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MAGNETIC MINERALOGY OF THE LOWER GONDWANA FORMATIONS OF INDIA - PRELIMINARY RESULTS FROM THE DAMODAR VALLEY

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Abstract: As part of a reevaluation of the suitability of the sediments of the Late Palaeozoic - Early Mesozoic Lower Gondwana Formations of Peninsula India for palaeomagnetic study, a detailed rock magnetic study has been carried out on rocks from two coalfields in the Damodar Valley. Results show wide variations in the relative contribution of paramagnetic and ferromagnetic minerals to the susceptibility. Whilst some horizons have a stable remanent magnetisation, pyrite seems to be the dominant iron mineral in the carbon-rich units, making them unsuitable for palaeomagnetism.

Keywords: Gondwana Formations, Damodar Valley, magnetic mineralogy, sediments, rock magnetism.

Introduction

From Late Carboniferous times onwards, continental sediments of the Lower Gondwana Formations were deposited on the Precambrian shield of Peninsula India (Krishnan 1968, Pascoe 1959). The original extent of these sediments is unclear, but they are now restricted to a number of basins, which are aligned along three linear belts within the Precambrian shield (Fig. 1), the E - W Damuda trend, the minor NW - SE Mahanadi trend and the narrow NW - SE Godavani trend (Sen 1991). These appear to mark zones of weakness in the Precambrian shield. There is evidence for differential subsidence (Khan & Tewari 1991) and syndepositional faulting (Geological Survey of India, unpub. data) within the basins, though the present lateral extent of the sediments may be partially due to later faulting, with a strike-slip component related to the breakup of the Gondwana supercontinent in the Mesozoic.

If these lineaments mark strike-slip fault zones, then the sedimentary basins along them may have undergone differential rotation, which could be detected by detailed palaeomagnetic studies of the different basins. Palaeomagnetic study may also assist the correlation between the various basins, which has proved difficult. Although the onset of sedimentation in many of the basins is marked by the diamictites and other sediments of the Talchir Group recording the Late Carboniferous Gondwana glaciation (Das & Sen 1980; Sen 1991), the subsequent depositional histories vary, particularly between the different belts of basins. Correlation has been made more difficult by a lack of suitable zone fossils in many of the units.

Earlier palaeomagnetic work on the Gondwana sediments in the late 1960s and early 1970s by Indian (Athavale et al. 1970; Bhalla & Verma 1969; Verma & Bhalla 1968) and Dutch (Klootwijk 1974 1975; Wesink 1968, 1973; Wesink & Klootwijk 1968) workers was intended to define an apparent polar wander path for the Indian subcontinent. In this they were largely successful, though overprinting from the later Deccan igneous activity proved a problem in some areas (Klootwijk 1975). In this new study we aim to determine a magnetostratigraphy for the various Gondwana Formations from several different areas in order to aid cross-correlation between the basins, and also to determine whether inter-basinal rotation has occurred.

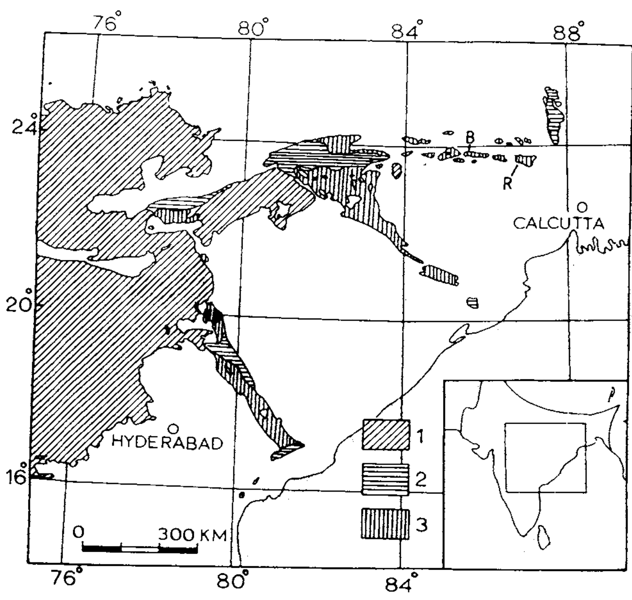

Fig. 1. Geological sketch map of central and eastern India (after Klootwijk (1974)) showing outcrops of:
1 - Deccan Traps; 2 - Upper Gondwana Formations (including Rajmahal Traps); 3 - Lower Gondwana Formations. The West Bokaro (B) and Raniganj (R) coalfields are indicated.

