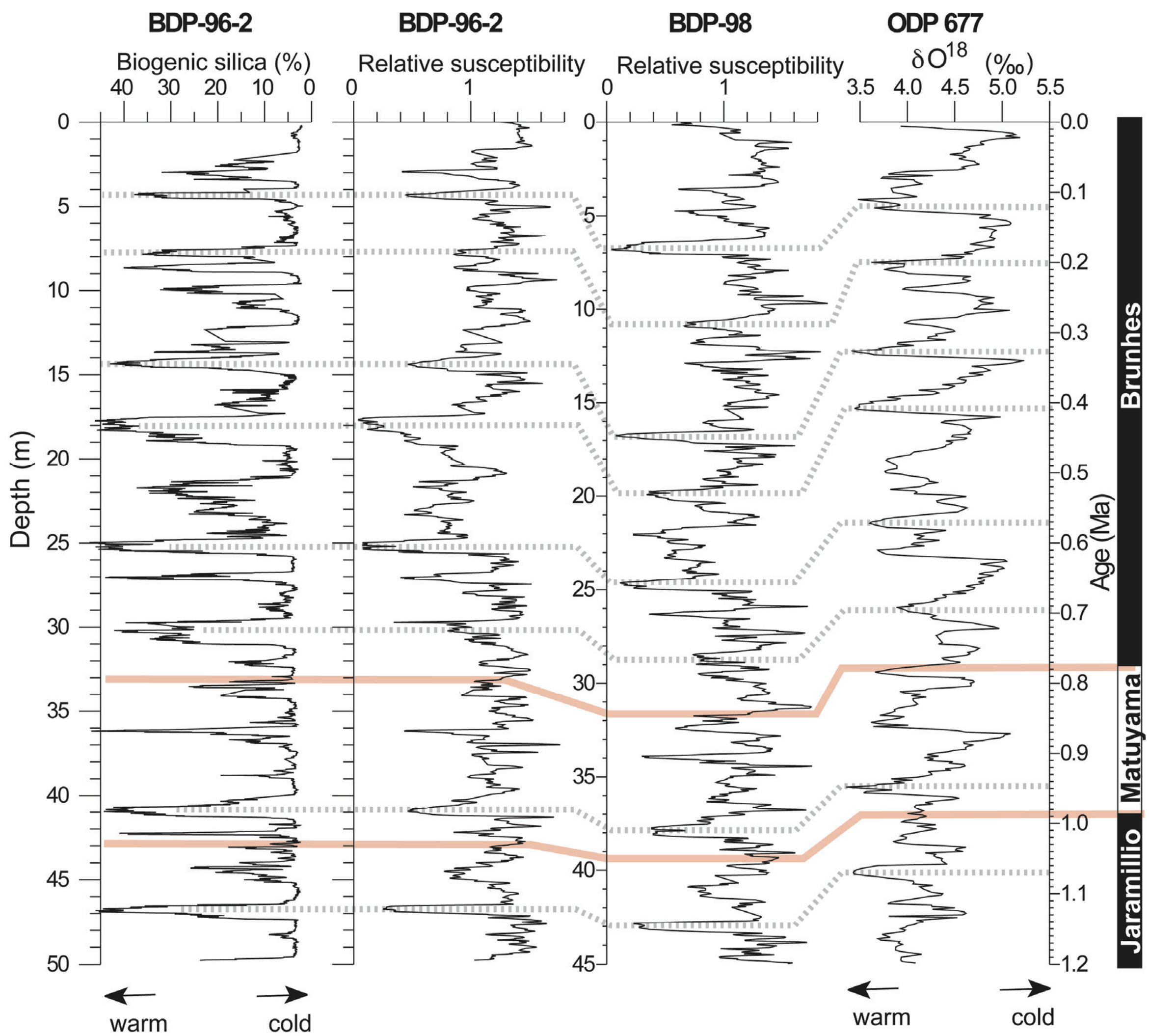

Figure1: Correlation between magnetic susceptibility profile from hole BDP-98 (Kravchinsky et al., 2003), biogenic silica (Williams et al., 1997) and magnetic susceptibility (Krainov et al., 2001) for hole BDP-96-2, oxygen isotope data from ODP-677 (Shackleton et al., 1990) and the geomagnetic polarity scale (Cande and Kent, 1995). Biogenic silica values are given in weight %. Susceptibilities are plotted on a logarithmic scale. Solid lines illustrate polarity correlation, dashed lines illustrate paleoclimatic correlation.

