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A palaeomagnetic study of Turonian carbonates from the southeastern Münsterland area, NW Germany

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Abstract. A palaeomagnetic study of Turonian carbonates from the southeastern Münsterland area, NW Germany (8°15′E/51°30′N) has been carried out. The initial intensities of natural remanent magnetization of 450 collected specimens range from 5×10^{-5} to 3×10^{-4} A/m. The main carriers of magnetization are magnetites or titanomagnetites. Most of the samples show a strong VRM overprint probably caused by multidomain magnetite grains. Specimens from only one out of five sampling sites yield a stable component which is believed to represent the Late Cretaceous geomagnetic field direction. The mean direction of this remanent magnetization after demagnetization is 17°/52° (declination/inclination). The corresponding Upper Cretaceous palaeopole position is located at 68°N/149°E ($\alpha_{95} = 5.3°$).

Key words: Palaeomagnetism – Carbonates – Turonian – Middle Europe – Viscous remanent magnetization

Introduction

Largely because of the very low intensity of magnetization in the Upper Cretaceous sediments of Middle Europe, only few palaeomagnetic pole determinations and no magnetostratigraphic data are currently available. Andreeva et al. (1965) carried out a palaeomagnetic study of rocks from the Bohemian Massif, CSSR, including samples of Upper Cretaceous age. However, the palaeopole position found in this study lies very close to the present geomagnetic pole and, therefore, may not be representative of the Late Cretaceous geomagnetic field. Heller and Channell (1979) sampled a number of sites in Upper Cretaceous rocks of the Münsterland area, NW Germany, and determined a reliable geomagnetic pole position.

The purpose of the present study of Turonian carbonates of the Münsterland basin, NW Germany, was to evaluate the suitability of these rocks for magnetostratigraphic work and to check the existence of a reversal within the Turonian as reported by Krumsiek (1982) from Turonian limestones of SW Morocco.

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Geological setting

The Upper Cretaceous rocks of the Münsterland area were deposited in a basin which was formed in Albian and Cenomanian times by subsidence of the northern part of the Rhenish Massif (Arnold, 1964). During the Albian, the sea transgressed into the central and eastern parts of the basin. The basal sediments in the southwestern part are of Cenomanian and Turonian age. According to Arnold (1964) and

