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Short reversals of the earth's magnetic field and its relative paleointensity variations as chronostratigraphic tools – perspectives and limitations

NORBERT R. NOWACZYK
GeoForschungsZentrum Potsdam, Projektbereich 3.3
"Sedimente und Beckenbildung" – Laboratory for Paleo- and Rock
Magnetism, Telegrafenberg Haus C, 14473 Potsdam, Germany
e-mail: nowa@gfz-potsdam.de

Abstract: Geomagnetic variations in direction as well as in intensity throughout the geologic history as documented in the remanent magnetization of sediment successions generally offer a potential (the investigations are performed in correlation) for dating of these sediments. Therefore, magnetostratigraphic investigations are performed in order to monitor geomagnetic fluctuations and to correlate them to established reference datasets such as the geomagnetic polarity time scale. The last major reversal of the earth's magnetic field occured at about 780 ka. Since then, a quite large number of so-called reversal excursions with a duration of a few thousand years interrupted the normal polarity phase of the geomagnetic field, known as the 'Brunhes Chron', about each 50 to 100 kyr. According to absolute as well as relative paleointensity determinations the field intensity throughout the Brunhes Chron was not constant but variable at least within the range of one order of magnitude. Especially reversal excursions, as expressed by magnetization directions differing largely from the expected dipole direction for a certain site, are associated with pronounced lows in the field intensity. So, in principle, determination of the sediment's magnetization in terms of direction and intensity of time-calibrated curves can provide a detailed age model of (late) Quaternary sediments.

Key words: paleomagnetism, geomagnetic excursions, paleointensity fluctuations, time scales.

Introduction

Modern geomagnetic polarity time scales generally still postulate a continuous normal polarity for the Brunhes Chron with only one interval of reversed polarity at 493–504 ka (Cande & Kent 1995). However, more geomagnetic events or ’reversal excursions’ than this are reported in the literature. Recent syntheses concerning ages and duration of these short-term geomagnetic features (Løvlie 1989a, b; Nowaczyk *et al.* 1994; Langereis *et al.* 1997; Lund *et al.* 1998; Gubbins 1999) indicate, that the geodynamo went into unstable states much more frequently. However, only a few types of sediments are able to record the directional changes related to these geomagnetic events since most of Brunhes age sediments do not show any evidence for non-normal directions.

Sediments are also frequently investigated in terms of geomagnetic paleointensity variations, because their magnetization intensity is not only proportional to the concentration of magnetic particles, but also to their degree of alignment within the ambient geomagnetic field. So, in principle, by normalizing the intensity of the natural remanent magnetization (NRM) by concentration-related parameteres such as magnetic susceptibility, anhysteretic (ARM) and isothermal (IRM) remanent magnetization, the obtained record mainly should reflect the variations of the geomagnetic field strength (e.g. Tauxe 1993). A rising number of relative paleointensity records from all over the globe now give a more and more consistent image of intensity changes of the geomagnetic field during the Brunhes Chron (Guyodo & Valet 1999). Large intensity fluctuations with lows coinciding with geomagnetic reversal excursions events offer a great potential for a detailed correlative dating of late Quaternary sediments.

Methods

After depth-dependent sampling of a sediment section/core the natural remanent magnetization (NRM) of the resulting sample collection is subjected to several paleo- and rock magnetic procedures. After measurement of the NRM, the samples are stepwise demagnetized (with measurements of the remaining magnetizations in between) in order to eliminate subsequently acquired viscous magnetizations (Fig. 1). The demagnetization results are then subjected to principle component analysis (Kirschvink 1980) in order to determine the primary or ‘characteristic remanent magnetization’ (ChRM), which is assumed to represent the local magnetic field vector during time of deposition of the sediment. Then, artificial magnetizations are induced or imprinted in order to determine the concentration and granulometric properties of the remanence carrying minerals. These results are also necessary for estimation of the relative paleointensity variations documented in the magnetization of the investigated sediments. Ideally, a sediment sequence investigated for paleointensity variations should show minimum variations in concentration as well as grain size of the remanence

