JOURNAL OF GEOINTERFACE, Vol.1, No.1, July 2022 pp.8-15

Rock Magnetic Properties of a Paleolake Sedimentary sequence, Binta Basin, Kumaun Lesser Himalaya, India

M. Venkateshwarlu* and N. Ramesh Babu
CSIR-National Geophysical Research Institute, Uppal Road, Hyderabad-500007, India
*Corresponding author: mvwarlu@ngri.res.in

Abstract: The current paper presents the rock magnetic results from a lacustrine sediment sequence of a 17 m thick paleolake with unconsolidated sediments from the Binta basin in the Kumaun Lesser Himalaya, India. This paleolake is situated in the zone of the active North Almora Thrust (NAT). This work aims to characterize these sediments and test their suitability for carrying out paleomagnetic as well as palaeoclimatic studies, which are scarce in this region. Oriented samples from 108 sites (5 samples per site) were collected from the vertical levels of this sequence. The results mainly include measurements of magnetic susceptibility in the low field and high field with dual frequency, Natural Remanence Magnetization (NRM), and AF demagnetization which reveals hematite as the main remanence carrier with magnetite in accessory in a few of the representative samples. The more manent curves show reversible nature indicating no mineralogical alteration upon heating the samples and thus are thermally stable. The hysteresis loops of the analysed samples display consistently identical loops in the shape which was thinly opened and near but not wasp-waisted. The Isothermal Remanent Magnetisation (IRM) acquisition curves show a significant rise in saturation of magnetization ~ 400mT and above indicating that the samples carried hematite as the remanence carrier. SIRM, HIRM, S-ratio, and L-ratio parameters indicate the shape and size of the sediment grains which preserve the magnetic material within them.
Keywords: Rock Magnetism, Paleolake, Lesser Himalaya, Hematite.

Introduction

Geomagnetism, being the oldest Earth science, studies the Earth's magnetic field (EMF) and the way it changes with time. The fact is that the geomagnetic field, as recorded in rocks and sediments, undergoes a complete polarity reversal and has been well-known for many decades. Studies on rock magnetic parameters of sediments are very useful in establishing paleoenvironmental and paleoclimatic conditions during the deposition in the marine and continental realm. Mineral magnetism is a widely used technique to characterize the sediment source and their mixing patterns under a variety of depositional environments (Thompson and Oldfield, 1986; Yu and Oldfield, 1989, 1993; Walling et al., 1993; Lees, 1994; Walden, et al., 1997; Caitcheon, 1998; Sangode et al., 2007; Horng and Huh, 2011). The mineral magnetic parameters are also commonly used as a proxy for paleoenvironmental and paleoclimate reconstructions (Alekseeva et al., 2007; Geiss et al., 2008). With a set of remnant magnetic hysteresis parameters, mineral magnetism provides a robust technique of rapid and accurate qualitative and quantitative estimates on various aspects of sedimentation (Thompson and Oldfield, 1986; Evans and Heller, 1994), these studies were exercised previously in Bengal fan sediments (Sagar and Hall, 1990; Sangode et al., 2001). Quick and cost-effective magnetic measurements were attempted by many workers to arrive at the possible extent of industrial contamination, heavy metal (HM), petroleum hydrocarbons, and urban environments. The study areas spread from the Himalayan proglacial lakes to peninsular lakes (Lonar lake) and coastal (Kolleru) lakes of India. The study materials consisted of the Himalayan paleolake sediments, the wind-blown sediments called loess, core sediments from marine/lacustrine environments, surface lake-bed sediments, earthquake-affected soft sediments, top soils near thermal power plants, road dust particulates, plant leaves, and vegetable samples. The current paper presents the rock magnetic properties of a paleolake from the Binta basin, Kumaun Lesser Himalaya, India.

