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PALAEOMAGNETIC AND ROCK MAGNETIC PROPERTIES OF LOESS-PALAEOSOL SEQUENCES IN BELGIUM

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(7 figures and 1 photograph)

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ABSTRACT. Palaeomagnetic investigation of several sections in the loess cover of Belgium proves that they contain a stable remanent magnetization reflecting ancient field behaviour. Reversed magnetozones could not be detected so far indicating that the examined sections belong to the Brunhes Chron. Also short-term reversals seem not to be present and large directional deviations can be attributed to frost wedging, solifluction and other periglacial activities. In contrast with Central and Eastern Europe and Asia, soil magnetic enhancement is absent except for the humic soil horizon overlying the Rocourt soil. The strong magnetic properties in this horizon revealed in Tongrinne and Rocourt are mainly due to the presence of minerals of volcanic origin.

KEYWORDS: Belgium, Pleistocene, loess, magnetic susceptibility, rock magnetic parameters.

SAMENVATTING. Paleomagnetisch onderzoek van de loess-palaeobodem sekwenties in België toonde aan dat deze een stabiele remanente magnetizatie bezitten die het gedrag van het fossiel geomagnetisch veld weergeeft. Inverse magnetozones werden tot nog toe niet ontdekt, erop wijzend dat de onderzochte sekwenties tot de Brunhes Chron behoren. Ook veld inversies van korte duur blijken niet aanwezig te zijn en grote afwijkingen in de magnetisatierichting kunnen toegeschreven worden aan vorstwiggen, solifluktie en andere periglaciale verschijnselen. Geen uitgesproken magnetische contrast treedt op tussen loess en palaeobodems met uitzondering van de humeuze horizont boven de Rocourt bodem en dit in tegenstelling met de loess-palaeobodem sekwenties in Centraal en Oost-Europe en Asië. De sterk magnetische eigenschappen in de humeuze bodem, vastgesteld in Tongrinne en Rocourt, zijn vooral te wijten aan de aanwezigheid van mineralen van vulkanische oorsprong.

SLEUTELWOORDEN: België, Pleistoceen, loess, magnetische susceptibiliteit, magnetische parameters.

RESUME. L'étude paléomagnétique de plusieurs coupes dans la couverture loessique de la Belgique a mis en évidence la présence dans ces terrains d'une aimantation rémanente stable qui témoigne du comportement du champ géomagnétique ancien. Aucune magnétozone négative n'y a été retrouvée, ce qui indique que les sections examinées appartiennent à la période de Brunhes, et l'on n'a pas plus détecté d'événements de courte durée. Les importantes déviations mises en évidence doivent être attribuées à des fentes de gel, de la solifluction ou à d'autres activités périglaciaires. Contrairement à ce qui a été trouvé en Europe Centrale et de l'Est et en Asie, on ne voit aucun renforcement des caractéristiques magnétiques dans les sols, si ce n'est dans l'horizon humifère surmontant le sol de Rocourt. Ce contraste des propriétés magnétiques, observé à Tongrinne et à Rocourt, est du principalement à la présence de minéraux d'origine volcanique.

MOTS-CLES: Belgique, Pléistocène, loess, susceptibilité magnétique, propriétés magnétiques.

1. Introduction

Already in the seventies the authors started to investigate the palaeomagnetic properties of loess deposits in Belgium although one was unaware of how purely eolian loess may acquire a remanent or permanent magnetization (Hus *et al.*, 1976). Many palaeomagnetists were at that time rather reluctant to measure non-consolidated continental sediments and sceptical about the outcome. The discovery of reversed magnetozones in loess-palaeosol sequences in different parts of the world proved that they can acquire and retain a stable remanence for a long period of time (Koci *et al.*, 1973, Heller and Liu Tungsheng, 1984).

However, the exact mechanism of the acquisition of the natural remanent magnetization (NRM) in loess and palaeosols remains an enigma. As reliable absolute dates for loess deposits are scarse but highly needed for the reconstruction of the palaeoclimate and other palaeoenvironmental conditions prevailing at the time it was indicated to verify the presence of loess in Belgium older than Late-Pleistocene on the basis of its magnetic polarity.

Our first concern was to assess the fidelity of the geomagnetic record in loess and to find out if valid information about the fine structure of the ancient geomagnetic field could be recovered. Indeed, several researchers reported the presence of short-term anomalous directional changes of the magnetization in the Brunhes Chron which they attributed to field behaviour and which were called "excursions". These excursions, which may even be short term reversals of the field, are still a matter of dispute and it is not yet clear if they represent a real field behaviour or whether they are due to disturbances in the sediment. If they are a real property of the field, they would provide important stratigraphic markers.