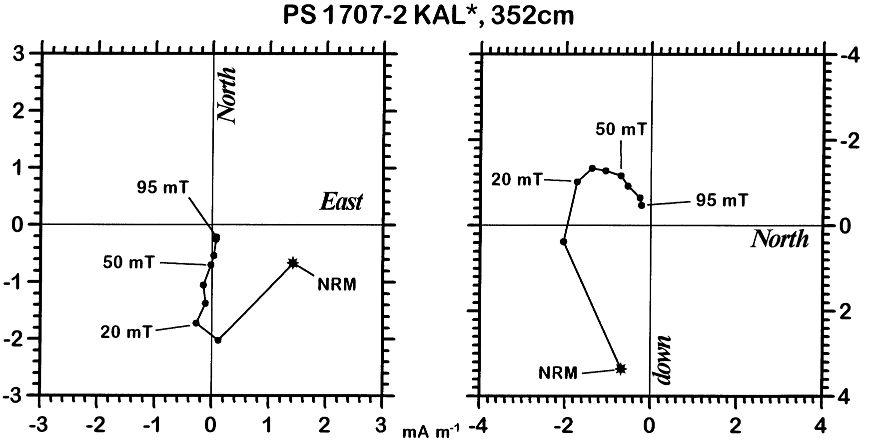

Fig. 1. Demagnetization behavior of a sample from sediments deposited in the Greenland Basin during the Laschamp geomagnetic reversal excursion at about 35 ka (after Nowaczyk 1997). Projection of the orthogonal magnetization components in absolute coordinates (mA m^{-1}). The primary direction, upward and pointing to the south, is revealed after application of 50 mT and more.

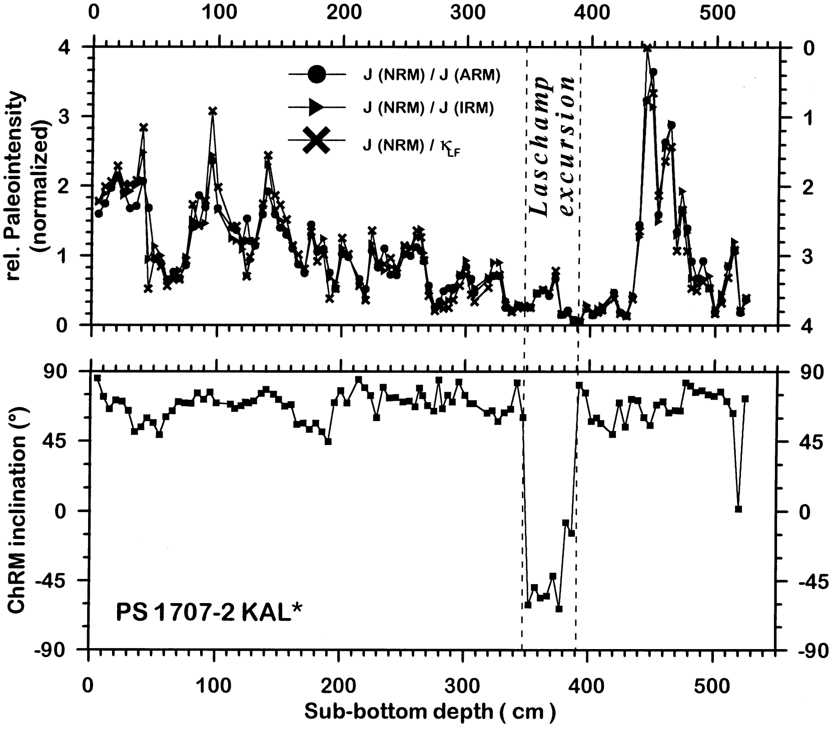

Fig. 2. Three different relative paleointensity estimates (normalized to mean) for a core from the Greenland Basin together with variations of the ChRM inclination (after Nowaczyk 1997). J(NRM) and J(ARM) measured after demagnetization with 50 mT.

