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Paleomagnetism of the Geulhemmerberg K/T boundary section, the Netherlands

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Abstract

Paleomagnetic samples of six clay layers from an interval containing the Cretaceous/Tertiary (K/T) boundary in the Geulhemmerberg cave show only normal polarities, contrary to the expected reversed directions. The unique preservation of the sediment makes it unlikely that the normal polarities are an overprint through weathering or that the acquisition of the remanence has been delayed by post-depositional diagenetic formation of magnetite. Possibly, the normal polarities are the result of a relatively short relaxation time of the magnetic minerals which would cause the magnetic domains to realign with the present-day field, a process which would occur without affecting the preservation.

Introduction

Upon the discovery in the Geulhemmerberg caves of clay layers close to the Cretaceous/Tertiary (K/T) boundary in the Maastrichtian type area, multidisciplinary research was started (see Brinkhuis and Smit, this issue) which included a paleomagnetic study of these layers. For this purpose, four to five oriented samples were taken from each clay layer in February 1994, by pushing 8 cm^3 perspex cylinders into grey-coloured and unweathered clay (Table 1). The cylinders were kept in a refrigerator to delay dehydration and oxydation until their measurement. In addition, we took two hand samples from the yellow-coloured calcarenites, one 50 cm (GHB 1), and the other 200 cm (GHB 2) below the lowermost clay layer (A1). In the laboratory, standard specimens were drilled from these hand samples. Paleomagnetic measurements included stepwise progressive alternating-field (af) demagnetisation in steps of 5 or 10 mT up to 60 mT. The natural remanent magnetisation (NRM) was measured with a 2G cryogenic magnetometer. Further, stepwise isothermal remanent magnetisations (IRM) were acquired in direct fields for one specimen from each clay layer to provide information on the rock magnetic characteristics of the clays.

Earlier studies have shown that the K/T boundary occurs in a reversed polarity zone which has been identified as Chron C29R, for instance in the Gubbio section in Italy (Alvarez et al. 1977). The magnetic polarity sequence in Gubbio has been proposed as the magnetostratigraphic reference section for the Late Cretaceous–Danian (Lowrie et al. 1982). According to the most recent geomagnetic polarity time scale (GPTS) of Cande and Kent (1995), Chron C29R ranges from 65.578 to 64.745 Ma, while a consensus is developing for an age of 65.0 Ma for the K/T boundary itself (Swisher et al. 1992). Hence, if the clay-bearing succession in the Geulhemmerberg cave indeed contains the K/T boundary, we would expect to find reversed polarity magnetisations.

Results

The demagnetisation results of the yellow-coloured calcarenites do not permit any reliable interpretation. The initial NRM intensities are low (20–30 μA/m) and the directions highly scattered (Figure 1a). The samples from the clay layers have been demagnetised in three series, each series consisting of one specimen per clay layer. The first series was demagnetised soon