The second aim was to improve our knowledge of the remanence acquisition mechanism in loess and loess-like deposits. Are we dealing with a depositional or post-depositional remanence (DRM or PDRM), due to the statistical alignment of magnetized particles in the ambient field during deposition or shortly afterwards, or as others think, with a crystalline or chemical remanence (CRM) due to phase changes or grain growth ?

Finally we wanted to ascertain to what extent one can make use of palaeomagnetic and rock magnetic properties for between-site correlations and to built up a magnetostratigraphy.

2. Area description and sampling

Since the seventies several loess-palaeosol deposits representing at least the last two glacial-interglacial cycles could be sampled in brickyards and other excavation pits in Fleurus, Grand-Manil, Harmignies, Kesselt, Lixhe, Tongrinne, Rocourt, Romont, Warneton and recently in a trench in Remicourt (Fig.1). Only results from a few sites are presented. For the description and stratigraphy, the authors refer to the publications by Gullentops (1954), Paepe and Vanhoorne (1967), Haesaerts (1984) and Juvigné (1977).

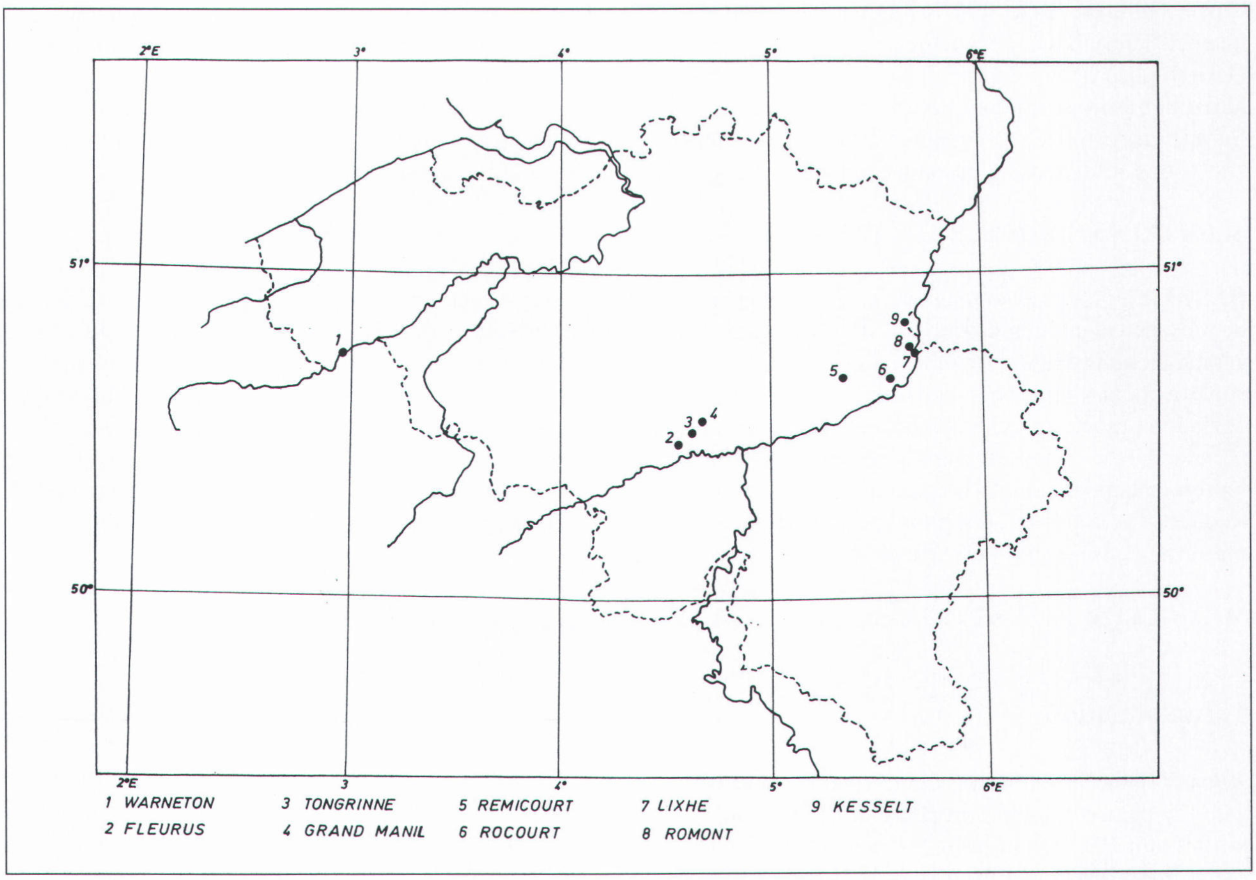

Figure 1. Location map of sites in Belgium where loess-palaeosol sequences were sampled for palaeomagnetic investigation.