The earlier palaeomagnetic studies were concentrated on rocks exhibiting a reddish colour, presumably haematite-rich sediments. As part of the new study it will necessary to evaluate the palaeomagnetic potential of all sediment types. This paper describes the preliminary results of rock magnetic experiments on a range of sediments from two coalfields in the Damodar Valley which form part of the Damuda trend, the Raniganj and West Bokaro Basins (Fig. 1).

Stratigraphy

The two basins lie towards the eastern end of the Damuda trend, and have a long history of coal mining dating back to the last century. The stratigraphic succession is similar in both basins (Fig. 2). Variations in subsidence rates are indicated by the variable formation thicknesses, and the absence of the oldest formations in many parts of the basins.

The oldest Gondwana units are the glacial sediments of the Talchir Formation, which cover the largely granitic Precambrian basement. These are well exposed in the west of the West Bokaro basin. The basal diamictites pass upwards into greenish silts and sandstones with intercalated conglomeratic units, some of which seem to have been ice-rafted. These are succeeded by a more argillaceous sequence of mudstones, silts and fine sands, interpreted as glacial outwash deposits. The Talchir sequence in West Bokaro has been interpreted as representing multiple glacial retreat and advance (Das & Sen 1980).

The Talchir Formation is followed by the fluvial Karharbari Formation. In West Bokaro this is commonly a dark micaceous greywacke of variable grainsize, with feldspar crystals of up to several centimetres across derived from the Precambrian basement. Examination shows the dark coloration to be caused by carbon derived from plant debris.

The overlying Barakar Formation marks a major expansion of the Gondwana basins with more widespread sedimentation and subsidence. Up to 880 m of fluvial sediments were deposited: these exhibit cyclothems of coarse sandstones, silts, shales and coals (Khan & Tewari 1991).

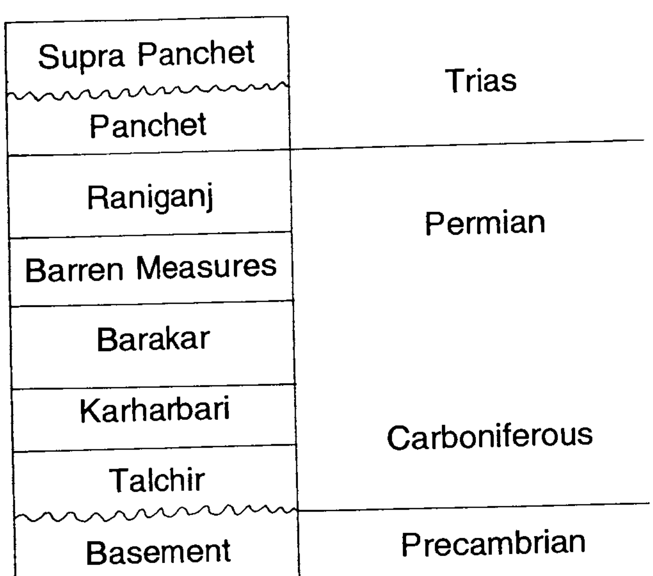

Fig. 2. Simplified stratigraphy of West Bokaro and Raniganj coalfields.

The Barren Measure Formation is, as its name suggests, devoid of coal. It comprises darkish shales with ironstone bands and lenticular sandstone bands. It was followed by the Raniganj Formation, whose cyclic sedimentation is similar to that of the Barakar Formation, though the sandstones tend to be finer grained.

The end of the Permian seems to have been marked by a change in the depositional environment: the coal measures of the Raniganj Formation were superseded by the alluvial deposits of the Triassic Panchet Formation. Greenish sandstones, siltstones and clays make up the lower part of the Panchet - these pass upwards into alternating green and chocolate coloured clays, with occasional sandstone units.