carrying minerals, a condition rarely found in nature. Results from measurements of low field magnetic susceptibility (κ_{LF}), anhysteretic remanent magnetization (ARM), and isothermal remanent magnetization (IRM) are measures of the concentration. Normalizing the NRM intensity with these parameters should eliminate the influence of concentration variations on the NRM intensity, leaving variations mainly due to fluctuations of the geomagnetic field strength. All three methods of paleointensity estimations (NRM/ARM, NRM/IRM, and NRM/κ_{LF}) should yield more or less similar succesions of minima and maxima such as in Fig. 2, as an expression of geomagnetic field strength fluctuations (Tauxe 1993). However, paleointensity estimates might be biased by grain size variations of the magnetic phase, since the allignment of magnetic particles as well as the response to artificial fields during susceptibility measurements and ARM and IRM acquisition experiments, is grain-size dependent, fortunately in different ways. Therefore, calculation of different ratios of rock magnetic parameters such as ARM/IRM or ARM/κ_{LF} are used to estimate relative grain size variations. If these are large, paleointensity estimates have to be restricted to intervals with minimum variations, or paleointensity estimates have to be corrected for grain size variations, a procedure not well developed up to now.

Examples

Fig. 3 shows the high-resolution paleomagnetic record of a sediment core recovered from the Arctic Ocean, northeast of Svalbard. The mean sedimentation rate between 15 and 35 ka is about 18 cm/kyr. Sediments older than 35 ka were deposited at a rate of only 1.4 cm/kyr. Two, possibly three short reversal excursions are documented in the sediment's remanent magnetization. The intervals of reversed ChRM inclinations at 35 and 25 ka are the well known Laschamp and Mono Lake excursions, respectively (now dated to last from 40 to 41 ka; Channall *et al.* 2000; Laj *et al.* 2000). They are associated with pronounced lows in the relative paleointensity record. The single reversed sample at 19 ka, also linked to low intensities, might be an additional, previously unknown excursion (Nowaczyk & Knies 2000). The Arctic Ocean record can be correlated peak to peak to a paleointensity record from the North Atlantic, ODP Site 983 (Channell *et al.* 1997), but the dynamic range here is lower. Since the sedimentation rate before 35 ka is much lower than for the younger section, the resolution in the Arctic record is worse when compared to ODP Site 983 with a relatively constant rate of 10–12 cm/kyr. A longer paleomagnetic record from the Kolbeinsey Ridge area (Nowaczyk & Frederichs 1999) is shown in Fig. 4. Back to about 300 ka a succession of 10 reversal excursions are documented. Although the temporal resolution is low, the typical direction / intensity pattern again is obvious: Short directional excursions are linked to low paleointensities. Looking into detail, a slight intensity recovery can be seen for longer excursions such as