Photograph 1. Collecting of oriented samples for a palaeomagnetic investigation of the loess-palaeosol sequence at Rocourt. The sampling starts from the top of the humic soil horizon overlying the reddish Rocourt soil until the tertiary sands.

Earlier we had to solve the problem of how to retrieve oriented non-disturbed samples with the difficulty that they had to be protected in order to prevent them of falling into pieces during measurement with the relatively high speed "spinner" magnetometers available. Non-disturbed, oriented samples were obtained by gently hammering thin-walled plastic tubes in the sediments. A known orientation was carried over with a theodolite and. The dip of the tubes was measured with a clinometer, resulting in well oriented samples with a maximum dip and bearing error less than 1° (Photograph 1).

The sealed plastic tubes protected the samples well during the remanence measurements but excluded thermal "cleaning" to remove spurious magnetization components. Recently, with the advent of cryogenic magnetometers, where the remanence measurement is independent of the velocity with which the sample is inserted in the detection coils of the instrument, the sampling technique completely changed. At present, large oriented block samples are cut in the field and subsampled in the laboratory. This not only reduces mechanical disturbance during sampling in the field to a minimum but also avoids the remanence contribution of the plastic tubes, which turned out never to be completely non-magnetic. Moreover, one avoids anisotropy induced during sampling and opens the possibility of thermal "cleaning".

3. Magnetic stability tests

3.1. Alternating field demagneti-zation tests

Magnetic stability of the NRM was examined by progressive stepwise demagnetization in increasing alternating fields up to a peak value of 0.1 Tesla. This gives an idea of the stability of the remanent magnetization components present and allows to determine an alternating field value necessary to remove undesired magnetization components. This is the case for the viscous remanent magnetization (VRM) which is acquired spontaneously by samples which are kept in a magnetic field, even in fields as weak as the geomagnetic field. In case of non-overlapping coercive force spectra, it is possible to isolate the most stable magnetization component which is called the characteristic remanence (ChRM). A typical alternating field demagnetization curve of a loess sample is given in Figure 2 where the ratio of the residual remanence after each demagnetization step is given in function of the alter-

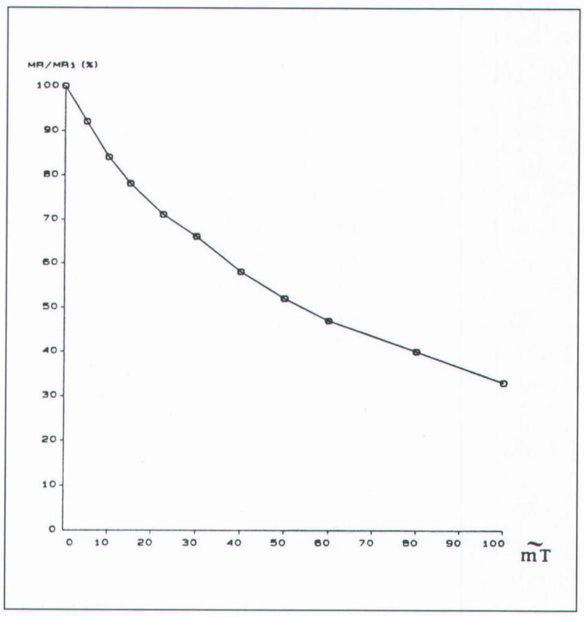

Figure 2. Alternating field demagnetization curve of a typical loess sample at Tongrinne giving the residual remanence after each demagnetization step normalized with the initial remanence in function of the alternating field intensity.

