A PALAEOMAGNETIC REVERSAL IN EARLY QUATERNARY SEDIMENTS IN MASSON HILL, MATLOCK, DERBYSHIRE.

by

M. Noel, R.P. Shaw
and T.D. Ford

Summary

A section of fluvio-glacial sediments in Old Jant Mine, Masson Hill, Matlock, shows a palaeomagnetic reversed to normal transition which it is argued is most likely to have occurred at the Brunhes/Matuyama event of 730,000 years ago. The sediments thus appear to be the oldest record of Pleistocene glaciation in Britain.

Introduction

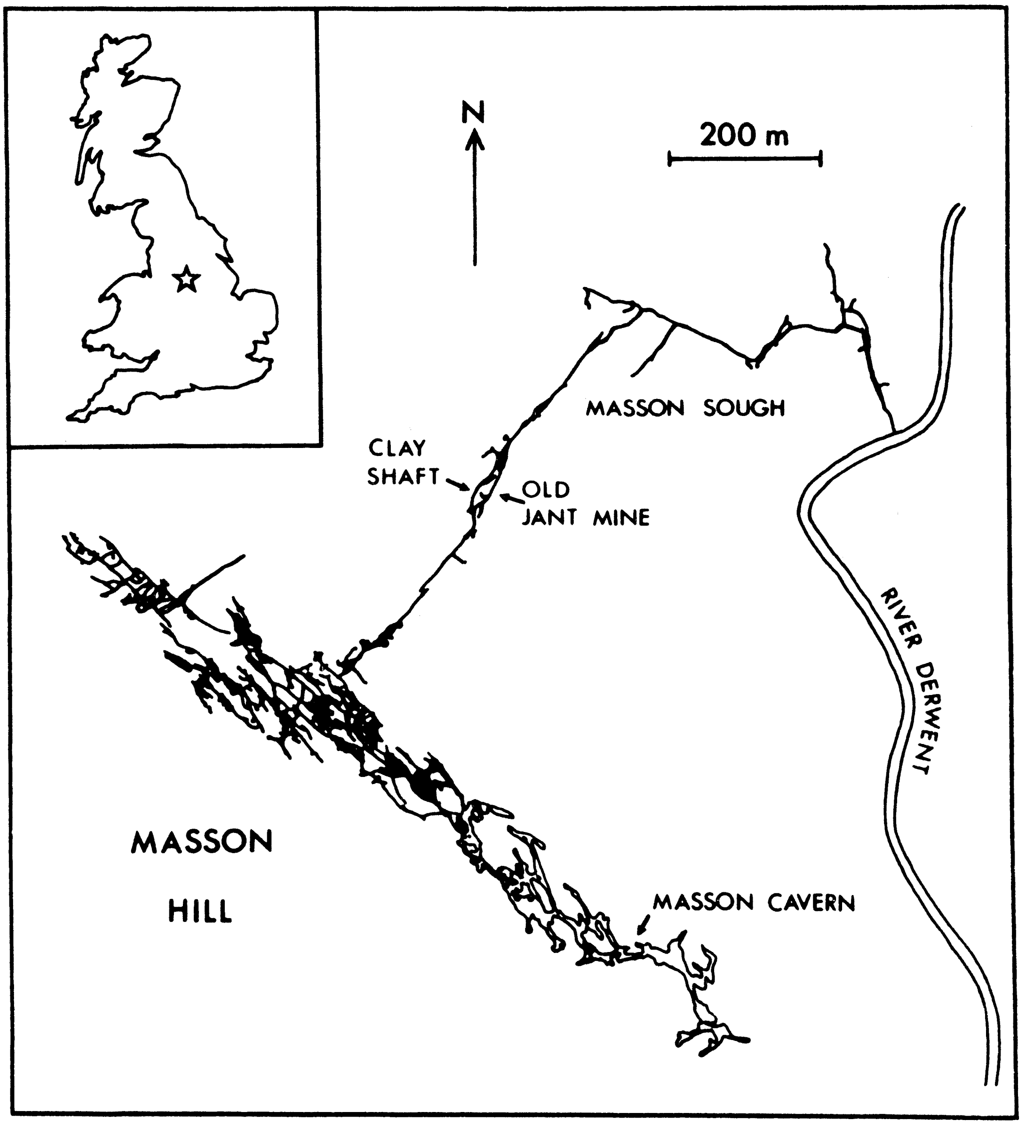
The feasibility of applying high-resolution magnetostratigraphy to the regional correlation and dating of Quaternary deposits has been demonstrated in palaeomagnetic studies of European and North American lake sediment cores (Stober and Thompson, 1977; Creer, 1981, 1982; Creer and Tucholka, 1982a, b). However, the use of lacustrine deposits to extend the timescale beyond about 15 kyr BP is hampered by the difficulty of retrieving deeper core material and by scouring during the Devensian glaciation which affected the majority of upland lake basins. In contrast, many caves contain extensive deposits of fine-grained sediments that are largely protected from surface erosional events, weathering or bioturbation (Bull, 1980; Bögli, 1980) and which may have ages up to or in excess of 350 kyr BP (Atkinson *et al.*, 1978; Gascoyne *et al.*, 1981; Schmidt, 1982). These sediments can retain a reliable record of the geomagnetic field and hence offer the potential for extending the existing lake sediment magnetostratigraphy into the Middle or Lower Quaternary (Creer and Kopper, 1976; Noel, 1983; Noel and St. Pierre, 1984).