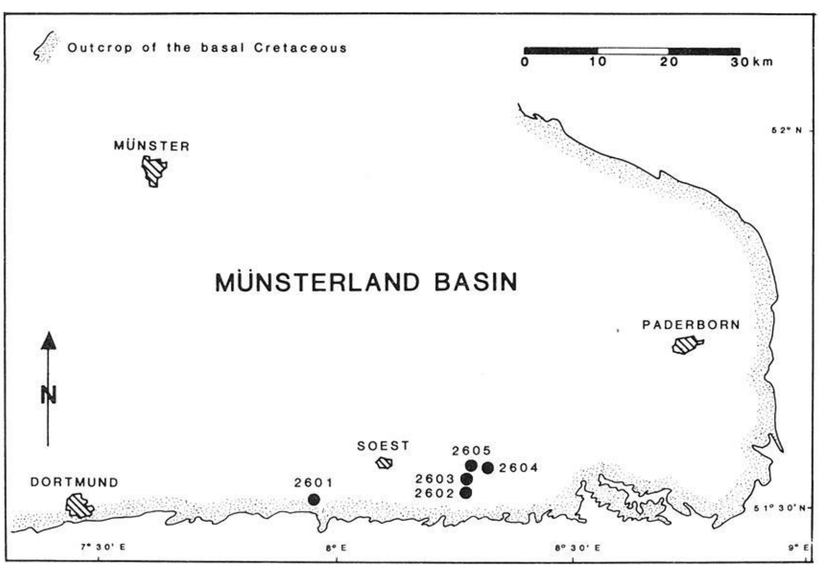

Fig. 1. Geological setting and location of sampling sites

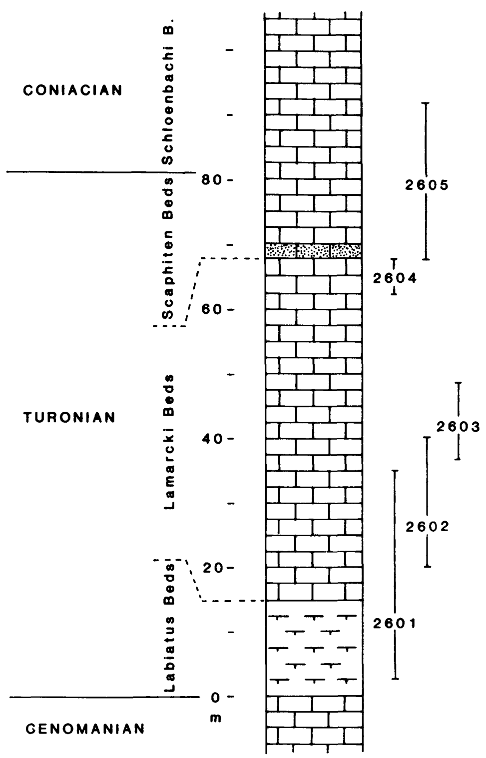

Fig. 2. Stratigraphy and stratigraphical extent of the sampling sites

Seibertz (1979a), the water depth during deposition of the Cretaceous sediments did not exceed 250 m.

A stratigraphically nearly complete section of Turonian carbonates in the southeastern Münsterland basin was sampled (Figs. 1 and 2). The total thickness of the Turonian sediments in this area is between 75 and 85 m.

The "Labiatus Beds" of Lower Turonian age comprise marls with nodular limestone layers. The "Lamarcki Beds" (Middle Turonian) are predominantly marly limestones. At the base of the "Scaphiten Beds" (Upper Turonian) a carbonaceous, glauconitic sandstone occurs, overlain be a sequence of marly limestones. These grade upwards into the "Schloenbachi Beds", which belong to the Coniacian (Seibertz, 1979b; Troeger, 1981).

The beds are tectonically undisturbed and dip northward at only 1°–2°, so that a bedding correction of the palaeomagnetic data was uneccessary and a fold test could not be applied. At five sites (2601–2605), 70 independently oriented samples were drilled, each sample consisting of at least six specimens. The total number of specimens used in the present study is 450.

Natural remanent magnetization (NRM)

The NRM of the specimens was measured with a UGF-4 spinner magnetometer (Geofysika, Brno, CSSR) at the Department of Geology, University of Bonn. NRM intensities were between 5×10^{-5} and 3×10^{-4} A/m.

In the specimens from sites 2601–2603 and 2605 a viscous remanent magnetization (VRM) dominated and no stable magnetization could be determined. At these sites the main VRM component is aligned with the present magnetic field at the sampling site, but this is partly overprinted by a component aquired in the laboratory field. Before measurement the cylindrical specimens were stored in an upright positition with their $+z$-axis downwards, but with randomly orientated x-axis. Since the inclination of the present magnetic field at Bonn is about 66°, the acquisition of a VRM in this field mainly resulted in a progressive increase in the component of magnetization along the z-axis. Due to different field orientations of the z-axis for each sample, the NRM vectors show a wide scatter of directions (Fig. 3). On an equal area projection the mean NRM vectors of all specimens of one sample lie on great circles passing through the direction of the present geomagnetic field at the sampling site and the z-axis for each sample (Fig. 4). Calculating the mean over all specimens of one sample averages out the component in the xy-plane. Furthermore, this component, due to the steep inclination angle of the laboratory field, is small in comparison to the component along the z-axis.

In marked contrast, the 44 specimens from site 2604 show a close grouping of the NRM vectors with a mean direction of 16°/53° (declination/inclination), $\alpha_{95} = 5.3°$ (Fig. 5).

Stability tests

Storage test

After the first NRM measurement the specimens were again stored in the laboratory for a period of between 2 and 4 weeks, before a second measurement of the specimens selected for demagnetization was carried out. By this procedure acquisition of a VRM aligned parallel to the $+z$-axis was identified, which continued in the specimens of sites 2601–2603 and 2605. After storage such a VRM could also be detected in specimens from site 2604, although the amount of this component was comparatively small.