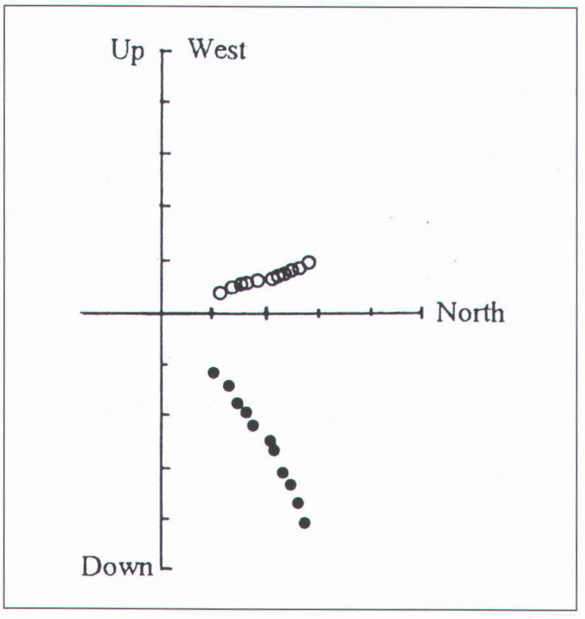

Figure 3. Orthogonal plot of the magnetization vector during stepwise alternating field demagnetization. Open (full) circles denote the projections of the magnetization vector end-point respectively on the horizontal plane (NS, WE) and a vertical plane through the NS direction (NS, up down).

nating field intensity applied. The directional change of the magnetization vector during stepwise demagnetization in increasing alternating fields can be followed in Figure 3 where each circle represents the orthogonal projection of the magnetization vector endpoint respectively on the horizontal (open circle) and vertical (full circle) plane containing the NS direction. The rotation of the magnetization vector in the orthogonal plot clearly shows the presence of two magnetization components. The less stable one is probably of viscous origin. The alternating field demagnetization curves of many pilot samples show that the parent loess resists better to the action of alternating fields compared to the soils developed in them and that the Late Pleistocene coverloam is more stable than the older loesses.

3.2. Field test

In contrast to laboratory stability tests which estimate magnetic stability on a laboratory timescale (ranging from seconds or less until a few years maximum) field tests are more powerful as they give information about the remanence stability on a geologic timescale.

The presence of large periglacial features in the loess deposits in Belgium was an unique opportunity to set up a magnetic stability field test comparable to the classic fold test of Graham (1949). We examined in great detail the deformed strata near a large fossil ice wedge cast visible in the Late Pleistocene loess deposits in Tongrinne (Hus *and al.*, 1993). After removal of the viscous overprint by partial alternating field demagnetization, we could demonstrate that the upturned strata near the fossil wedge possess at least part of a magnetization which was acquired prior to deformation and which remained stable subsequent to deformation. Different wedge fillings could be recognized on the basis of their remanent magnetization intensity and weak field magnetic susceptibility.

This field test, which to our knowledge, is the first one of this kind ever applied to loess deposits, proves that loess can retain a stable magnetization for a long period of time. It also warns us that anomalous magnetization directions due to deformations caused by periglacial activities, which may escape observation such as in cores, may be erroneously mistaken as "excursions" of the earth magnetic field.

4. Directional properties

The magnetization direction defined by its inclination (I) and declination (D) in all the sections examined is normal like the present day field direction indicating that the deposits are of Brunhes age. The overall average direction differs only little from the one expected for an axial dipole field which suggests that no serious inclination error occurred as is sometimes noticed in other kinds of sediments. Large directional changes or excursions of the field could not be detected.

A sudden change in I and D was found at the level of the Rocourt soil and lower part of the overlaying humic horizon in Tongrinne and Rocourt (Figs. 4 and 5). The inclination decrease revealed in Tongrinne but a corresponding inclination increase in Rocourt, and consequently a lack of spatial consistency, excludes the possibility of a field behaviour. Inflected patches visible in the Rocourt soil in Rocourt point to cryoreptation along a small slope. Hence, the remanent magnetization vector can be used as a marker to visualize the movement "en masse" which occurred during solifluction. The nondiscovery of reversed magnetozones does not mean that Lower Pleistocene loess is absent. Therefore in the future, one should look for depressions or cavities where older loess has been trapped such as in dissolution pockets in chalk or in karsts.