This paper describes the palaeomagnetism of a 4 m section of natural cave fill exposed in Old Jant Mine, Matlock, Derbyshire. The sediments provide the first British record of a geomagnetic polarity transition whose age and significance can be discussed in relation to recognised global polarity events and both continental and marine palaeoclimatic records.

Mercian Geologist, vol. 9, no. 4,
1984, pp. 235-242, 5 text-figs.

Geological Setting

Old Jant Mine is situated to the west of the Derwent River Gorge, within Masson Hill (text–fig.1) forming part of a complex system of disused lead and fluorspar mines which worked ore deposits in the form of fissure, pipe and flat veins in the Carboniferous Limestone. The layout and history of the mine-workings were described by Warriner *et al.* (1981). At the same horizon post-mineralisation cavernisation has occurred by solutional enlargement of voids left by the hydrothermal fluids and these then acted as pathways for groundwater movement. This phase is thought to have been initiated during the late Tertiary or early Pleistocene when incision of the Derwent Gorge commenced and the necessary hydraulic gradients became established (Ford and Worley, 1977). Most of the phreatic network was subsequently filled with a mixture of autochthonous and allochthonous sediments after which the cave passages were permanently abandoned by active streams. Because many of these sediments contain alluvial galena, much has been removed by past mining activity but some relics still remain. The narrow Clay Shaft in Old Jant Mine penetrates vertically through about 4 m of alternating sands, silts and clays which fill a calcite-lined pipe vein cavity (text–fig.2). The sediments are compacted and partly desiccated but are uncemented. Because these sediments comprise the longest undisturbed section in the mine they were selected for a detailed palaeomagnetic and sedimentological study.