Geological setting and sampling

The Bagwalipokar paleolake (study area) is located in Binta basin, Kumaun Lesser Himalaya (Fig.1). The Binta basin is centrally eroded by the Gagas River which runs from north to south in two-thirds of the basin area, and east to the west direction in the remaining one-third area. The basin comprises two lithotectonic units, e.g., Almora Nappe in the outer Lesser Himalaya, and Krol Nappe in the Inner Lesser Himalaya which are separated by the North Almora Thrust (NAT). Almora Nappe comprises deformed rocks of the Almora crystalline (Misra, 1971), whereas Krol Nappe is composed of Rautgara, Gangolihat, and Berinag formations of the inner Lesser Himalaya (Valdiya,1980). The Krol Nappe is a highly folded and faulted sequence of limestone, slate, amphibolite, schist, and orthoquartzite (Taloor et al., 2017). Bagwalipokar paleolake is in the down current part of a 5km long and 2km wide inter-mountain valley, the excavated profile reveals a 17m thick lithological section comprising interbeds of sandy gravel, sandy clay, and micaceous sand. The rocks form the hillocks surrounding the valley fill deposits and also have acted as the sediment source to them. Figure 2 shows the representative field photograph of the Bagwalipokar paleolake sequence. The field investigations were conducted in the study area and collected a total of 540 oriented unconsolidated sediment samples from 108 sites in cylindrical plastic boxes (2.5 cm diameter x 2.5 cm height).

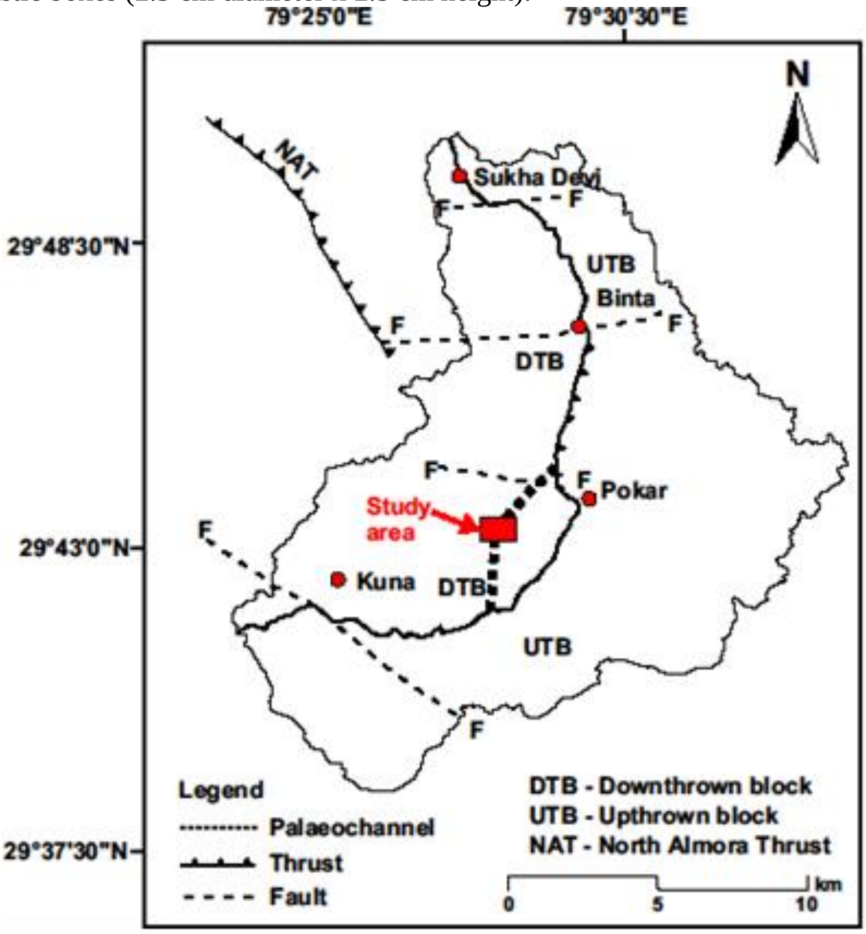

Fig. 1. Geomorphological features in the Binta basin, Kumaun Lesser Himalaya. The yellow rectangular box shows the study area (modified after Misra,1971).

Fig. 2. Lithosection of the Bagwalipokar paleolake, Binta basin, Kumaun Lesser Himalaya, Yellow rectangular box shows the sampling section.