The youngest Gondwana rocks in the Damodar Valley are the coarse sandstones and conglomerates of the Supra-Panchet Formation. These cover the Panchet rocks unconformably, and mark a period of renewed tectonic activity and erosion.

The Lower Gondwana sediments in the Damodar Valley have been intruded by two phases of dykes: a series of lamprophyres, and a series of basic dykes. The lamprophyres are thought to be associated with the Rajmahal Trap volcanism in the Mid-Cretaceous, whereas the doleritic dykes have been linked both to the Rajmahal volcanism and the later Deccan volcanism (Athavale & Verma 1970). It is hoped that further palaeomagnetic measurements will be able to distinguish between Rajmahal-related and Deccan-related dykes.

Our studies so far have concentrated on the Palaeozoic part of the sequence. The main reason for this was the difficulty in finding suitable exposure of the Panchet and Supra-Panchet rocks.

Rock magnetic measurements

We have carried out rock magnetic experiments on a wide range of lithologies, in order to determine their suitability for palaeomagnetic study. These have included low-field susceptibility, alternating field (AF) demagnetisation, hysteresis, and strong-field thermomagnetic measurements. Determination of hysteresis loops using a Molspin vibrating sample magnetometer (VSM) with a peak field of 1T allowed us to determine the relative contributions of paramagnetic and ferromagnetic minerals to the susceptibility. These hysteresis measurements were repeated on samples that had been heated to 700 °C, in order to determine the type of alteration that would occur during routine thermal demagnetisation. A horizontal translation Curie balance (field ~0.4T) was used to determine the Curie point of the ferromagnetic minerals (if present in sufficient quantity). It also indicated the onset of thermal alteration in some samples.

Our studies so far have allowed us to divide the majority of the sediments into five main types, some of which are suitable for palaeomagnetic analysis, others of which are not.

Type 1 - redbeds

Red coloured sandstones and mudstones seem to be quite rare in these two coalfields. However, occasional horizons occur within the Barakar and Raniganj Formations. These seem to possess a stable remanence. The remanence carrier seems to be exclusively haematite: AF demagnetisation up to 100 mT has little or no effect on the remanence (Fig. 3a); there is a single Curie temperature of about 680 °C (Fig 3b); and the open hysteresis loop indicates a high coercive force mineral (Fig. 3c), which after heating to 700 °C is harder still (Fig. 3d).