Demagnetization experiments

Eighty selected specimens, at least one from each sample, were demagnetized by thermal or alternating field (AF) methods using a Schonstedt TSD-1 furnace and an AF demagnetizer developed in Bonn (Krumsiek, 1980, 1982). In some cases a combination of both methods was applied. Thus some specimens were thermally demagnetized up to 120° C to remove a component probably carried by goethite (Heller, 1978). Then demagnetization was continued using the AF method. Other specimens were thermally demagnetized up to 150° C, then AF demagnetized at 16 and 24 mT. After that, the specimens were further thermally demagnetized. This method can help to distinguish between hematite and magnetite as carries magnetization (Krumsiek, 1982).

As a criterion for the stability of the remanence vectors during demagnetization, the change of angle between successive demagnetization steps was calculated. Stability was considered to be good if the total change between three successive remanence vectors was less than 10°.

Sites 2601–2603, 2605. During AF demagnetization, the specimens showed a rapid initial decrease of intensity. Some specimens appeared to acquire a magnetization at fields higher than 24 mT (Fig. 6a). Since a two-axis tumbler was used, this magnetization is, most likely, a rotational remanent magnetization (Stephenson, 1976).

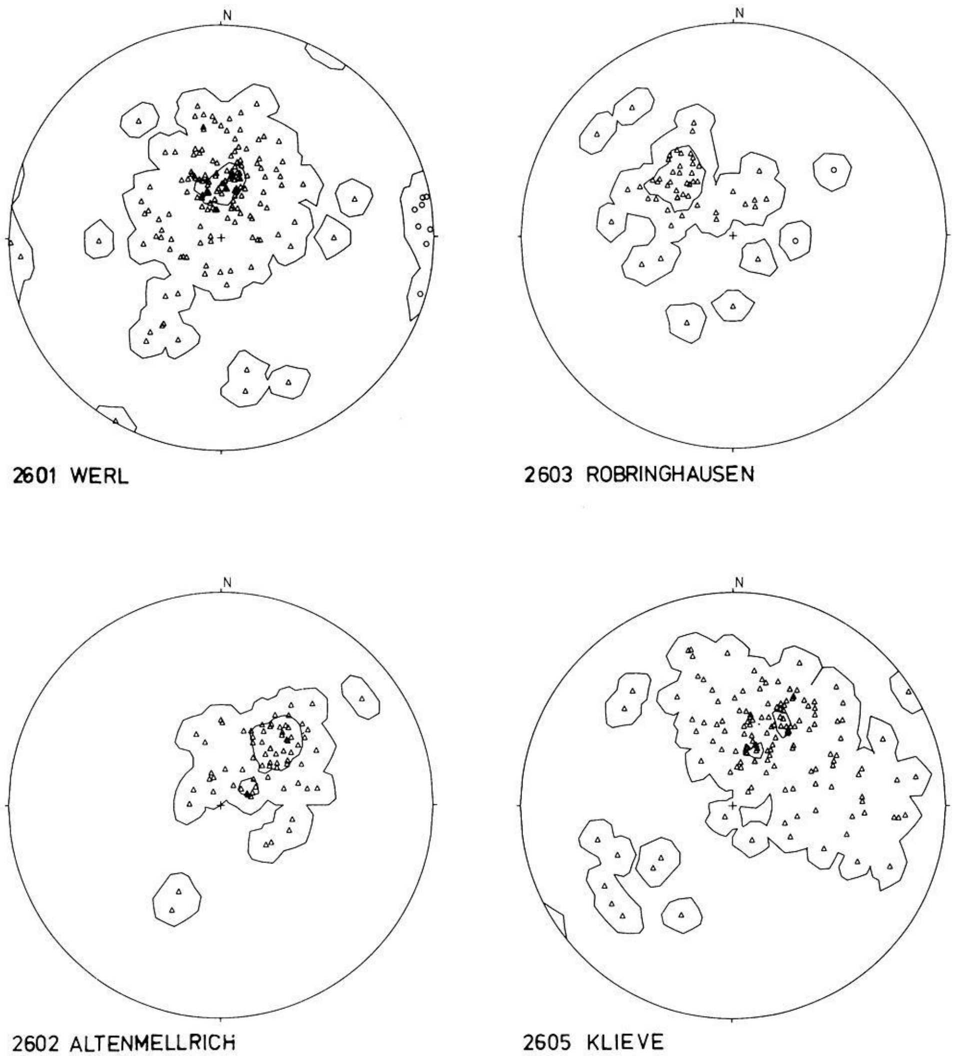

Fig. 3. NRM of all specimens from sites 2601–2603 and 2605. The vectors have been plotted with a Fortran program (Krumsiek and Siehl, 1976). The two lines are the 0% and 16% isolines of point density distribution. *Triangle:* Lower hemisphere, *circle:* Upper hemisphere. The vectors show a wide scatter which is due to a VRM overprint in the laboratory field. The overprint occurs mainly along the $+z$-axis of the samples. Site 2602 has been sampled at a west-facing exposure, so that the $+z$-axis of the specimens are pointing towards easterly directions. Site 2603 has been sampled at a mainly east-facing exposure. This results in a maximum of the NRM directional distribution to the east of north at site 2602 and to the west of north at site 2603. At sites 2601 and 2605 the sample orientation is variable resulting in a much larger scatter of NRM directions