Materials and methods

Natural Remanent Magnetization (NRM) of all the samples was measured using a mini spin Molspin spinner magnetometer (Magnetic Measurements, U.K.) and Dual speed JR-6 Spinner magnetometer (AGICO, Czechoslovakia). Low-field and high-field with dual- frequency susceptibility (k) of all the paleolake sediment samples were measured using MS-2 Dual- frequency Bartington Susceptibility Meter (Bartington,U.K.). Alternating Field (AF) demagnetization experiment is carried out using Molspin AF Demagnetiser (Magnetic Measurements, U.K.). The following magnetic parameters were measured at room temperature using an Advanced Variable Field Translation Balance (AVFTB). Saturation magnetization (Ms), Coercivity (Hc), Hysteresis loops, Saturation remanent magnetization (Mr), and Isothermal remanent magnetization (IRM) acquisition curves, and Thermoremanent curves were obtained. Saturation isothermal remanent magnetization (SIRM, IRM acquired at 1000 mT field) and isothermal remanent magnetization at the varying field were produced. The hysteresis parameters of the samples, including saturation remanence (Mrs), saturation magnetization (Ms), coercivity (Hc), and coercivity of remanence (Hcr) were calculated using hysteresis loops data to investigate the main magnetic carrier grain size and domain state. These values were evaluated to plot the Day diagram (Day et al., 1977) to identify domain states of magnetic minerals. Thermoremanent curves reveal primary magnetic minerals by determining the Curie temperature (Tc) and thermal change during the heating and cooling processes. The magnetic parameter HIRM was calculated as [(SIRM + IRM-300mT)/2] to separate the signals of hematite and/or goethite from magnetite or maghemite in terms of coercivity. S-ratio determines the proportion of high-coercive minerals in a ferrimagnetic mixture with low-coercive minerals as (IRM- 300mT/SIRM), while L-ratio calculates the effect of hardness of hematite on HIRM and S- ratio as [(SIRM + IRM-300mT)/ [(SIRM + IRM-100mT)] (Liu et al., 2012). All the measurements were carried out at the Paleomagnetism laboratory of CSIR-National Geophysical Research Institute, Hyderabad, India.

Results and discussion

Rock magnetism

Rock magnetism is a non-destructive and easy-access ethod, useful in identifying magnetic mineralogy. Rock magnetic analyses (thermoremanent curves, hysteresis loops, IRM acquisition curves, and coercivity spectra) were performed to understand the magnetic mineralogy, curie temperatures (Tc), mineral grain sizes, and domain state of samples. Magnetic signatures of transport and enrichment of magnetic particles in sedimentary sequences can be detected using environmentally sensitive, rapidly detectable, and physically predictable sedimentary processes (Thompson and Oldfield, 1986). An attempt is made in the present study to generate a more refined dataset using the available modern and sophisticated instrument, i.e. Advanced Variable Field Translation Balance (AVFTB).

AF Demagnetization

Few selected samples have been demagnetised to obtain the magnetization decay curves to know the remanent carrier minerals. Figure 3 represents the AF demagnetisation decay curves for the paleolake samples. As seen in this figure that the samples are showing different saturation levels and represent the remanence carrier minerals. Based on the observations, it is interpreted that the paleolake samples of Bagwalipokar carry hematite as the main and magnetite in accessory in a few of the samples as a remanence carrier.

Thermoremanent curves

The thermoremanent curves can be used to identify different types of magnetic materials (Dunlop and Ozdemir, 1997). Figure 4 shows the thermoremanent curves for Bagwalipokar paleolake samples. All the analysed samples show the reversible nature of thermoremanent curves, which suggests no alteration of the magnetic minerals have been taken place. A gentle magnetic susceptibility increase in the cooling curves from 400°C is observed in sample number SB95 suggesting bulk magnetic mineralogy is dominated by ferrimagnetic minerals like magnetite (Dunlop and Ozdemir, 1997) in a few of the samples otherwise most of the samples carry hematite as the main remanence carrier mineral in these sediments.

In the present study NRM, Susceptibility, IRM, Hysteresis curves, Thermoremanent curves SIRM, HIRM, S-ratio, L-ration, and AF demagnetization decay curves were analysed to characterize the paleolake sedimentary magnetic properties of some selected samples.