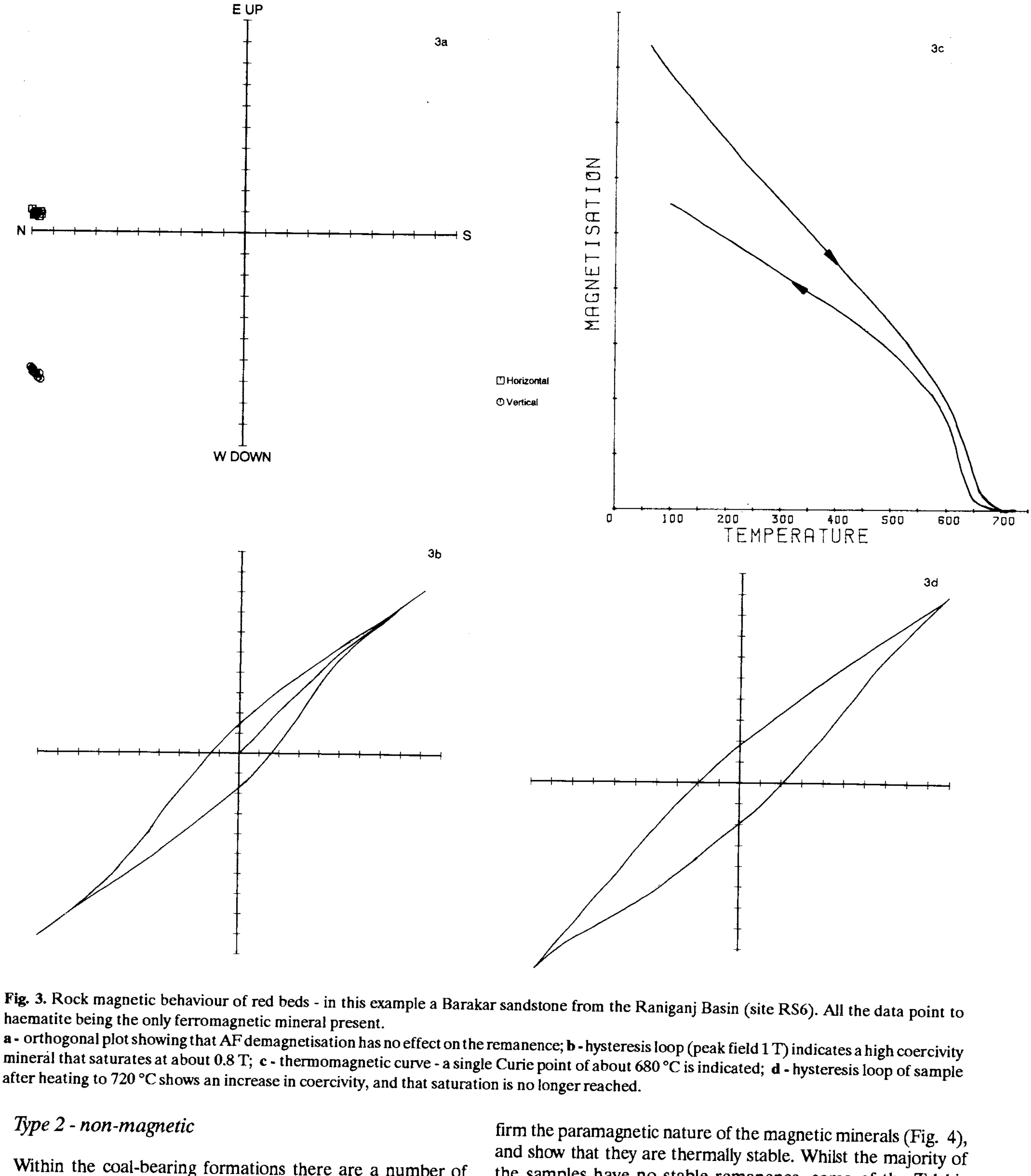

Fig. 3. Rock magnetic behaviour of red beds - in this example a Barakar sandstone from the Raniganj Basin (site RS6). All the data point to haematite being the only ferromagnetic mineral present.
a - orthogonal plot showing that AF demagnetisation has no effect on the remanence; **b** - hysteresis loop (peak field 1 T) indicates a high coercivity mineral that saturates at about 0.8 T; **c** - thermomagnetic curve - a single Curie point of about 680 °C is indicated; **d** - hysteresis loop of sample after heating to 720 °C shows an increase in coercivity, and that saturation is no longer reached.

Type 2 - non-magnetic

Within the coal-bearing formations there are a number of coarse whitish sandstones, which seem to be devoid of either ferromagnetic or paramagnetic material, with the result that there is no detectable remanence or susceptibility.

Type 3 - stable paramagnetic

A number of horizons have an easily measurable susceptibility, which from hysteresis measurements appears to be caused by paramagnetic material. Thermomagnetic measurements confirm the paramagnetic nature of the magnetic minerals (Fig. 4), and show that they are thermally stable. Whilst the majority of the samples have no stable remanence, some of the Talchir samples have a stable remanence which must be held by ferromagnetic minerals whose presence is obscured by the paramagnetic minerals (Fig. 5).

Type 4 - unstable paramagnetic

A considerable number of samples exhibit paramagnetic hysteresis behaviour (Fig. 6a), but after heating produce a large quantity of ferromagnetic material (Fig. 6b). Thermomagnetic curves