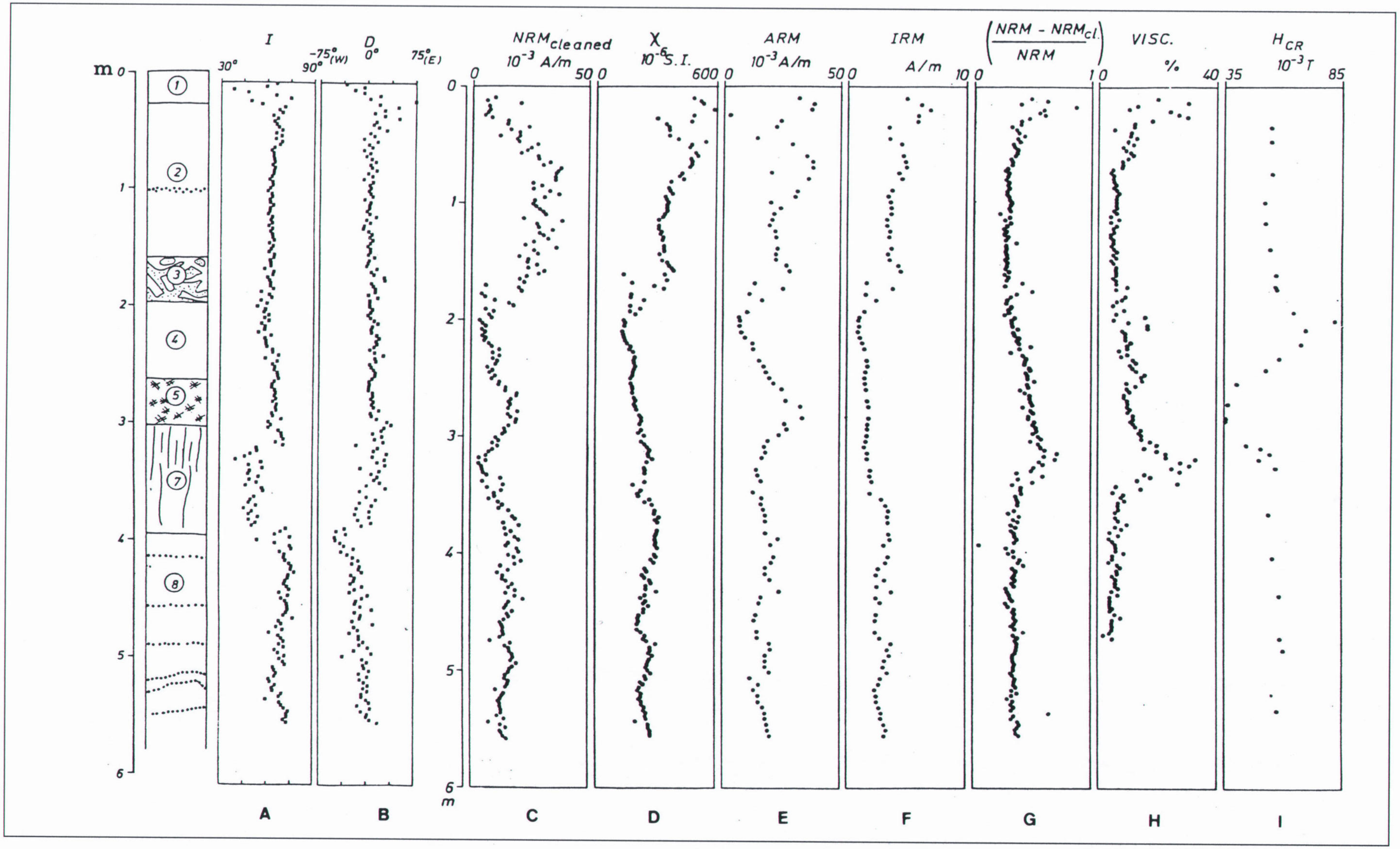

Figure 4. Palaeomagnetic and rock magnetic records in the loess-palaeosol sequence at Tongrinne. (A) inclination, (B) declination, (C) "cleaned" NRM (AF = 30 mT), (D) volume magnetic susceptibility (c), (E) anhysteretic remanent magnetization (ARM), (F) isothermal remanent magnetization (IRM), (G) ratio residual remanence after "cleaning" to initial remanence, (H) viscous remanent magnetization in percentage, (I) remanent coercive force (HCR).
1: present soil, 2: coverloam, 3: cryoturbated tongue horizon of Nagelbeek, 4: loess, 5: Warneton soil, 6: whitish loam, 7: Rocourt soil, 8: loess (Saale), 9: sand (Tertiary).