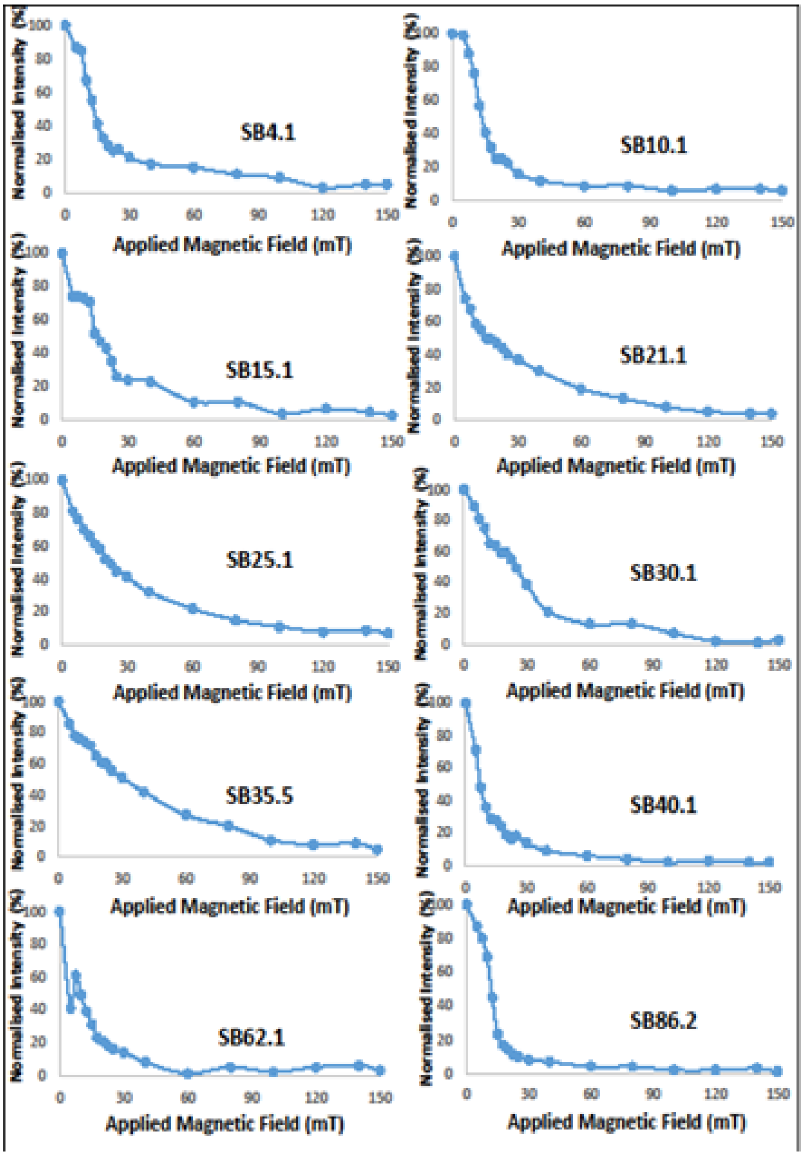

Fig. 3. AF demagnetization decay curves for few representative paleolake samples from the Binta basin, Kumaun Lesser Himalaya, India.

Hysteresis loop study

The magnetic hysteresis loop analysis was conducted on some selected samples. The magnetic hysteresis loops obtained for these samples are presented in Figure 5. The samples withdifferent mineral assemblages and dissimilar grain sizes showcase different shapes of magnetic hysteresis loops. The remanence ratio (Mrs/Ms) and coercivity ratio (Hcr/Hc) were determined from the hysteresis parameters of saturation magnetization (Ms), saturation remanence (Mrs), coercivity force (Hc), and coercivity remanence (Hcr). These ratios (Mrs/Ms versus Hcr/Hc) are plotted on a 'Day plot' (Day et al., 1977) and shown in Figure 6. This Day plot specifies and distinguishes the Single Domain (SD), Pseudo-Single Domain (PSD), and Multidomain (MD) magnetic grains and will also serve as a better magnetic granulometry indicator when plotted together with theoretical mixing curves (Dunlop, 2002). The samples have Mrs/Ms ranging from0.17 to 0.18, and Hcr/ Hc ranging from 3.06 to 3.19. The loops in Figure 5 show S-curve nature and are not saturated till 800mT indicating the presence of magnetic mineral hematite in the sediments. The samples display consistently look alike hysteresis loops in the near wasp- waisted shape due to fine-grain size magnetic mineral. These results reveal that most of the recorded remanence is held by grains falling within the PSD region (Fig.6), as is typical for natural sedimentary samples. 0.17 to 0.18, and Hcr/ Hc ranging from 3.06 to 3.19. The loops in Figure 5 show S-curve nature and are not saturated till 800mT indicating the presence of magnetic mineral hematite in the sediments. The samples display consistently look alike hysteresis loops in the near wasp- waisted shape due to fine-grain size magnetic mineral. These results reveal that most of the recorded remanence is held by grains falling within the PSD region (Fig.6), as is typical for natural sedimentary samples.