During heating, the remanence intensity dropped at temperatures of 400° C. Above 250° C the specimens changed their colour from grey to red. Over 400° C a rapid increase of remanence intensity occurred (Fig. 6b), which is related to the formation of a new magnetic phase (see later) and its alignment in the very weak field of the furnace. Neither method revealed a stable remanance vector in the specimens of these sites and the change of angle between successive steps exceeded 10° for most of the specimens. Some specimens showed a decrease of the VRM component acquired in the laboratory field during demagnetization. This can clearly be seen by plotting the remanence vectors on an equal area projection (Fig. 6c). With increasing AF amplitudes or temperatures, the remanence vectors move towards the relatively more stable component aligned parallel to the present magnetic field at the sampling site. However, when the remanence vector after a particular demagnetization step was re-measured after 48 or 72 h, it moved back to a position nearer to the $+z$-axis, thus showing again the acquisition of VRM along the $+z$-axis during this time interval.

Site 2604. The behaviour of the remanence intensities during thermal demagnetization was similar to that of specimens from the other sites (Fig. 6d). However, the VRM component acquired during storage in the laboratory could be removed by heating up to 75° C. For all samples of site 2604 the $+z$-axis field orientation is nearly horizontal, so that an acquisition of a component along the $+z$-axis lowers the inclination angle of field-corrected data. In Fig. 6d it can clearly be seen that the inclination angle becomes steeper after the first thermal demagnetization step has been applied. Thus, this initial steepening of the inclination angle, which is typical for all demagnetized specimens