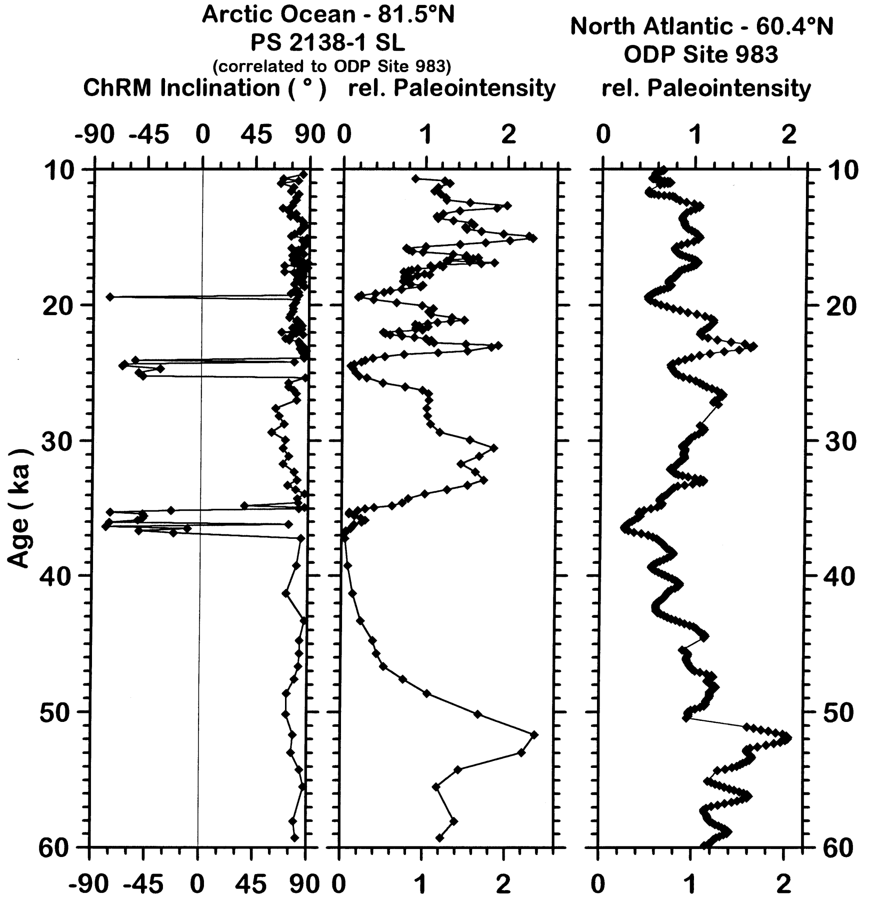

Fig. 3. High-resolution magnetostratigraphic record, ChRM inclination and relative paleointensity variations, of the time interval 10 to 50 ka drived from Core PS 21381 SL, Arctic Ocean (Nowaczyk & Knies 2000) correlated to paleointensity variations from North Atlantic, ODP Site 983 (after Channell *et al.* 1997).

for the Laschamp excursion (380 cm in Fig. 2, 35 ka in Fig. 3) or the Jamaica excursion at 180 ka and the Biwa II excursion at 280 ka (both Fig. 4).

Fig. 5 shows a tentative compilation of paleomagnetic results from the Brunhes Chron. Black (white) indicates normal (reversed) polarity. The paleointensity stack by Guyodo & Valet 1999 is plotted with the standard error. Especially for the time interval back to about 300 ka the dynamic behavior of the earth's magnetic field with several reversal excursions, all linked to low intensity, is quite impressive, and in a clear contrast to polarity time scales (e.g. Cande & Kent 1995). For older time windows the link between intensity lows and directional excursions of the magnetic field is less visible, but this is mainly due to uncertainties within the dating of the excursions.