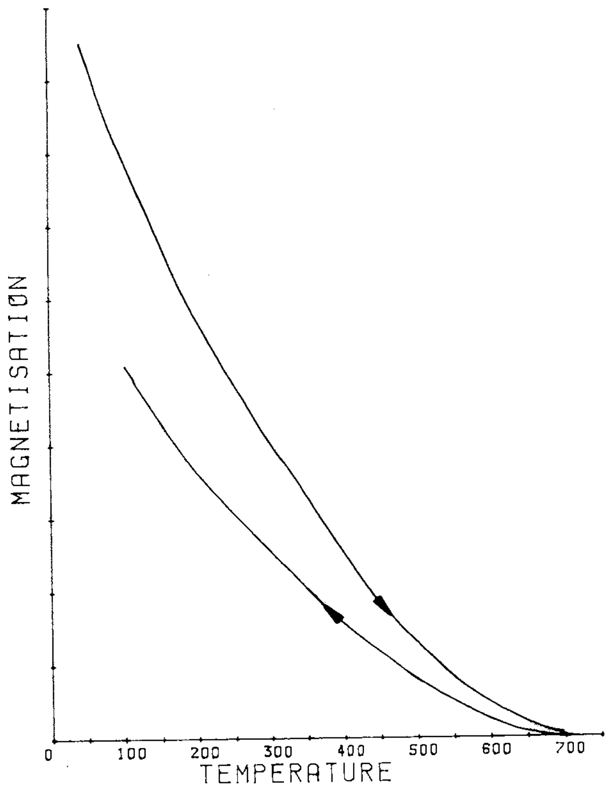

Fig. 4. A sample of Raniganj sandstone from the Raniganj Basin (site RS2) shows a typical paramagnetic thermomagnetic curve, indicating that ferromagnetic minerals are not present in significant quantities.

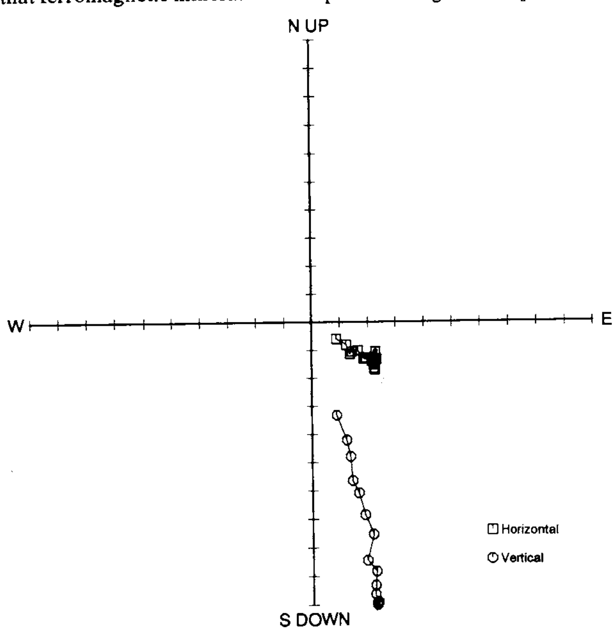

Fig. 5. An orthogonal plot of the AF demagnetisation up to 160 mT of a Talchir sandstone from West Bokaro (site BS6). The rock magnetic measurements failed to detect any ferromagnetic minerals, finding only paramagnetic ones. However, there is a significant ferromagnetic fraction which holds a stable remanence.

show the decrease in magnetisation expected from paramagnetic material until a little over 400 °C where the magnetisation begins to increase (Fig. 6c). The Curie temperature on heating seems to be about 570 °C, though on cooling from 700 °C it appears that a slightly higher temperature phase, interpreted as cation-deficient magnetite, has also been formed.

Further examination shows that this behaviour is confined to rocks where organic carbon has been preserved: carbonaceous sandstones, silts and mudstones. Similar behaviour has been noted by one of us (GJS) in sandstones and siltstones of the Carboniferous Coal Measures of western Europe. The presence of carbon indicates that these sediments formed under reducing conditions, and it seems likely that any iron was taken up into pyrite, FeS, rather than forming iron oxide. On heating in air pyrite will oxidise to form magnetite, and this seems to be the cause of the observed thermomagnetic behaviour (Fig. 6c).

Type 5 - mainly ferromagnetic

The ironstone bands in the Barren Measures also appear to be carriers of ferromagnetic minerals. From preliminary studies it seems that goethite and magnetite are the major ferromagnetic minerals, though other paramagnetic iron minerals are also present. Samples from some ironstone bands exhibit thermomagnetic behaviour similar to type 4. This behaviour is interpreted as due to the breakdown of paramagnetic iron minerals (probably either pyrite or iron carbonate) on heating to form magnetite. The ironstones are thought to be diagenetic in origin, but there is no evidence as to the timing of their formation. Doubt about the primary nature of a remanence held by ironstone bands has been expressed in the past (Klootwijk 1974).