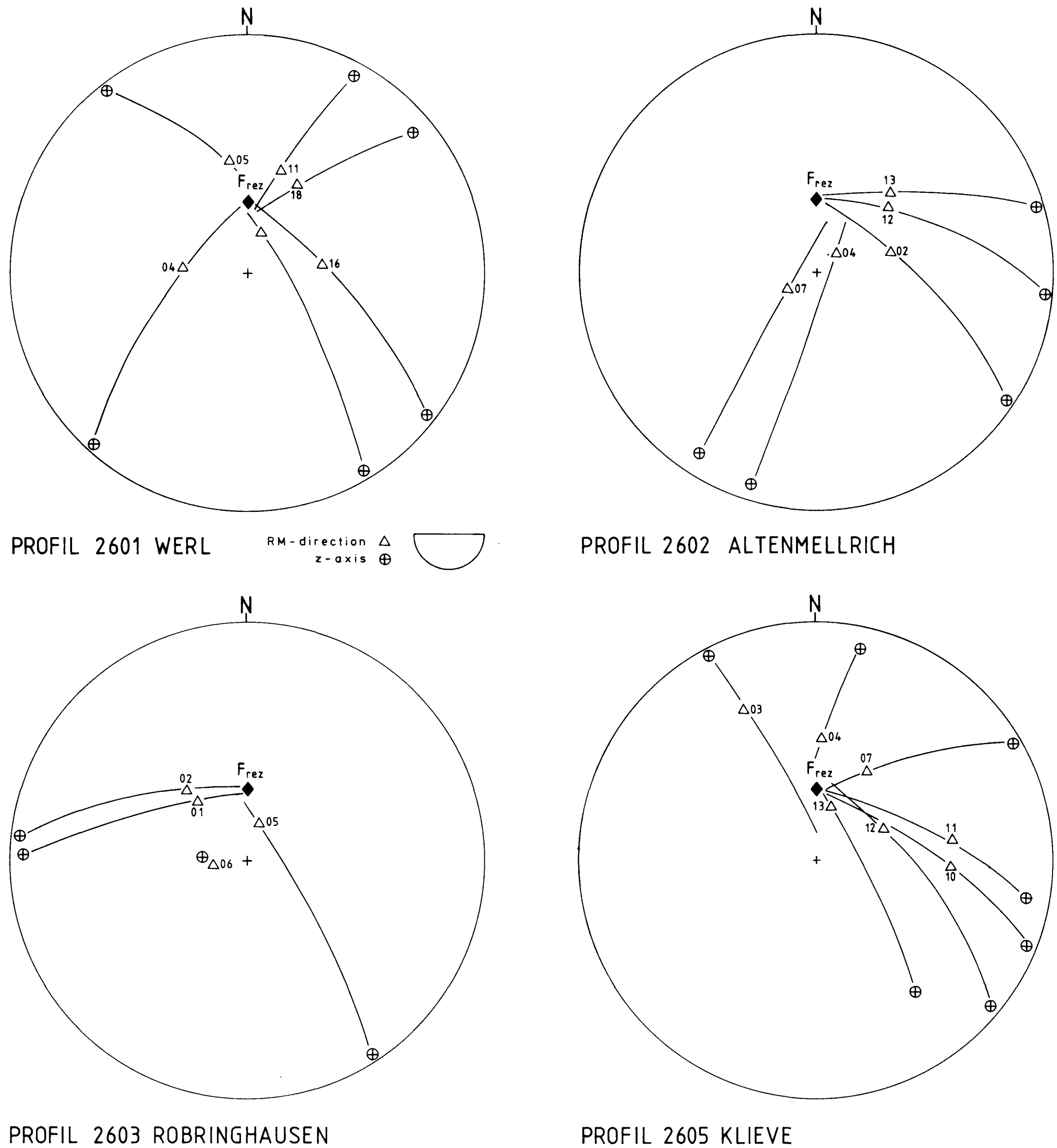

Fig. 4. Mean NRM vectors of all specimens of one sample for sites 2601–2603 and 2605, corresponding *z*-axes orientations and the present day field directions at the sampling sites. In each case, the three directions lie on great circles and therefore indicate a VRM acquired in the laboratory overprinting the VRM aligned with the present day field at the sampling site

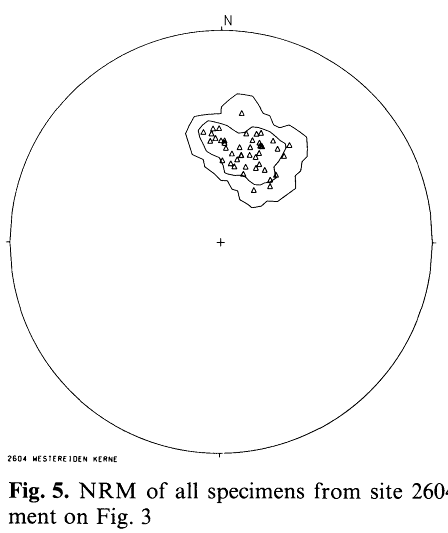

Fig. 5. NRM of all specimens from site 2604. *Symbols:* see comment on Fig. 3

of site 2604, is believed to represent the removal of the VRM acquired in the laboratory field.

Isothermal remanent magnetization (IRM)

Thirteen AF demagnetized or untreated and five thermally demagnetized specimens were subjected to IRM-acquisition experiments with a maximum field strength of 0.6 T. The thermally untreated specimens showed a strong initial increase of the remanence intensity in fields up to 0.1 T. Above 0.1 T the increase became very small and some specimens reached saturation magnetization in fields of about 0.2–0.3 T (Fig. 7a). Only specimen 260118 1 2, which has a reddish colour, showed a large component which did not saturate in fields up to 0.6 T.