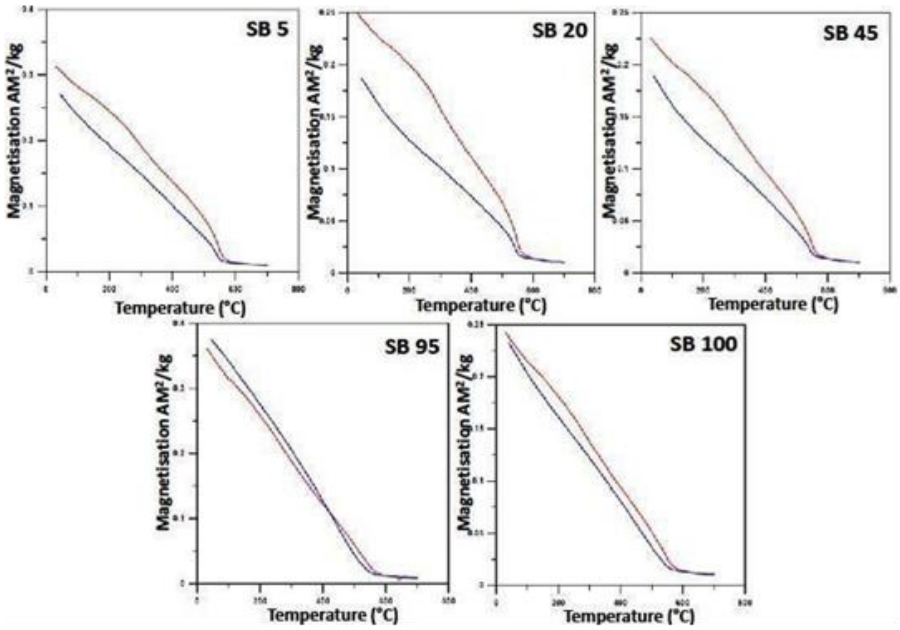

Fig. 4. Representative thermoremanent curves (magnetization versus temperature) for the samples from Bagwalipokar paleolake. Red lines indicate heating cycles and blue lines are cooling cycles.

IRM acquisition curves and coercivity spectra

The IRM acquisition curves are significant in identifying the saturation magnetisation of different rock types. The maximum applied magnetic field is 1 Tesla. All the samples show a significant rise in IRM acquisition curves with saturation at ~ 400mT and above (Fig. 7). The coercivity spectra for the same set of samples show coercivity values above 20mT (Fig. 8), which deciphers the predominance of high coercive magnetic minerals in the samples. Both IRM acquisition curves and coercivity spectra (Fig. 7 and 8) suggest that the resultant remanent magnetization is dominated by high coercivity magnetic minerals. The rock magnetic properties of the Bagwalipokar paleolake samples suggest that the samples have minor variations. In the present study NRM, Susceptibility, IRM, Hysteresis curves, Thermoremanent curves SIRM, HIRM, S-ratio, L-ration, and AF demagnetization decay curves were analysed to characterize the paleolake sedimentary magnetic properties of some selected samples (Table- 1). The NRM values vary from 1.6 x 10-1 to 1.2 x 10-4 indicating the variations within the samples. The susceptibility values vary from 1.4 x 10-3 to 1.1 x 10-4. The presence of many magnetic mineralogical phases in samples is revealed by the parameters: SIRM, HIRM, S- ratio, and L- ratio values. The values of SIRM indicate the concentration of magnetic grains whereas the variation of HIRM depends upon the concentration of high-coercive magnetic minerals with respect to low-coercive magnetic minerals present in studied samples. The values of S-ratio revealed that the samples were influenced by high-coercive magnetic minerals such as hematite and/or goethite. The S-ration values in the studied samples range from 0 to 0.8, indicating lower mass-specific magnetic susceptibility. This pattern indicates antiferromagnetic hematite or highly heterogeneous magnetite. The values of L-ratio reveal the effect of hardness of hematite on the values of S-ratio and IRM (Evans & Heller, 2003).