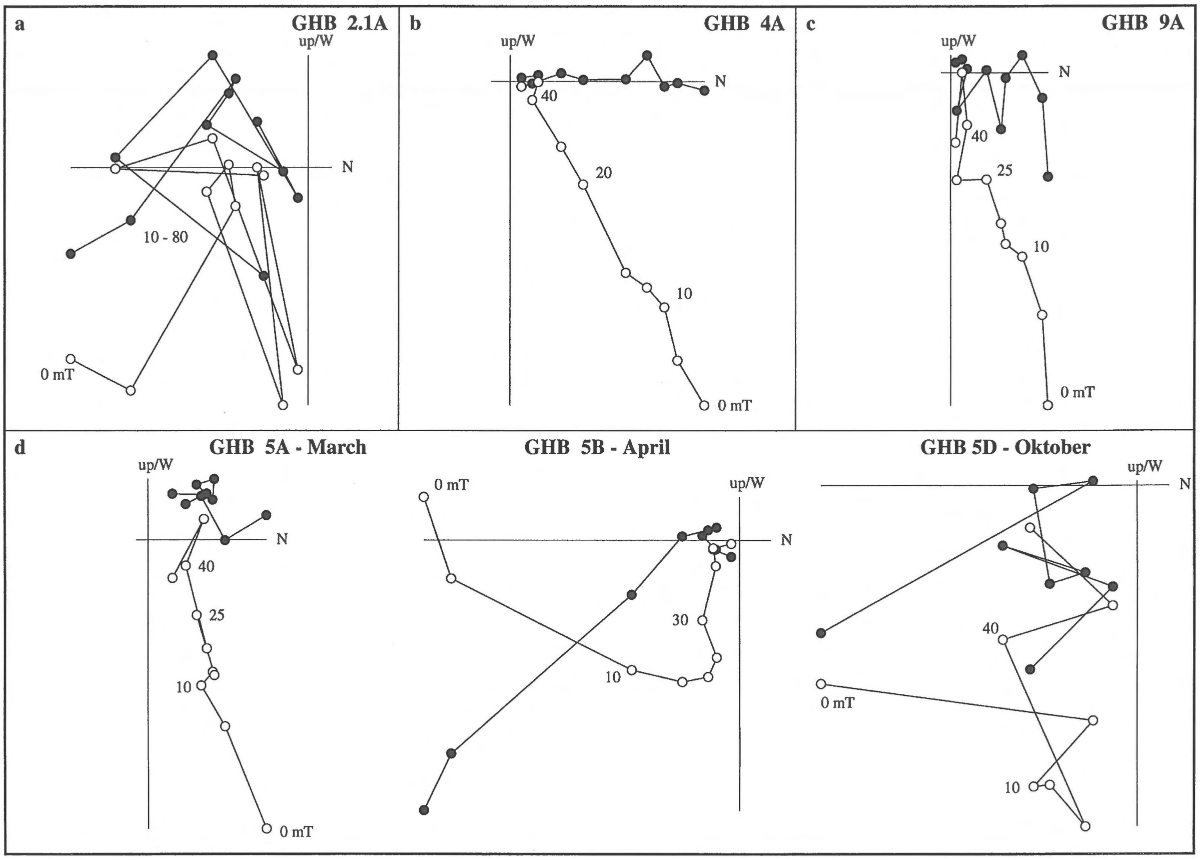

Figure 1. Alternating-field demagnetisation diagrams of samples from the Geulhemmerberg cave. Solid (open) symbols denote projection on the horizontal (vertical) plane; numbers refer to the alternating field in milliTesla (mT). Specimen GHB 2.1A (a) is taken from the yellow-coloured calcarenite below the clayey interval and shows only scattered directions, while specimens GHB 4A and GHB 9A were taken from unweathered clays and show a consistent normal polarity (b, c). Storage in the laboratory causes increased oxidation of the samples and the development of a high-intensity overprint (d).

Table 1. Paleomagnetic samples from the Geulhemmerberg clay-layers (GHB). For the stratigraphic position of the clay-layers A to G see Brinkhuis and Smit, this issue.

Samples	Clay layer
GHB 10 A–E	G
GHB 9 A–E	F
GHB 8 A–H	E
GHB 7 A–E	D
GHB 6 A–E	C
GHB 5 A–D	B
GHB 4 A–D	A2
GHB 3 A–D	A1

after sampling, in March 1994, when the samples were still fresh. The second series was treated in April and the third one in October of the same year. In the latter series, the samples were clearly dried out and showed signs of oxidation.

Typically, the first series shows the lowest initial NRM intensities, ranging from 20 to 200 μA/m, whereas the third series shows increased intensities of 200 to 500 μA/m. This suggests oxidation and the subsequent development of a new magnetic mineral phase. Although the fresh samples have very low intensities, the demagnetisation results are consistent and point to a normal polarity (Figure 1b, c), except for specimens GHB 6 and 10 which have extremely low intensities. A possible exception is perhaps GHB 7A (Figure 2) which shows a tendency to southerly declinations. Upon demagnetisation at low alternating fields most samples quickly approach the sensitivity level of the

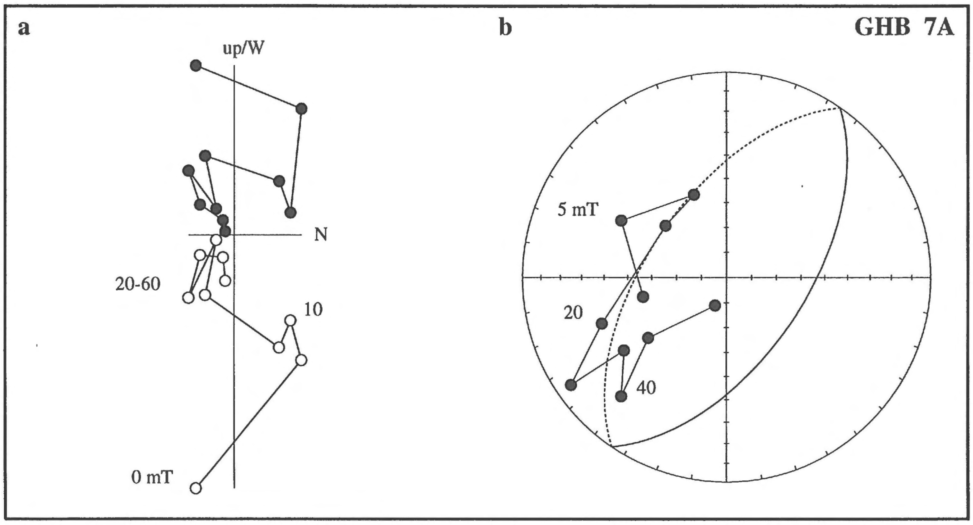

Figure 2. Alternating field demagnetisation of specimen GHB 7A, which shows a tendency to reversed directions, with southerly declinations (a), as can also be seen from the best-fitting great circle through the demagnetisation points (b).