After thermal demagnetization up to 500° C (50° C steps and 1 h heating-cooling cycle), the IRM intensities were 5–10 times higher than the values of the untreated speci-

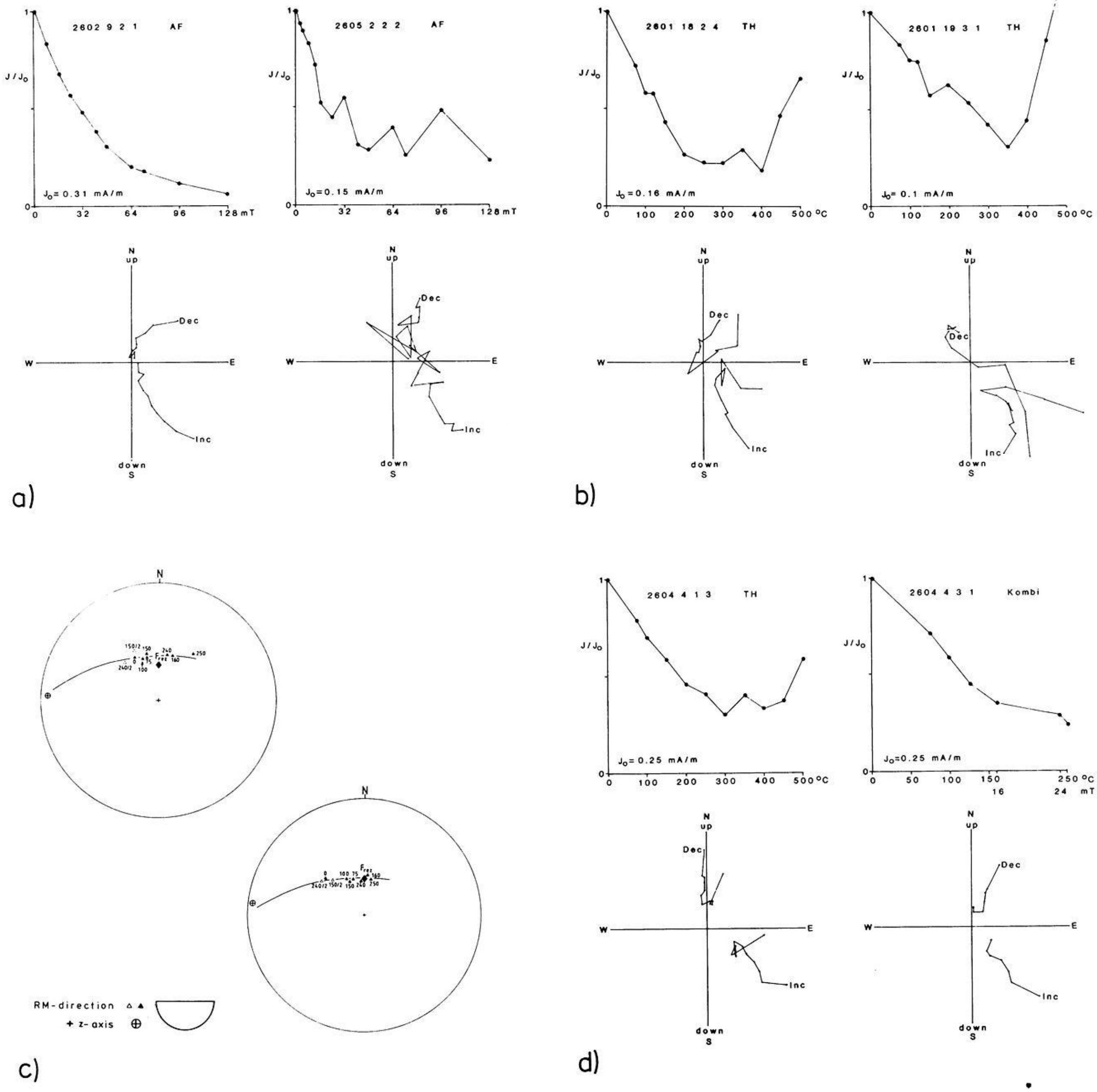

Fig. 6 a–d. AF demagnetization curves. Some of the samples show the acquisition of an artificially produced remanent magnetization. **b** Thermal demagnetization curves. The samples acquire a magnetization when heated above 400° C, which is related to the formation of new magnetic phases. **c** Remanence vectors of all demagnetization steps for two specimens in a stereographic projection. The (*open symbols*) vectors marked with 100/2, 150/2 etc. are measurements of the remanence vector at this particular demagnetization step repeated after 48 or 72 h storage in the laboratory field. **d** Demagnetization curves of specimens from site 2604

mens (Fig. 7b). Once again, the remanence strongly increased in fields up to 0.1 T, but none of the specimens reached saturation in the maximum applied field of 0.6 T.