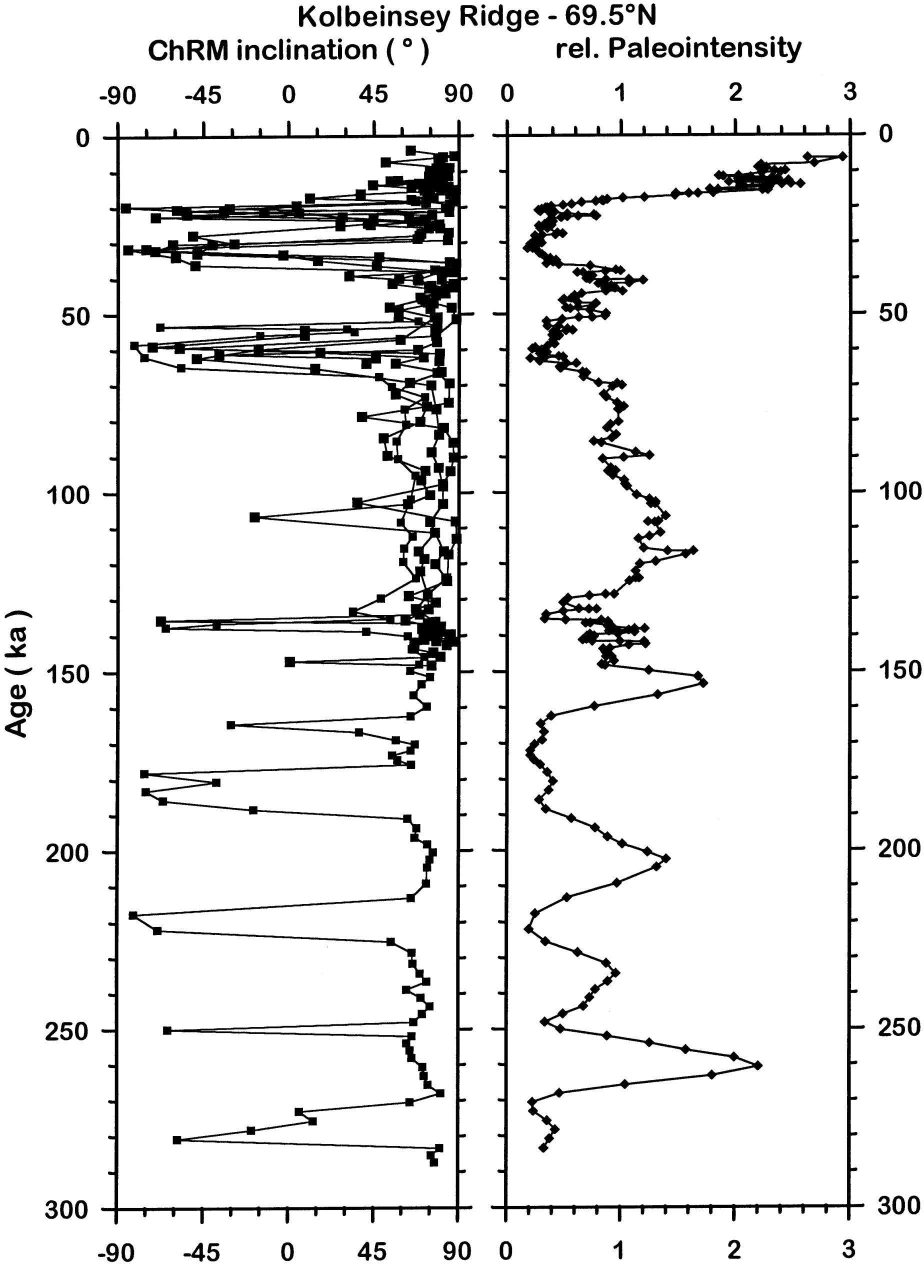

Fig. 4. Magnetostratigraphic records of five sediment cores from Kolbeinsey Ridge, Iceland Sea, ChRM inclination and relative paleointensity variations (adopted from Nowaczyk & Frederichs 1999).

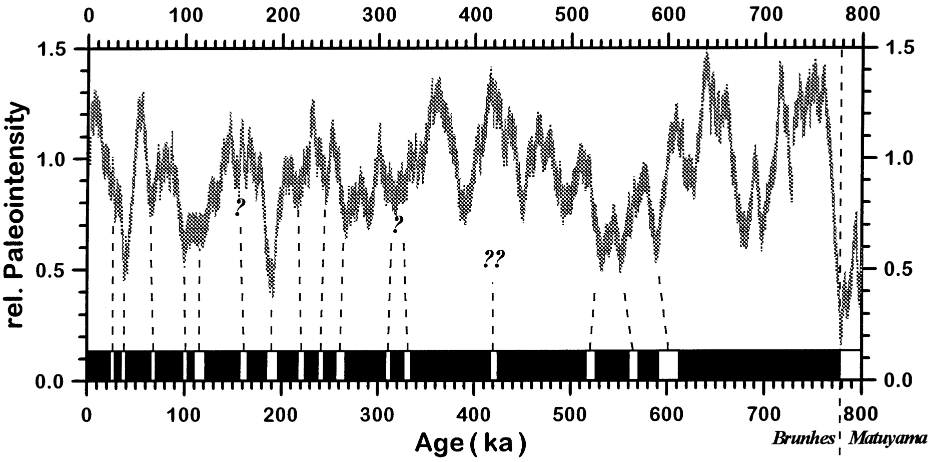

Fig. 5. Polarity excursions (white) within the Brunhes Chron (black) adopted from Langereis *et al.* (1997), Lund *et al.* (1998), Nowaczyk & Frederichs (1999), Nowaczyk & Knies (2000) combined with the SINT800 stack of relative paleointensity variations by Guyodo & Valet (1999). At least for the younger excursions with good age control a clear link to low intensities is quite obvious.

So, in principle, detailed magnetostratigraphic investigation of sediment successions can provide a fairly high resolution age model. However, the chronology of reversal excursions and stacking of well dated paleointensity records still have to be improved.