Conclusions

Various magnetostratigraphic techniques were applied to date and correlate five deep drilling sedimentary cores. Although every method has its own limitation, mostly because of the absence of the reference continues curves, all of techniques were applied successfully in the Lake Baikal study. Matching to the geomagnetic polarity scales was applied for 6.7 Myr. Magnetic susceptibility was correlated to the oceanic oxygen isotope record for last ~2.5 Myr based on the early studies that demonstrated that the suceptibility variations reflect the orbital parameter changes and correspond to the Milankovitch periodicities. Relative paleointensity and geomagnetic excursions were used to refine age model for the normal polarity Brunhes chron. Analogous approach can be largely used for numerous sedimentary sequences in order to date and correlate different stratigraphic sections. Described here geomagnetic parameter variations have global nature and can be as well applied for correlation of very distant cross-sections and drilling cores.

Acknowledgements

I would like to acknowledge all my colleagues who participated in the project with me, especially my long-term collaborators: M.E. Evans, T. Kawai, J.W. King, M.A. Krainov, M.I. Kuzmin, J.A. Peck, H. Sakai and D.F. Williams.

References

Cande, S.C., and Kent, D.V., 1995, Revised calibration of the geomagnetic polarity time scale for the late Cretaceous and Cenozoic, Journal of Geophysical Research, **100**, 6093–6095.

Guyodo, Y., and Valet, J.-P., 1999, Global changes in intensity of the Earth's magnetic field during past 800 kyr. Nature, **399**, 249-252.

Krainov, M.A., Kravchinsky, V.A., Peck, J.A., Sakai, H., King, J.W., and Kuzmin, M.I., 2001, Paleoclimate record of the Lake Baikal sediments with magnetic susceptibility studying result, Russian Geology and Geophysics, **42** (1-2), 87–97. In Russian.

Kravchinsky, V.A., Krainov, M.A., Evans M.E., Peck, J.A., King, J.W., Kuzmin, M.I., Sakai, H., Kawai, T., and Williams, D., 2003, Magnetic record of Lake Baikal sediments: chronological and paleoclimatic implication for the last 6.7 Myr. Palaeogeography, Palaeoclimatology, Palaeoecology, **195**, 281–298.

Kravchinsky, V.A., M.E. Evans, J.A. Peck, H. Sakai, M.A. Krainov, J.W. King, and M.I. Kuzmin, 2007, A 640 kyr geomagnetic and paleoclimatic record from Lake Baikal sediments. Geophysical Journal International, **170** (1), 101–116.

Peck, J.A., King, J.W., Colman, S.M., and Kravchinsky, V.A, 1994, A rock-magnetic record from Lake Baikal, Siberia: evidence for Late Quaternary climate change. Earth Planet. Science Letters, **122**, 221–238.

Shackleton, N.J., Berger, A., and Peltier, W.R, 1990, An alternative astronomical calibration of the lower Pleistocene timescale based on ODP Site 677. Trans. Roy. Soc. Edinburgh: Earth Sciences, **81**, 251–261.

Williams, D.F., Peck, J.A., Karabanov, E.B., Prokopenko, A.A., Kravchinsky, V.A., King, J.W., Kuzmin, M.I., 1997, Lake Baikal. Record of continental climate response to orbital insolation during the past 5 million years. Science, **278**, 1114–1117.