Results

Magnetomineralogy

Both the AF and the thermal demagnetization experiments and the IRM acquisition experiments indicate magnetite or titanomagnetite as the main carrier of magnetization. In the AF demagnetization experiments no high coercivity components have been recognized. According to the IRM aquisition curves, the remanent magnetization in some samples is entirely due to magnetite or titanomagnetite, while others contain small amounts of hematite or geothite ["type 1 limestone" and "type 4 limestone" of Heller and Channell (1979)].

The viscous behaviour of the specimens can be interpreted as the result of multidomain magnetites as the main carriers of magnetization. The movement of the remanence vectors during demagnetization away from a VRM component acquired in the laboratory field towards a component aligned parallel to the present day geomagnetic field at the

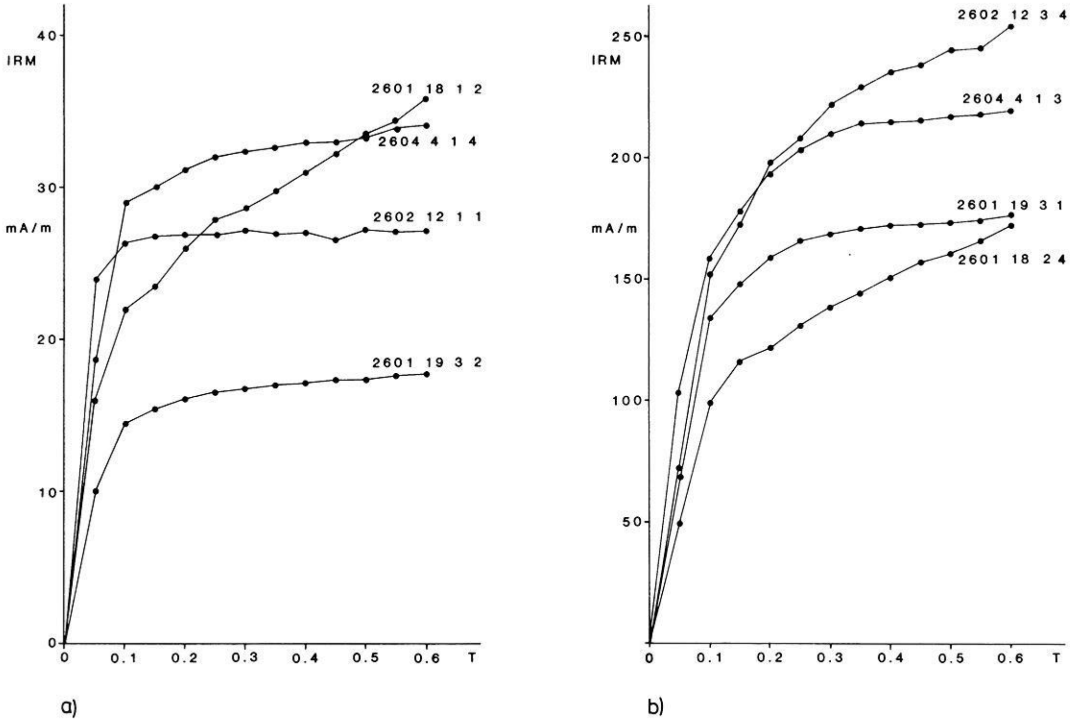

Fig. 7 a and b. IRM acquisition of **a** unheated limestone specimens, **b** specimens thermally demagnetized up to 500° C