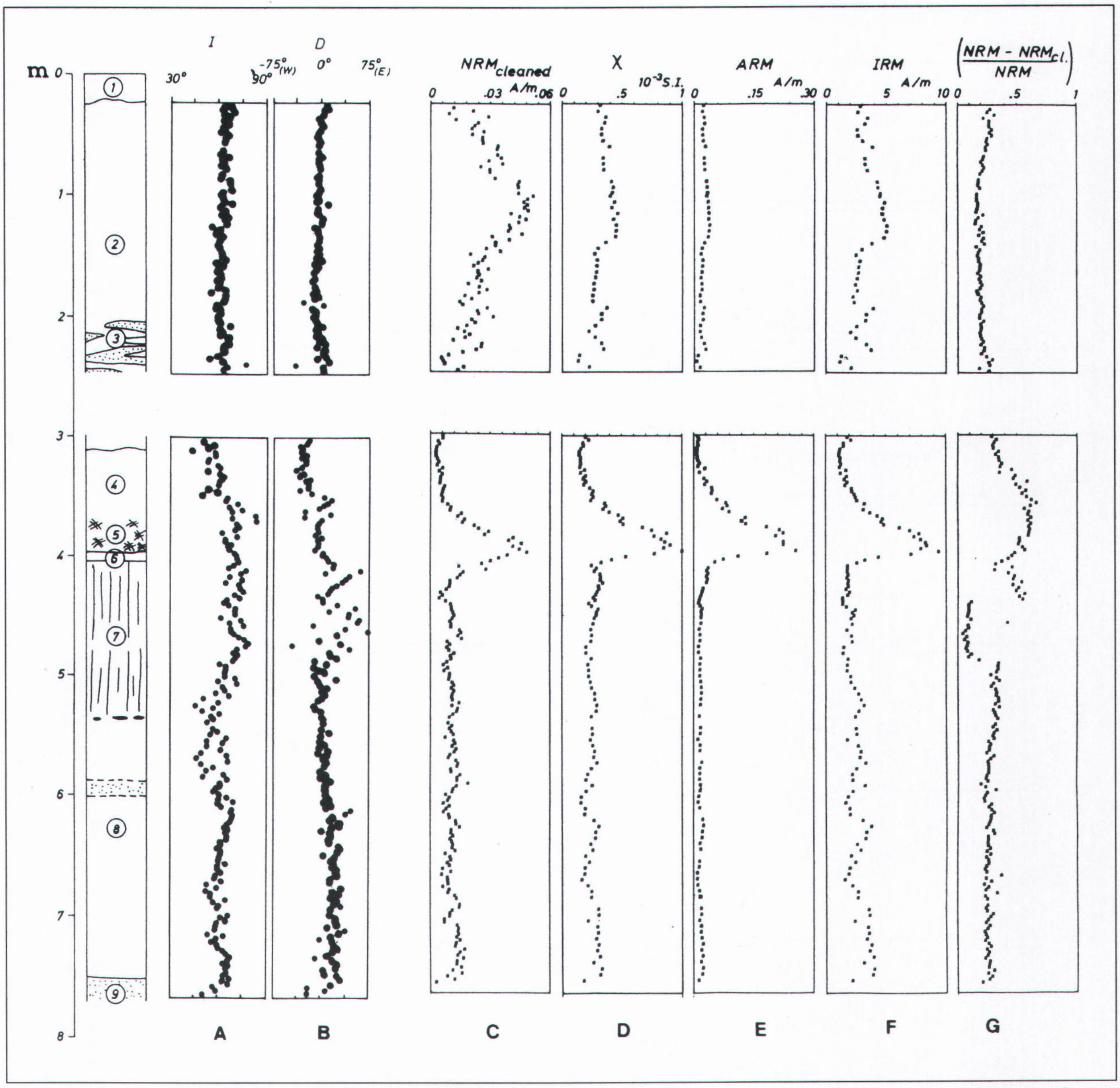

Figure 5. Palaeomagnetic and rock magnetic records in the loess-palaeosol sequence at Rocourt. See Fig. 4 for legend.

5. Magnetic susceptibility and other rock magnetic parame-ters

The weak field magnetic susceptibility (MS) or weak field response, reflecting the magnetic content of a sample, proved to be an interesting rock magnetic parameter in the study of loess-palaeosol sequences as it is considered as a proxy indicator of the palaeoclimate. In Central and Eastern Europe and in Asia a great contrast in MS occurs between the parent loess and interbedded soils. This magnetic enhancement in the palaeosols can only be explained by "in situ" neoformation of "magnetites" (Hus and Han, 1992). It is thought that they result from bacterial activity as can be observed in the present soils. Certain bacteria create a microenvironment suitable for "magnetite" to form, called extracellular magnetite. In suitable conditions these fine-grained submicrometer "magnetites" can survive. In a periglacial environment, however, they may corrode or even completely dissolve.