In the present study NRM, Susceptibility, IRM, Hysteresis curves, Thermoremanent curves SIRM, HIRM, S-ratio, L-ration, and AF demagnetization decay curves were analysed to characterize the paleolake sedimentary magnetic properties of some selected samples (Table- 1). The NRM values vary from 1.6 x 10-1 to 1.2 x 10-4 indicating the variations within the samples. The susceptibility values vary from 1.4 x 10-3 to 1.1 x 10-4. The presence of many magnetic mineralogical phases in samples is revealed by the parameters: SIRM, HIRM, S- ratio, and L-ratio values. The values of SIRM indicate the concentration of magnetic grains whereas the variation of HIRM depends upon the concentration of high-coercive magnetic minerals with respect to low-coercive magnetic minerals present in studied

samples. The values of S-ratio revealed that the samples were influenced by high-coercive magnetic minerals such as hematite and/or goethite. The S-ration values in the studied samples range from 0 to 0.8, indicating lower mass-specific magnetic susceptibility. This pattern indicates antiferromagnetic hematite or highly heterogeneous magnetite. The values of L-ratio reveal the effect of hardness of hematite on the values of S-ratio and IRM (Evans and Heller, 2003).

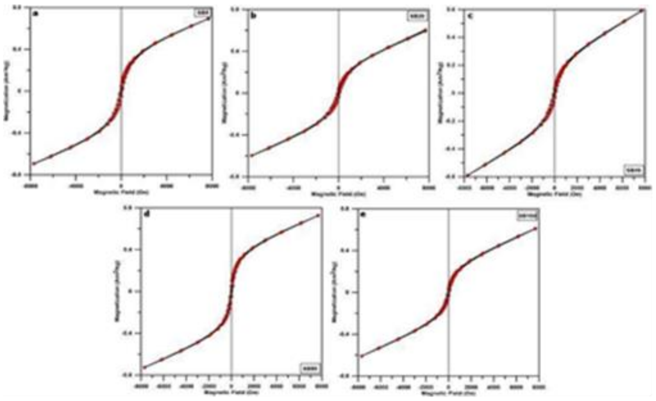

Fig. 5. Representative hysteresis loops for the samples from Bagwalipokar section, Kumaun Lesser Himalayas, India.

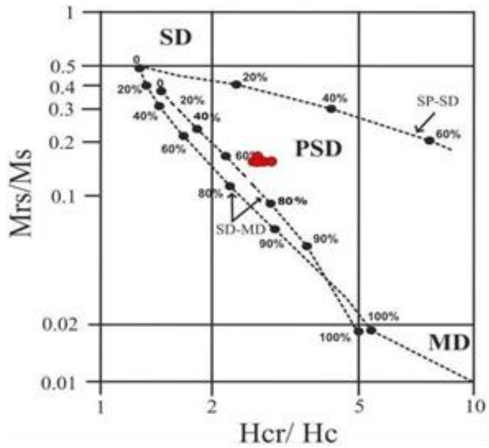

Fig. 6. The hysteresis parameters, Mrs/ Ms and Hcr/ Hc are plotted on a Day plot (Day et al., 1977) with the theoretical SD-MD and SP-SD mixing lines from Dunlop (2002).

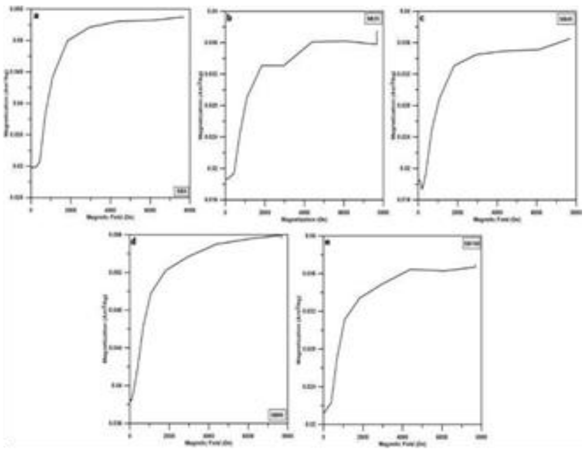

Fig. 7. Stepwise acquisition of isothermal remanent magnetization (IRM) in field up to 1T of Bagwalipokar paleolake samples.

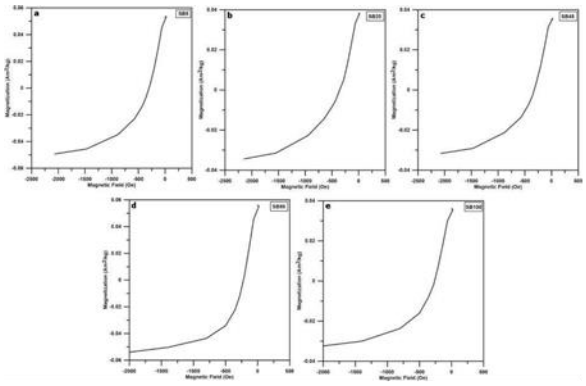

Fig. 8. Backfield coercivity responses of the samples for Bagwalipokar paleolake sediments.