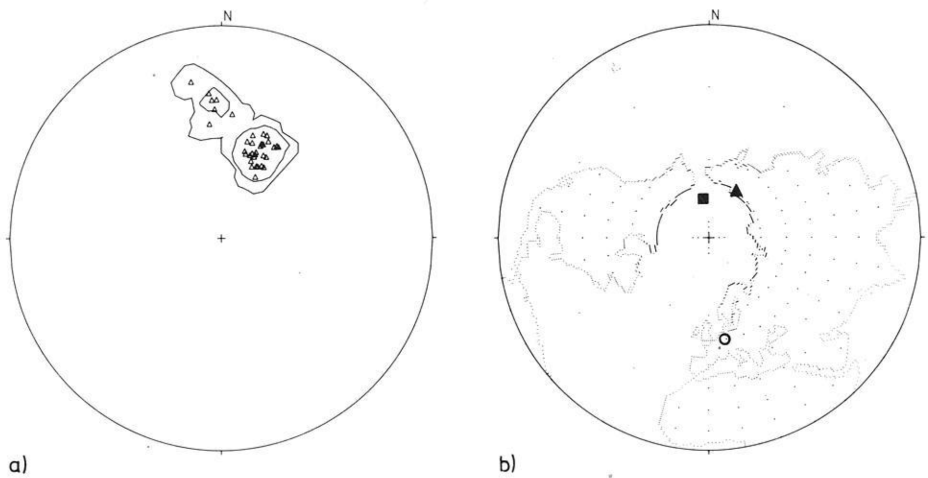

Fig. 8 a and b. Stereographic plot of all stable remanence directions from site 2604. *Symbols:* see comment on Fig. 3. **b** The sampling location (*circle*), the palaeopole position found in the present study (*triangle*) and the pole position from Heller and Channell (1979) (*square*)

sampling site indicates higher stability of the latter component. The higher stability can be explained by the acquisition of this VRM over a long period of time (e.g. throughout the Brunhes normal epoch).

The higher stability of remanence directions during demagnetization of specimens from site 2604 may be explained in terms of relatively smaller, pseudo-single domain magnetites being present.

The rapid increase of remanence intensity and the strong increase in IRM intensity after thermal treatment above 400° C can be explained by the alteration of pyrite, which is abundant in the Turonian carbonates, to magnetite (Kruczyk, 1977). The high coercivity component created after thermal treatment might be caused by the desintegration of ironhydroxides formed during weathering of the carbonates at temperatures above 290° C (Hedley, 1968) and the formation of hematite pigment (Heller, 1978).

Palaeofield and palaeopole position

As discussed above, stable remanence directions up to 250° C were only found in the specimens from site 2604. No indication of a reversed field direction in the time interval represented by this site has been found. The stable remanence mean direction after demagnetization is N 17° E/ 52° (declination/inclination). The corresponding palaeomagnetic pole position is located at 68°N/149°E, $\alpha_{95} = 5.3°$ (from ten specimens out of the five samples of site 2604) (Fig. 8), which is in good agreement with the pole determined by Heller and Channell (1979).

Discussion

The suitability of the Turonian carbonates from the southeastern Münsterland area for palaeomagnetic work is very limited. Only about 10% of the specimens yielded useful palaeomagnetic information. Therefore, the initial aim of the present study to check the occurrence of a reversal within the Turonian, recognized by Krumsiek (1982), was not achieved. However, all specimens which revealed a stable direction showed normal polarity. This is in agreement with the most recent Cretaceous timescale (Lowrie et al., 1980).

The palaeopole position found in the present study confirms the conclusions drawn by Heller and Channell (1979) such as the shortening of the Tethyan realm by the order of 1000 km since the Late Cretaceous and the rotation of the Iberian peninsula in its present position prior to Late Cretaceous times.

Kligfield and Channell (1981) described magnetic viscous behaviour of Helvetian limestones from the northern Alps similar to that found in the present study. They assume very small-sized pyrrhotites causing the strong viscosity of magnetization. However, their IRM curves have saturation values between 0.4 and 1.0 T, so that pyrrothite as a carrier of magnetization in the limestones of the present studies appears to be excluded.

Mumme (1964) investigating Cenozoic basalts from Victoria, Australia found the instability of magnetization to related to an increasing titanium content of the titanomagnetites. Probably, the observed VRM in the Turonian limestones is not only related to grain size, but also to the composition of the magnetites.

Heller and Channell (1979) in their study of the Upper Cretceous limestones of the Münsterland basin mention a large number of unstable specimens in the more southerly region of the Münsterland.

The viscous behaviour of the specimens in the present study might be related to carbonate facies factors or to weathering processes of the carbonates. A detailed study of the carbonate facies and its relation to magnetic properties of Cenomanian and Turonian rocks in the Münsterland basin is presently being carried out by Hambach (1985).

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