The bulk MS-signature of all the sections examined in Belgium hardly reveals any contrast between the soils and loess except for the humic horizon overlying the Rocourt soil in Rocourt and Tongrinne (Figs. 5 and 4). The magnetic enhancement here is caused by the presence of minerals of volcanic origin (Juvigné, 1977). The MS-changes with depth follow the same trend as

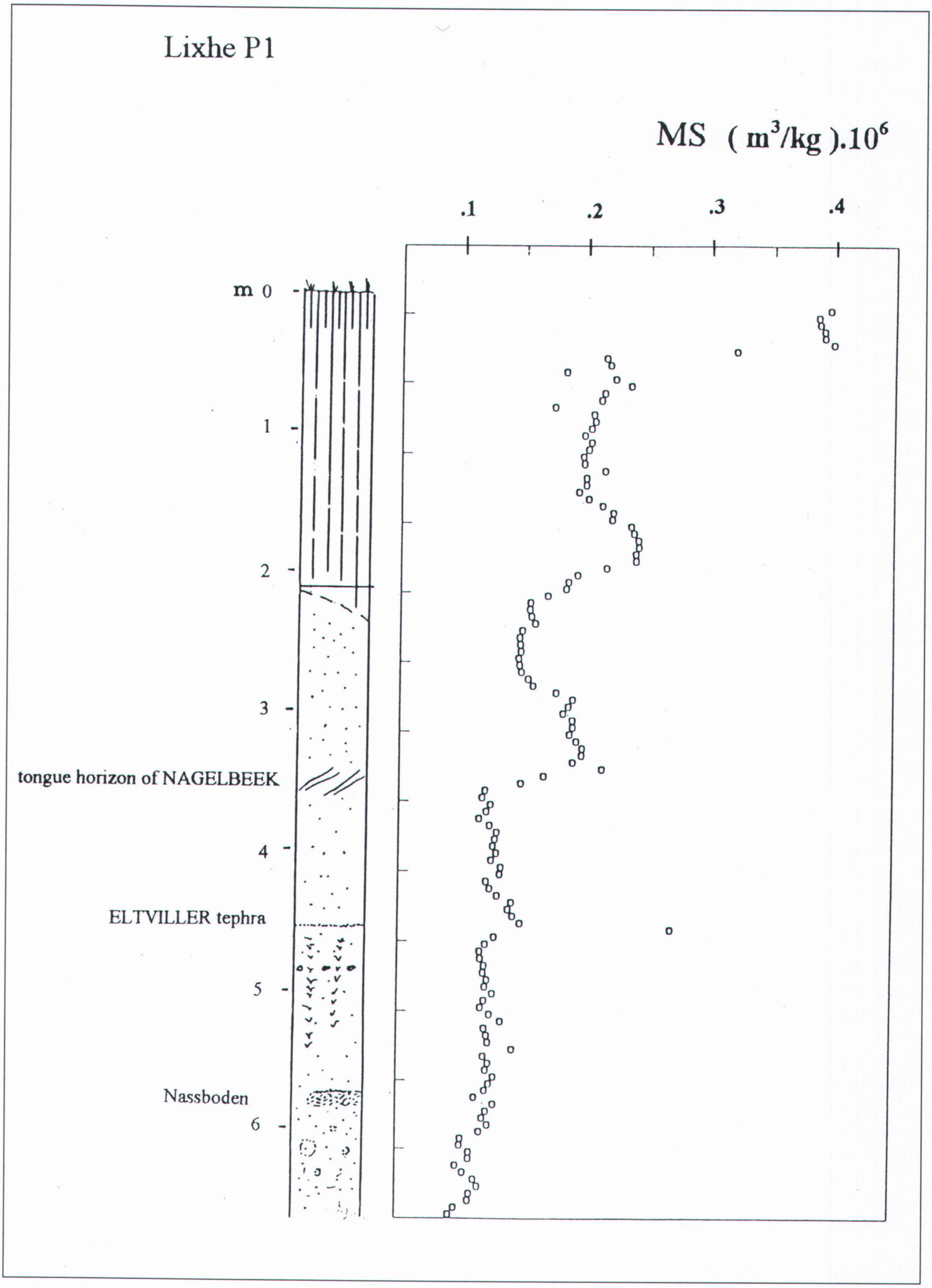

Figure 6. Magnetic susceptibility profile of the upper loess in Lixhe. The Eltviller Tephra is characterized by a high MS.