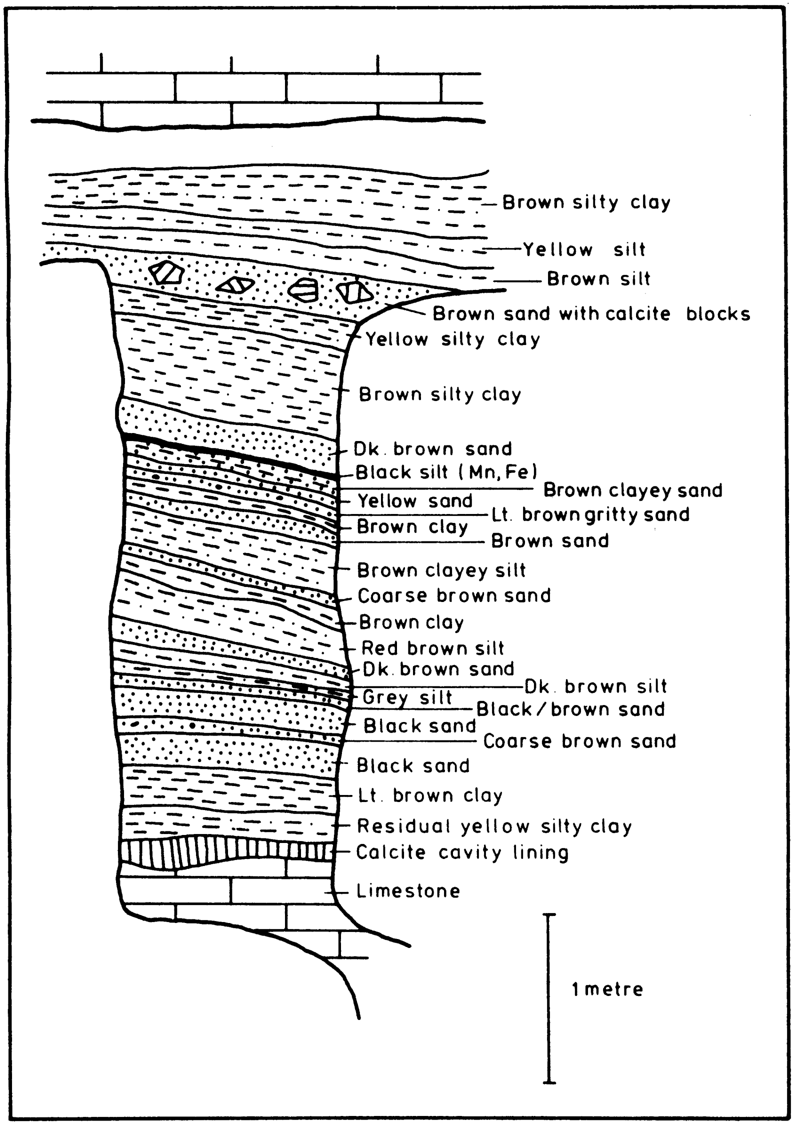


Text–fig.1. Location of the Clay Shaft and Old Jant Mine within the Masson Mines complex, Matlock, Derbyshire. Redrawn from Warriner *et al.* (1981).

Sampling and Measurement

A clean sediment surface was first prepared using non-magnetic tools. A vertical set of seventy-eight samples were then obtained from the section by forcing 5×5 cm plastic cylinders into the sediment using a hydraulic jack. The orientation of each specimen was recorded using a spirit level and magnetic compass. Multiple samples were taken from six horizons to assess the precision of the palaeomagnetic record. The sediment section contains several coarse sand layers which could not be sampled and hence it was impossible to obtain a regular sample spacing.

The direction and intensity of the natural remanent magnetisation of each specimen were measured using a fluxgate spinner magnetometer (Molyneux, 1971). Samples representing typical lithologies were then selected and their stability of magnetisation examined using stepwise partial demagnetisation (Creer, 1959). As a result of these tests, it was decided to partially demagnetise the remaining samples in an alternating magnetic field of 15 mT to remove secondary components of magnetisation after which their remanence was remeasured.



Text–fig.2. The sedimentary sequence exposed in Clay Shaft, Old Jant Mine, Matlock, Derbyshire.

The orientation of the magnetic susceptibility anistropy (magnetic fabric) was measured in the groups of multiple samples by using a modified spinner magnetometer (Singh *et al.*, 1975). This technique is analogous to optical fabric measurement and provides evidence for the extent of post-depositional disturbance in a deposit (Hamilton and Rees, 1970). A magnetic separate was also prepared from the sediment and its Curie temperature measured using a thermomagnetic balance.