magnetometer. The relatively low alternating fields of approximately 50 mT, needed to remove the magnetisation of the fresh samples (Figure 3), point to magnetite as the main magnetic mineral carrying the remanence in the fresh samples. The mean direction (declination D = 3.8 °, inclination I = 66.0 °, cone of confidence α_{95} = 4.6 °) of the samples from which a reliable characteristic remanent direction could be obtained (*N* = 7) is not significantly different from the expected late Cretaceous direction (D = 3.9 °, I = 56.6 °, α_{95} = 10.0 °; derived from Besse and Courtillot 1991) nor from the expected axial dipole direction (D = 0°, I = 67.9 °) at the Geulhemmerberg location.

The effect of drying, despite storage in a refrigerator, and subsequent oxidation can be seen, for example, in specimens from GHB 5 (Figure 1d). The first demagnetisation in March shows a normal polarity direction and low intensity (I_{NRM} = 60 μA/m), while in the second demagnetisation in April already a large overprint is seen, accompanied by higher initial intensity (I_{NRM} = 140 μA/m). In the last demagnetisation in October, the original direction is entirely overprinted and the intensity has even more increased (I_{NRM} = 410 μA/m).

IRM acquisition curves were measured between the second and third demagnetisation series after some oxidation had already occurred. The curves show a steep initial rise at relatively low fields of 100 to 200 mT, pointing to the presence of magnetite. At higher fields, there is still an increase in IRM, which indicates the presence of a high-coercivity mineral. The typical curved increase at higher fields suggests that the mineral responsible for this behaviour is goethite (cf. Lowrie and Heller 1982; Dekkers 1989a, b). In most cases, the increase at fields higher than 200 mT is small (20% for GHB 4C), but occasionally the increase is considerably larger (300% for GHB 8C; Figure 4). Possibly, this high-coercivity mineral is the result of low-temperature oxidation of clay minerals, for instance through iron adsorption onto clay mineral surfaces. This may lead to the formation of ferric nanophases in which parts are magnetic (Hirt et al., 1993). In the first (March) series, af demagnetisation does not show the presence of goethite, since the NRM is removed at relatively low fields and goethite is largely resistant to af demagnetisation, even at very high fields (Dekkers 1989a). In the third (October) series, however, several samples show a negligible decrease upon af demagnetisation (GHB 3D, Figure 3) which is indeed compatible with the presence of goethite.

The fact that alteration of the samples produces a new magnetic mineral, with often randomly scattered magnetisation directions, in a short time span of weeks or months strongly supports the primary origin of the magnetic minerals of the fresh samples. Within each clay layer both fresh (grey) and altered (tan, beige) colours occur and vary laterally. However, we sampled only the grey clays, and it is surprising how well these