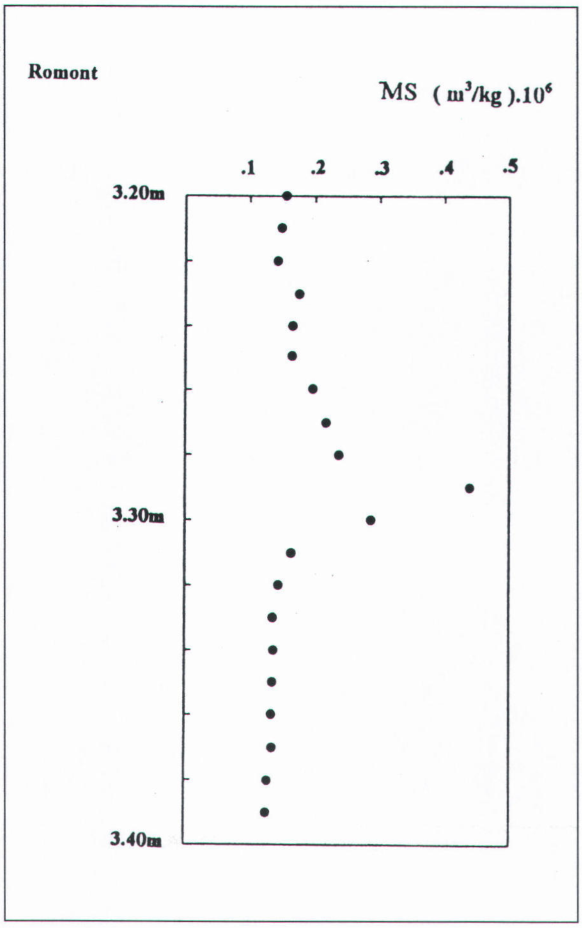

Figure 7. Magnetic susceptibility profile through the Eltviller Tephra at Romont.

the NRM indicating that these variations reflect in the first place concentration changes of the ferrimagnetic minerals. The coverloam above the cryoturbated Nagelbeek horizon differentiates clearly from the older loesses by its higher MS. MS also depends on the effective grain size or magnetic state of the magnetic grains. This effect can clearly be seen in the cryoturbated tongue horizon and stratified loess.

In Rocourt, the humic horizon overlying the Rocourt soil gives high values in MS, NRM and other laboratory imparted remanences such as the anhysteretic remanence (ARM) and isothermal remanence (IRM) (Fig. 5). In Tongrinne, only NRM and ARM, attain high values (Fig. 4). This can be well explained by a higher amount of single domain grains in the latter, and multi-domain grains in the former.

The decrease of the magnetic grain size from Rocourt to Tongrinne or from East to West supports an Eifel origin for the volcanic minerals present in this horizon. MS can thus be used to map the spatial distribution of this fall out.

Other examples of the use of MS to trace volcanic tuff layers are given in Figures 6 and 7 for the Eltviller Tuff in the loess deposits in Lixhe and Romont. In Lixhe (Fig. 6) the MS profile was obtained on loose samples taken with a sampling interval of 5 cm starting from the top of the present soil. The level of occurrence of the Eltviller Tuff betrays itself by a high MS value obtained in one single sample at a depth of about 4,6 m below the surface. High MS values are found for the topsoil and the upper loess above the Tongue Horizon of Nagelbeek. In Romont (Fig. 7) a high-resolution MS-profile was obtained through the Eltviller Tuff with a sampling interval of 1 cm. MS is about three times higher in the volcanic tuff compared to the loess. The asymmetry of the MS peak enables us to study the dispersion of the volcanic material with depth.

Curie point determinations in order to better identify the magnetic carriers have not been done so far. Magnetization curves in increasing constant fields point to magnetite as the most important remanence carrier (Hus and Geeraerts, 1986).

6. Conclusions and future research

Palaeomagnetic investigations of several loess-palaeosol sections in Belgium proved that they carry a stable remanence of normal polarity suggesting that they belong to the Brunhes Chron. The weak field response or magnetic susceptibility MS proved to be very useful to differentiate the units and to correlate between-site and in particular to trace tuff layers of volcanic origin. The upper loess unit clearly differentiates from the middle and lower ones by its high MS. Nowadays the availability of state of the art equipments to measure weak remanences of non-consolidated sediments and to measure induced magnetizations in weak fields with high precision and accuracy drives us to foster deeper into the palaeomagnetic and rock magnetic properties of the loess-palaeosol sequences of Belgium in particular as they are good indicators of past climatic changes. MS may give us also insight into erosion, and weathering processes and pedogene-sis.

Anisotropy of magnetic susceptibility, which reveals the magnetic texture of a sample, can now be measured in a few minutes and may yield information about the depositional mode. The characteristic remanence of a sample can also be used as a marker to visualize soil movement which has occurred after deposition.

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