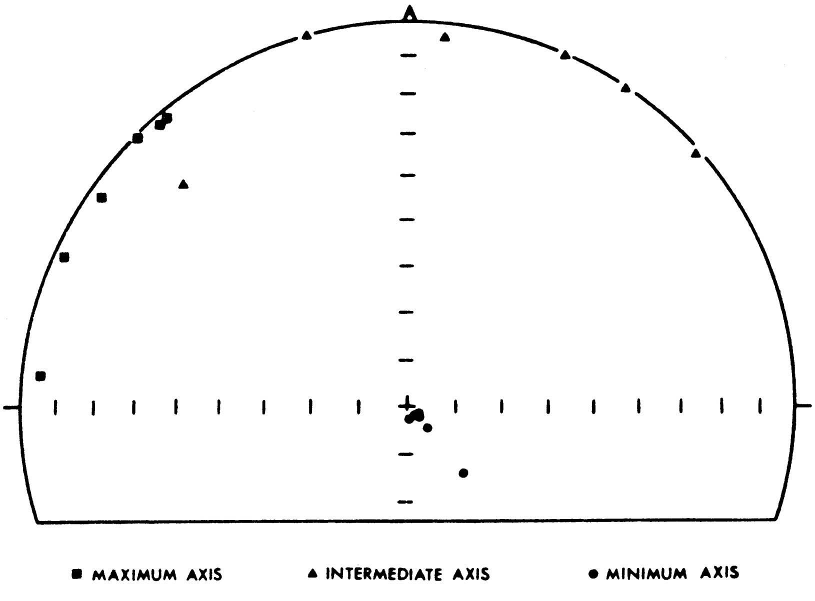
A total of 250 quartz grains were examined under a scanning electron microscope and their surface features compared to the classification scheme of Margolis and Krinsley (1974) in order to assess the palaeoenvironment of the sediment source.

Results and Discussion

The sediments were found during the demagnetisation tests to contain an original stable magnetisation. An undisturbed, depositional style of magnetic fibre (Hamilton and Rees, 1970) was revealed by the susceptibility anisotropy measurements (text–fig.3). The Curie temperature analysis indicated that the principal sedimentary magnetic mineral is magnetite. Therefore it is concluded that the sediment magnetisation has arisen from the alignment of magnetic particles by the earth's magnetic field during deposition. The consistent directions of multiple sample vectors (text–fig.4) support the conclusion that these sediments contain a reliable record of the geomagnetic field at the time of deposition.

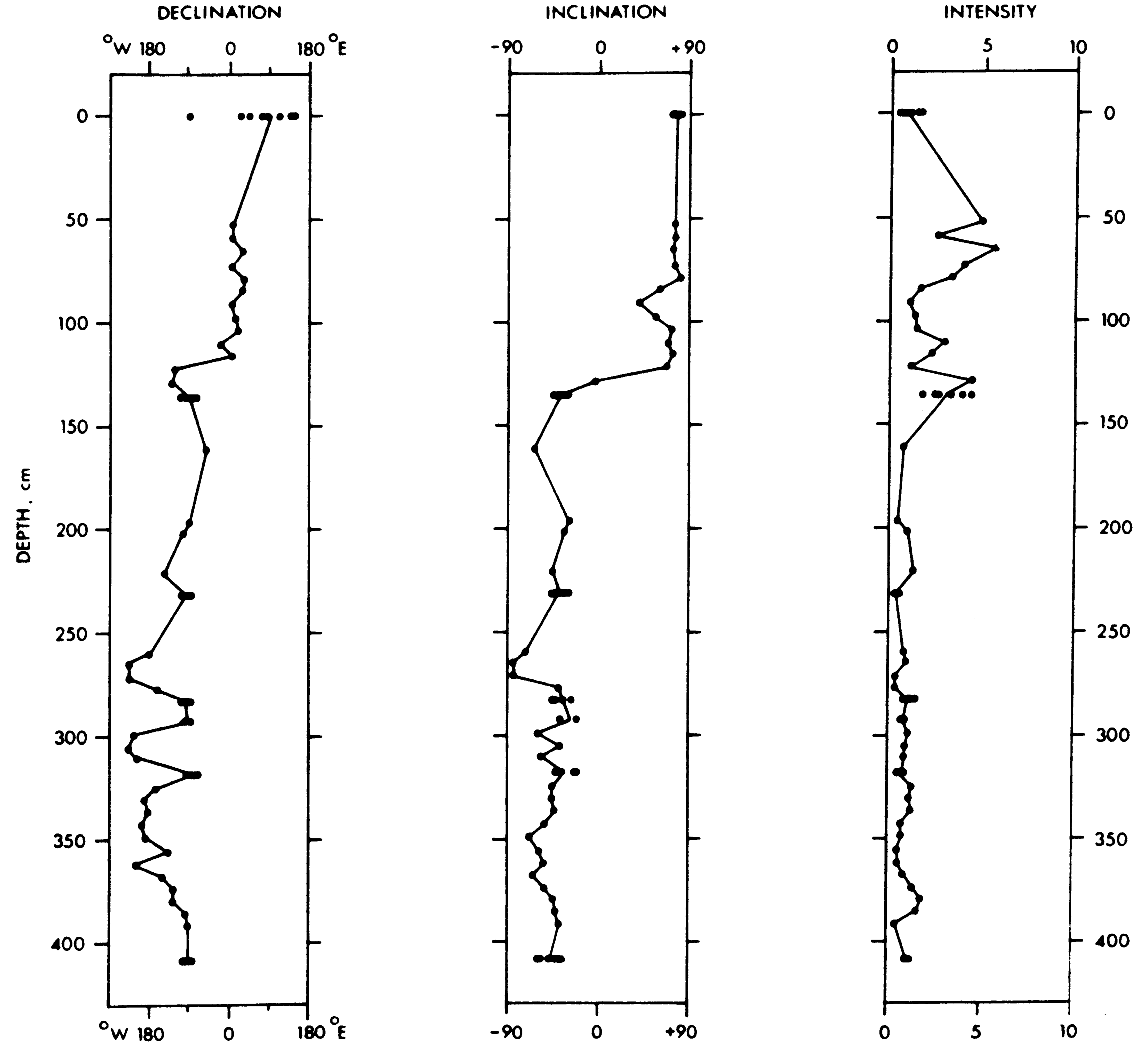
The profile can be considered in three parts: (a) lower, 400–250 cm from the top of the measured section (text–fig.4), the sediment records a period of reversed geomagnetic field as shown by the negative (upward) remanence inclinations and oscillating, southerly declinations. A pilot sample from this unit produced an initial rise in remanence intensity on partial demagnetisation, confirming the removal of normal polarity, secondary components from a reversed polarity primary magnetisation; (b) middle, from 250 up to 140 cm there is a steady trend in declination associated with diminished variability in inclination; (c) upper, at 130 cm from the top of the section there is an abrupt swing to positive inclination and northward declination values signifying a transition to the normal geomagnetic field polarity recorded by the remainder of the section. The lack of a marked intensity decrease previously associated with polarity transitions (Ninkovitch *et al.*, 1966; Hillhouse and Cox, 1976) may be due to variations in sediment lithology masking dependence of remanence intensity on the field strength.