Discussion

Our preliminary studies show that not all lithologies are suitable for palaeomagnetic study. This will make it more difficult to construct a magnetostratigraphy for the various Gondwana basins, and to determine whether inter-basinal rotations have occurred. One conclusion that could be drawn is that red-beds are the only horizons worth sampling. However, this is too simplistic.

Iron seems to have been present in solution at most times, and the geochemistry of the sediment has been the major controlling factor in deciding whether the iron is locked into iron oxides, iron sulphides or other iron minerals, or leached away. The geochemistry will depend mainly on the sedimentation rate and the supply of organic material.

The nature of the basement has also been important in controlling the magnetisation of the sediments. The Precambrian basement in the West Bokaro area is predominantly granitic, though other rock types were observed within the Talchir diamictites. Pilot palaeomagnetic measurements of clasts of basement material show magnetisation levels that are approaching the noise level of the magnetometer in most cases. This means that there is no source of detrital magnetite for the glacial and fluvial sediments of these basins.

The rock magnetic data suggest that there is a good possibility of obtaining reliable palaeomagnetic data from some horizons within the Palaeozoic part of the Gondwana basins of the Damodar Valley, and not only from red beds.

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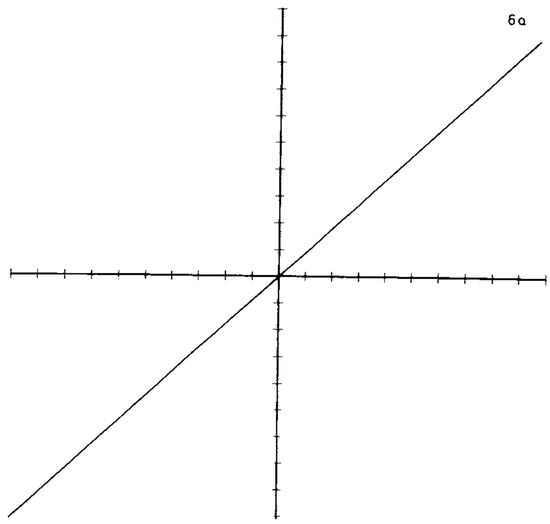