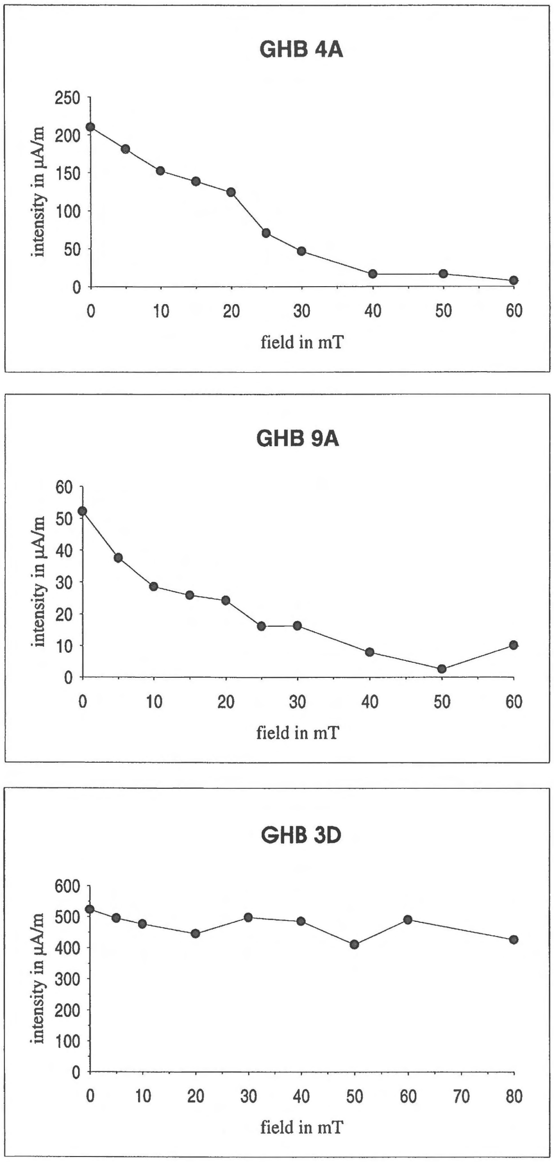

Figure 3. NRM decay curves of fresh specimens (GHB 4A, GHB 9A) show that the maximum unblocking coercivities are approximately 50 mT, in agreement with the presence of magnetite. After oxidation, however, the NRM is resistant to high alternating fields indicating that a high-coercivity mineral has formed (GHB 3D).

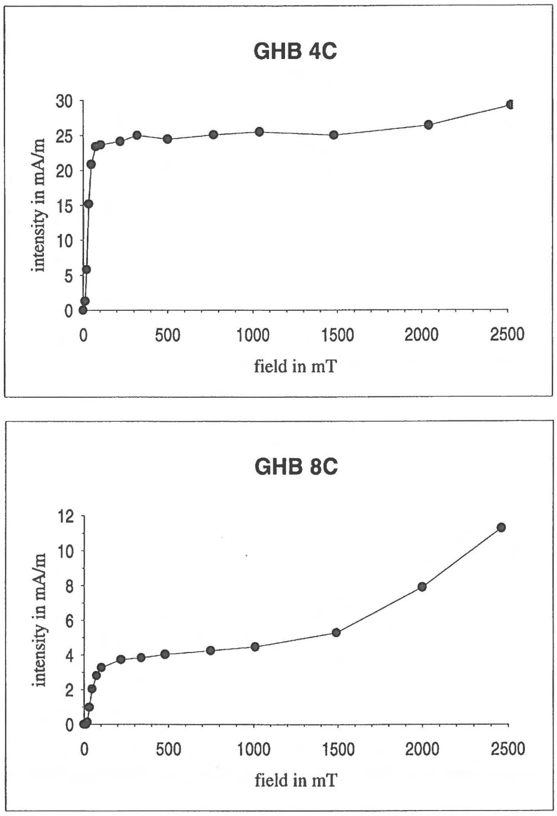

Figure 4. IRM acquisition curves of two clay specimens after some oxidation has occurred. The initial steep increase in fields up to 100–150 mT indicates that part of the IRM resides in magnetite. The curved increase at higher fields suggests the presence of goethite as the mineral formed upon oxidation.

clays are preserved and unaltered, possibly because of the favourable cave conditions of low temperature and high humidity.

The paleomagnetic results show that only consistent normal polarity directions occur in the clays. Considering the differences in magnetic properties between sampled and laboratory-stored specimens, we may exclude the possibility that this normal polarity is the result of a present-day normal overprint through weathering. This still leaves the possibility that the normal polarity has a 'near-primary' but post-depositional origin. Delayed NRM acquisition has been shown to occur in marine marls and clays, caused by early-diagenetic processes that produce magnetic minerals at some depth below the sediment–water interface (Van Hoof and Langereis 1991). This may happen, for instance, by remobilisation of ferrous iron in a reducing, anoxic environment, and subsequent precipitation of iron-oxides, including magnetite, if redox conditions become (sub)oxic again (Van Hoof et al. 1993; Dekkers et al. 1994). If the geomagnetic polarity changes during this timespan, the new polarity will be recorded by the magnetic minerals that are still being formed down to a certain depth, thus producing a delayed NRM with an apparent opposite polarity. This process typically occurs under cyclically changing redox conditions, and the resulting delay may be as much as 40–50 kyr (Van Hoof and Langereis 1991). Early diagenetic changes, however, can be virtually excluded in the case of the Geulhemmerberg clays, since the organic geochemical study of these clays shows the presence of ketones, indicating their excellent preservation (Yamamoto et al., this issue). Another process which may cause realignment of magnetic domains with the ambient present-day or recent magnetic field, is a relatively short relaxation time of the magnetic minerals carrying the remanence. Short relaxation times occur typically at the transition from ultra-fine superparamagnetic magnetite grains (instantaneous realignment) to single domain grains which are paleomagnetically stable, i.e. no significant realignment during geological times.

Conclusions

The paleomagnetic results show that only normal polarity magnetisations have been recorded in the grey clays of the Geulhemmerberg cave. On the basis of the rock magnetic properties it is argued that this normal polarity is not caused by weathering, and also that delayed acquisition of the NRM is unlikely because of the unique preservation of the clays and their constituents. It is more likely that short relaxation times of the magnetic minerals have caused realignment of the magnetic domains along the recent geomagnetic field.

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