Summary

The earth's magnetic field throughout the Brunhes Chron was much more dynamic than thought before. Numerous reversal excursions interrupted the last 780 ka normal polarity phase, known as the Brunhes Chron. These reversal excursions are linked to pronounced lows in field strength. Since the degree of alignment of magnetic particles when traveling down to the sediment surface is propotional to the geomagnetic field, the intensity of the sediment magnetization is also an image of field amplitude fluctuations. When concentration and grain size variations of the magnetic phase is known from rock magnetic investigation, the geomagnetic relative paleointensity record can be extracted from the sediment magnetization intensity. Therefore, in principle, late Quaternary sediments might be correlatively dated by analysing their paleomagnetic signal for directional as well as intensity variations.

References

CANDE S. C. & KENT D. V., 1995: Revised calibration of the geomagnetic polarity timescale for the Late Cretaceous and Cenozoic. *J. Geophys. Res.*, 100B: 6093–6095.

CHANNELL J. E. T., HODELL D. A. & LEHMAN B., 1997: Relative geomagnetic paleointensity and $\delta^{18}O$ at ODP Site 983 (Gardar Rift, North Atlantic) since 350 ka. *Earth Planet. Sci. Lett.*, 153: 103–118.

CHANNELL J. E. T., STONER J. S., HODELL D. A. & CHARLES C. D., 2000: Geomagnetic paleointensity for the last 100 kyr from the sub-antartic South Atlantic: a tool for inter-hemispheric correlation. *Earth. planet. Sci. Lett.*, 175: 145–160.

GUBBINS D., 1999: The distinction between geomagnetic excursions and reversals. *Geophys. J. Int.*, 137: F1–F3.

GUYODO Y. & VALET J.-P., 1999: Global changes in intensity of the Earth's magnetic field during the past 800 kyr. *Nature*, 399: 249–252.

KIRSCHVINK J. L., 1980: The least-squares line and plane and the analysis of palaeomagnetic data. *Geophys. J. R. Astr. Soc.*, 62: 699–718.

LAJ C., KISSEL C., MAZAUD A., CHANNELL J. E. T. & BEER J., 2000: North Atlantic paleointensity stack since 75 ka (NAPIS-75) and the duration of the Laschamp event. *Phil. Trans. R. Soc. Lond.* A, 258: 1009–1025.

LANGEREIS C., DEKKERS M. J., DE LANGE G. J., PATERNE M. & VAN SANTVOORT P. J. M., 1997: Magnetostratigraphy and astronomical calibration of the last 1.1 Myr from an eastern Mediterranean piston core and dating of short events in the Brunhes. *Geophys. J. Int.*, 129: 75–94.

LØVLIE R., 1989a: Palaeomagnetic stratigraphy: a correlation method. *Quat. Int.*, 1: 129–149.

– 1989b: Palaeomagnetic excursions during the last interglacial/glacial cycle: a synthesis. *Quat. Int.*, 3/4: 5–11.

LUND S. P., ACTON G., HASTEDT M. & WLLIAMS T., 1998: Geomagnetic field excursions occurred often during the last million years. *EOS*, 79(14): 178–179.

NOWACZYK N. R., 1997: High-resolution magnetostratigraphy of four sediment cores from the Greenland Sea II – Rock magnetic and palaeointensity data. *Geophys. J. Int.*, 131: 325–334.

NOWACZYK N. R. & FREDERICHS T. W., 1999: Geomagnetic events and relative palaeointensity variations during the past 300 ka as recorded in Kolbeinsey Ridge sediments, Iceland Sea: indications for a strongly variable geomagnetic field. *Int. J. Earth. Sci.*, 88: 116–131.

NOWACZYK N. R., FREDERICHS T. W., EISENHAUER A. & GARD G., 1994: Magnetostratigraphic data from late Quaternary sediments from the Yermak Plateau, Arctic Ocean: Evidence for four geomagnetic polarity events within the last 170 ka of the Brunhes Chron. *Geophys. J. Int.*, 117: 453–471.

NOWACZYK N. R. & KNIES J., 2000: Magnetostratigraphic results from Eastern Arctic Ocean – AMS^{14}C ages and relative palaeointensity data of the Mono Lake and Laschamp geomagnetic reversal excursions. *Geophys. J. Int.*, 140: 185–197.

TAUXE L., 1993: Sedimentary records of relative paleointensity of the geomagnetic field: theory and practice. *Rev. Geophys.*, 31 (3): 319–354.