Sediments in the Clay Shaft are not interbedded with any radiometrically datable speleothem material and preliminary assays indicate an exceptionally low content of indeterminable pollen. Thus conclusions concerning the age of the polarity transition are based on other factors which define chronological limits for sedimentation in the cave.



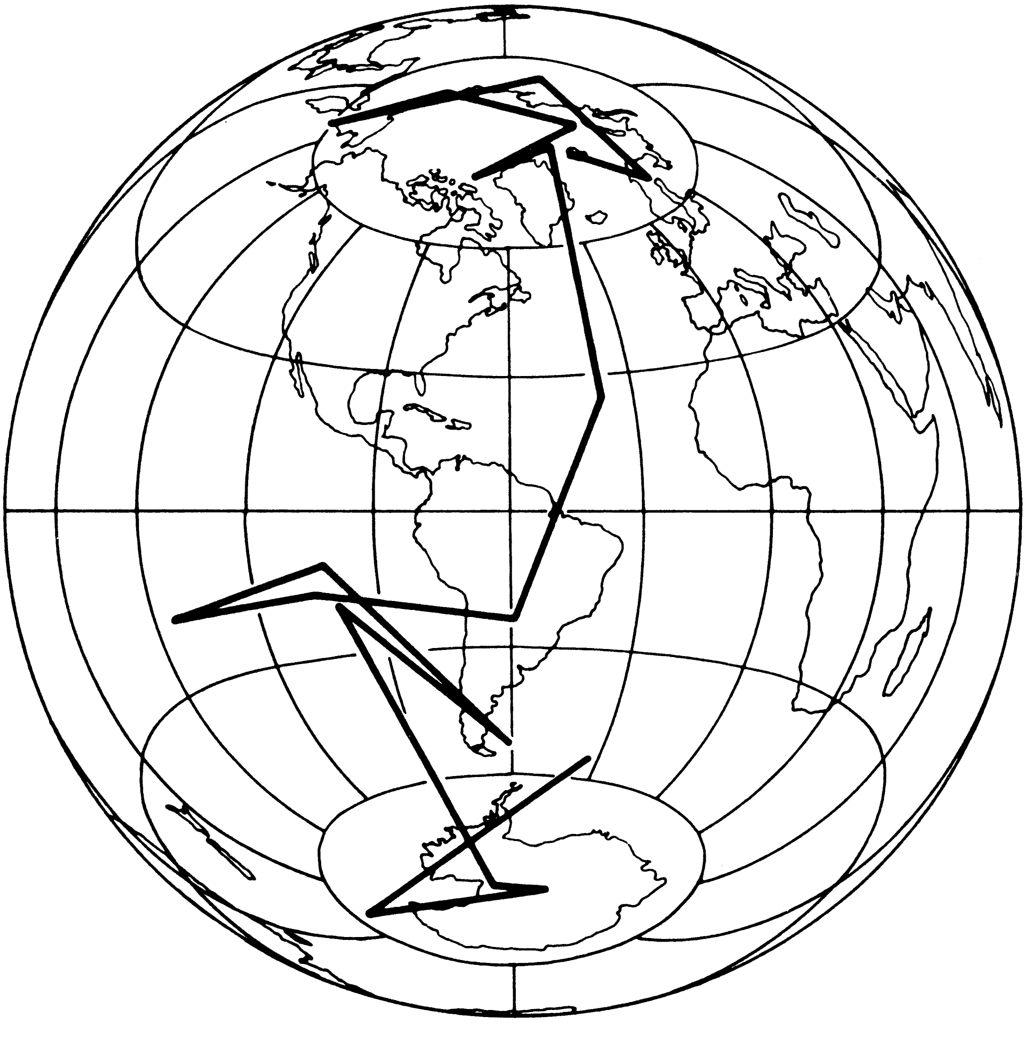
Text–fig.3. The magnetic susceptibility anisotropy of samples from a clay layer at a depth of 318 cm in the section. The anisotropy is shown in terms of the orientation of the three principal axes of susceptibility. The clustering of minimum axes normal to the bedding is typical of an undisturbed depositional style of fabric (Hamilton and Rees, 1970). Equal area projection, lower hemisphere.

An SEM study of 250 quartz grain surface textures shows some with angular chattermarks and fracture plates indicating derivation from a glacial environment; some with mechanical V-pits and subrounding suggesting a fluvial environment, and some with both. Although the fluvial characters could have been inherited from the primary source rock, the Millstone Grit deltaic sands, the overall implication is of a pro-glacial environment with grains derived from a glacier and transported into the cave by melt-water streams (Shaw, 1984). Though largely obscured by mining activities and the sedimentary fill the caves throughout Masson Hill show only phreatic forms, i.e. the caves were formed by solution beneath the water-table and it is quite possible that the sedimentary fills were also deposited below the water-table by relatively slow-moving melt-water streams (Ford & Worley, 1977) before the full incision of the Derwent Gorge. The Clay Shaft site is perched 140 m above present river level and so both cave and fill must predate the final incision of the Gorge, which Ford and Burek (1976) argued was during or immediately after the Late Wolstonian. A Wolstonian or earlier age for the cave sediments is also suggested by the absence of any local till which can be ascribed to the Devensian glaciation (Burek, 1977). On this basis, the polarity transition in the sediment of Old Jant Mine must predate the Laschamp, Mungo and Blake geomagnetic events (Bonhommet and Zähringer, 1969; Barbetti and McElhinny, 1972; Smith and Foster, 1969). The Biwa I and II events at 180 kyr BP and 295 kyr BP (Kawai *et al.*, 1972) are also improbable candidates since the marine $0^{18}/0^{16}$ record shows that these would have terminated under the full glacial conditions of stages 6 and 8 respectively (Shackleton and Opdyke, 1973).



Text–fig.4. Palaeomagnetic results from the Clay Shaft section after partial demagnetisation in a peak alternating field of 15 mT. Remanence intensity in units of $Am^2\ Kg^{-1} \times 10^{-5}$.