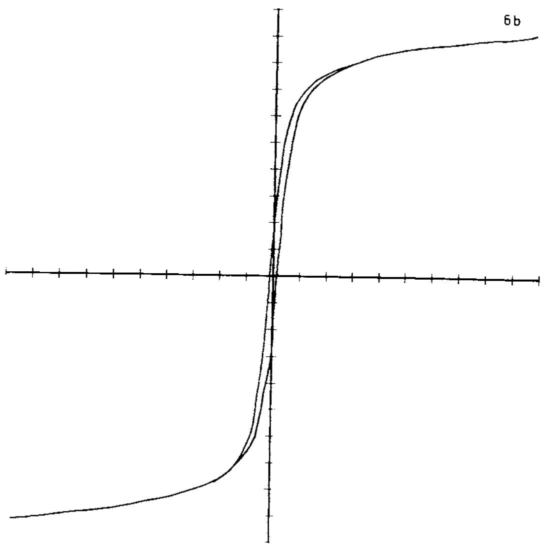

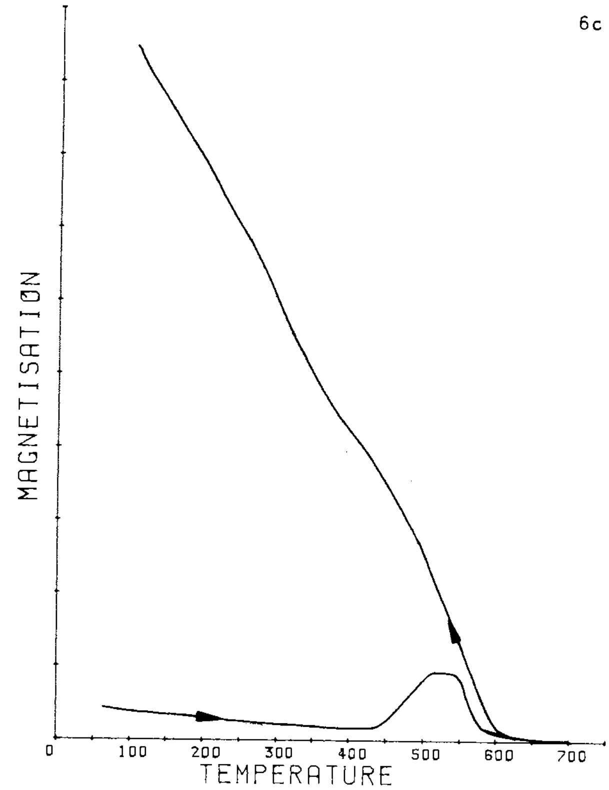

Fig. 6. Carbon-rich sediments all show behaviour similar to this carbonaceous Raniganj siltstone from West Bokaro (site BS11):
a - prior to heating the VSM shows typical paramagnetic behaviour with a linear increase in induced magnetisation with field; **b** - after heating to 720 °C, and subsequent cooling to room temperature,the hysteresis loop is shows a considerable amount of low coercivity ferromagnetic material; **c** - the thermomagnetic curve shows that the magnetisation begins to increase at about 430 °C. The heating curve indicates that magnetite has formed, but the increase in Curie temperature observed in the cooling curve may indicate the formation of cation-deficient magnetite.

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References

Athavale R. N. & Verma R. K., 1970: Palaeomagnetic results on Gondwana dykes from the Damodar Valley coalfields and their bearing on the sequence of Mesozoic igneous activity in India. *Geophys. J.*, 20, 303 - 316.

Athavale R. N., Verma R. K., Bhalla M. S. & Pullaiah G., 1970: Drift of the Indian sub-continent since Precambrian times. In: Runcorn S. K. (Ed.): *Palaeogeophysics. Academic Press*, London, 291 - 305.

Bhalla M. S. & Verma R. K., 1969: Palaeomagnetism of Triassic Parsora sandstones from India. *Phys. Earth Planet. Inter.*, 2, 138 - 146.

Das S. N. & Sen D. P., 1980 Depositional history of Permocarboniferous tillites and associated sediments in W. Bokaro Gondwana basin, Bihar, India. *Bull. Geol. Soc. India*, 21, 30 - 38.

Khan Z. A. & Tewari R. C., 1991: Net subsidence and number of cycles; their interrelationship in different Permian Gondwana basins of peninsular India. *Sediment. Geol.*, 73, 161 - 169.

Klootwijk C. T., 1974: Palaeomagnetic results from some Panchet clay beds, Karanpura coalfield, Northeastern India. *Tectonophysics*, 21, 79 - 92.

Klootwijk C. T., 1975: Palaeomagnetism of Upper Permian Red Beds in the Wardha Valley, Central India. *Tectonophysics*, 25, 115 - 137.

Krishnan M. S., 1968: Geology of India and Burma. *Higginbothams*, Madras, 5th Ed. 289.

Pascoe E. H., 1959: A manual of the geology of India and Burma, 2. *Government Press*, Delhi, 485 - 1342.

Sen D. P., 1991: Sedimentation patterns of the Talchir Group in the Giridih Gondwana basin, India: a case of multiple glacial advance and retreat. *Palaeogeogr. palaeoclimat. palaeoecol.*, 86, 339 - 352.

Verma R. K. & Bhalla M. S., 1968: Palaeomagnetism of Kamthi sandstones of Upper Permian age from Godavary Valley. *J. Geophys. Res.*, 73, 703 - 709.

Wesink H., 1968: Palaeomagnetism of some Gondwana red beds from Central India. *Palaeogeogr. palaeoclimat. palaeoecol.*, 5, 323 - 343.

Wesink H., 1973: The India - Pakistan subcontinent and the Gondwana reconstructions based on palaeomagnetic results. In: Tarling D. H. & Runcorn S. K. (Eds.): *Implications of continental drift to the earth sciences, 1. Academic Press*, London, 103 - 116.

Wesink H. & Klootwijk C. T., 1968: The palaeomagnetism of the Talchir Series of the Lower Gondwana System, Central India. *Earth Planet. Sci. Lett.*, 4, 191 - 196.