Records of the Brunhes/Matuyama polarity transition are available from several sites in central Europe (Hoffman, 1979); the most reliable data are probably those from clays at Brüggen, Germany (Koci and Sibrava, 1976). In these sediments the polarity change corresponds to a virtual pole which crosses the equator near 40°W in close proximity to the path shown in text–fig.5. An age of 730 kyr BP for the polarity transition is also supported by the results from DSDP Hole 552A (Shackleton *et al.*, 1984) which show that the Brunhes/Matuyama transition occurs near the stage 19/18 boundary which would provide the proglacial climate conditions required for cave sedimentation. However, we do not rule out the possibility that the sediments may record an earlier event within the Matuyama chron although their age is probably less than 2.37 Myr, the estimated date for the first major northern hemisphere glacial event (Shackleton *et al.*, 1984). The combination of palaeomagnetic results and SEM grain textures in these sediments implies an earlier episode of full glaciation than any previously recognised in the British Pleistocene which may correlate with one of the pre-Cromerian cold phases in East Anglia (West, 1980).



Text–fig.5. Virtual geomagnetic pole path during the polarity transition. Data correspond to samples from 73 to 277 cm depth in the section shown in text–fig.2. Lines of latitude and longitude at 30° intervals. Zenithal equal area projection.

Acknowledgements

M.N. thanks the Royal Society for support and A.J. Clark (D.O.E.), L. Molyneux (Newcastle) and E. Hailwood (Southampton) for the use of laboratory facilities. R.P.S. acknowledges a University of Leicester Research studentship and a grant from the Bill Bishop Fund. A. Kendall kindly assisted in the cave.

References

Atkinson, T.C., Harmon, R.S., Smart, P.L. and Waltham, A.C., 1978. Palaeoclimatic and geomorphic implications of $^{230}Th/^{234}U$ dates on speleothems from Britain. *Nature* 272, 24-28.

Barbetti, M. and McElhinny, M., 1972. Evidence of a geomagnetic excursion 30,000 yr BP. *Nature* 239, 327-330.

Bögli, A., 1980. *Karst hydrology and physical speleology*. Springer-Verlag, Berlin.

Bonhommet, N. and Zähringer, J., 1969. Palaeomagnetism and potassium argon age determinations of the Laschamp geomagnetic polarity event. *Earth planet. Sci. Lett.* 6, 43-46.

Bull, P.A., 1980. Towards a reconstruction of timescales and palaeo-environments from cave sediment studies. In Cullingford, R.A., Davidson, D.A. and Lewin, J. (Eds.) *Timescales in Geomorphology*. John Wiley and Sons, London.

Burek, C.V., 1977. The Pleistocene Ice Age and after. In Ford, T.D., (Ed.) *Limestones and caves of the Peak District*. Geo Books, Norwich.

Creer, K.M., 1959. A.C. demagnetisation of unstable Triassic Keuper marls from S.W. England. *Geophys. J.R. astr. Soc.* 2, 261-275.

Creer, K.M., 1981. Long-period geomagnetic secular variations since 12,000 yr BP. *Nature* 292, 208-212.

Creer, K.M., 1982. Lake sediments as recorders of geomagnetic field variations - applications to dating post-glacial sediments. *Hydrobiologia* 92, 587-596.

Creer, K.M. and Kopper, J.S., 1976. Secular oscillations of the geomagnetic field recorded by sediments deposited in caves in the Mediterranean region. *Geophys. J.R. astr. Soc.* 45, 35-58.

Creer, K.M. and Tucholka, P., 1982a. Secular variation in lake sediments: a discussion of North American and European results. *Phil. Trans. R. Soc. Lond.*, A 303, 87-102.

Creer, K.M. and Tucholka, P., 1982b. The shape of the geomagnetic field through the last 8,500 years over part of the northern hemisphere. *J. Geophys.* 51, 188-198.

Ford, T.D. and Burek, C.V., 1976. Anomalous limestone gorges in Derbyshire. *Mercian Geol.* 6, 59-66.

Ford, T.D. and Worley, N.E., 1977. Phreatic caves and sediments at Matlock, Derbyshire. *Proc. 7th Int. Speleol. Congr.*, Sheffield, 194-196.

Gascoyne, M., Currant, A.P. and Lord, T.C., 1981. Ipswichian fauna of Victoria Cave and the marine palaeoclimatic record. *Nature* 294, 652-654.

Hamilton, N. and Rees, A.I., 1970. The use of magnetic fabric in palaeocurrent estimation. In Runcorn, S.K. (Ed.) *Palaeogeophysics*. Academic Press, London.

Hillhouse, J. and Cox, A., 1976. Brunhes- Matuyama polarity transition. *Earth planet. Sci. Lett.* 29, 51-64.

Hoffman, K.A., 1979. Behaviour of the geodynamo during reversal: a phenomenological model. *Earth planet. Sci. Lett.* 44, 7-17.

Kawai, N., Yaskawa, K., Nakajima, T., Torii, M. and Horie, S., 1972. Oscillating geomagnetic field with a recurring reversal discovered from Lake Biwa. *Proc. Jpn. Acad.* 48, 186-190.

Koci, A. and Sibrava, V., 1976. The Brunhes-Matuyama boundary at central European localities. In *Quaternary glaciations in the northern hemisphere*. Rep. no. 3, Proj. 73/1/24 Prague 135.

Margolis, S.V. and Krinsley, D.H., 1974. Processes of formation and environmental occurrence of microfeatures on detrital quartz grains. *Am. J. Sci.* 274, 440-464.

Molyneux, L., 1971. A complete result magnetometer for measuring the remanent magnetisation of rocks. *Geophys. J.R. astr. Soc.* 24, 373-382.

Ninkovitch, D., Opdyke, N., Heezen, B.C. and Foster J.H., 1966. Palaeomagnetic stratigraphy, rates of deposition and tephrachronology in North Pacific deep-sea sediments. *Earth planet. Sci. Lett.* 1, 476-492.

Noel, M., 1983. The magnetic remanence and anisotropy of susceptibility of cave sediments from Agen Allwedd, South Wales. *Geophys. J.R. astr. Soc.* 72, 557-570.

Noel, M. and St. Pierre, S., 1984. The Palaeomagnetism and magnetic fabric of cave sediments from Grønligrotta and Jordbrugrotta, Norway. *Geophys. J.R. astr. Soc.* 78, 231-239.

Schmidt, V.A., 1982. Magnetostratigraphy of sediments in Mammoth Cave, Kentucky. *Science* 217, 827-829.

Shackleton, N.J. and Opdyke, N.D, 1973. Oxygen isotope and palaeomagnetic stratigraphy of equatorial Pacific core V28-238: oxygen isotope temperatures and ice volumes on a 10^5 year and a 10^6 year scale. *Quaternary Research* 3, 39-55.

Shackleton, N.J., Backman, J., Zimmerman, H., Kent, D.V., Hall, M.A., Roberts, D.G., Schitker, D., Baldaug, J.G., Despraines, R., Homrighausen, R., Huddlestun, P., Keene, J.R., Kaltenback, A.J., Krumsiek, K.A.O., Norton, A.C., Murray, J.W. and Westberg-Smith, J., 1984. Oxygen isotope calibration of the onset of ice-rafting and history of glaciation in the north Atlantic region. *Nature* 307, 620-623.

Shaw, R.P., 1984. Karstic sediments, residual and alluvial ore deposits in the Peak District of Derbyshire. Unpub. Ph.D. Thesis, University of Leicester.

Singh, J., Sanderson, D.J. and Tarling, D.H., 1975. The magnetic susceptibility anisotropy of deformed rocks from North Cornwall, England. *Tectonophys.* 27, 141-153.

Smith, J.D. and Foster, J.H., 1969. Geomagnetic reversal in Brunhes normal polarity epoch. *Science* 163, 565-567.

Stober, J.C. and Thompson, R., 1977. Palaeomagnetic secular variation studies of Finnish lake sediment and the carriers of remanence. *Earth planet. Sci. Lett.* 37, 139-149.

Warriner, D., Willies, L. and Flindall, R., 1981. Ringing Rake and Masson Soughs and the mines on the east side of Masson Hill, Matlock. *Bull. Peak Dist. Mines hist. Soc.* 8, 65-102.

West R.G., 1980. *The pre-glacial Pleistocene of the Norfolk and Suffolk coasts.* Cambridge University Press.

Mark Noel
Department of Geology
University of Sheffield
Sheffield S3 7HF

Richard P. Shaw and Trevor D. Ford
Department of Geology
University of Leicester
Leicester LE1 7RH