Table 1. Descriptive statistics of magnetic parameters of paleolake samples from the study area.

S No	NRM	χ	S-ratio	HIRM	SIRM	L-ration
SB4.1	1.3E-03	8.1E-04	0.95	5.53	1.47	1.25
SB10.1	6.9E-01	7.8E-04	0.91	5.36	1.39	1.26
SB15.1	1.4E-03	7.5E-04	0.94	5.39	1.16	1.31
SB21.1	4.3E-01	3.0E-04	0.87	2.11	0.45	1.00
SB25.1	3.7E-04	1.3E-04	0.85	0.59	0.13	1.41
SB30.1	1.2E-04	1.4E-04	0.84	1.05	0.20	1.45
SB35.1	3.5E+02	1.1E-04	0.87	0.70	0.13	1.47
SB45.1	7.9E-04	3.6E-04	0.87	2.51	0.55	1.33
SB62.1	9.0E-04	1.4E-03	0.94	7.51	2.02	1.13
SB86.1	1.7E-03	1.4E-03	0.95	6.13	1.68	1.11

Conclusions

Rock magnetic investigations on Bagwalipokar paleolake sediments resulted in the following findings:

a. The main magnetic carrier mineral in these samples is a fine-grained pseudo single domain (PSD) hematite.
b. Thermoremanent curves indicate none of the samples show the reversible nature of thermoremanent curves suggesting the transformation of magnetic minerals from unstable to stable magnetic phases.
c. The hysteresis loops show S-curve and are not saturated till 800mT indicating that magnetic mineral, hematite is present in the sediments.
d. The Isothermal Remanent Magnetisation (IRM) acquisition curves of the samples show a significant rise in saturation at ~ 400mT and above indicating that the samples carried hematite as the remanence carrier.

Acknowledgments

The authors are thankful to the Director, CSIR-NGRI, Hyderabad for the permission to publish this paper. The authors are also thankful to B. S. Kotlia and Anoop Kumar Singh for their help in the fieldwork. This work is a part of the project FBR-MLP-0003-28(AM).

References

Alekseeva, T., Alekseev, A., Maher, B.A. and Demkin, V. (2007) Late Holocene climate reconstructions for the Russian steppe, based on mineralogical and magnetic properties of buried palaeosols. Palaeogeogr. Palaeoclimatol. Palaeoecol., v.249(1), pp.103-127.

Caitcheon, G.G. (1998) The application of environmental magnetism to sediment source tracing: A new approach; CSIRO Land and Water technical report, 21/98.

Day, R., Fuller, M. and Schmidt V.A. (1977) Hysteresis properties of titanomagnetites: grain-size and compositional dependence. Phys. Earth Planet. Inter., 13(4), pp.260–267.

Dunlop, D.J. and Ozdemir, O. (1997) Rock Magnetism, Fundamentals, and Frontiers. Cambridge University Press, Cambridge 1-595.

Dunlop, D.J. (2002) Theory and application of the day plot (Mrs/Ms versus Hcr/Hc) 2. Application to data for rocks, sediments, and soils. J. Geophys. Res. 107, B3, 2057.

Evans, M.E. and Heller, F. (1994) Magnetic enhancement and paleoclimate: study of a loess/paleosol couplet across the Loess Plateau of China. Geophys. Jour. Int., v.117, pp257-264.

Evans, M.E. and Heller, F. (2003) Environmental magnetism: Principles and applications of enviromagnetics. Journal of Quaternary Science, Academic press, pp.311.

Geiss, C.E., Egli, R. and Zanner, C.W. (2008) Direct estimates of pedogenic magnetite as a tool to reconstruct past climates from buried soils. Jour. Geophys. Res., v.113, B11102.

Horng, C.S. and Huh, C.A. (2011) Magnetic properties as tracers for source-to-sink dispersal of sediments: A case study in the Taiwan Strait. Earth Planet. Sci. Lett., 309(1), pp.141-152.

Lees, J.A. (1994) Modelling the magnetic properties of natural and environmental materials. Unpublished Ph.D. Thesis, University of Coventry, U.K.

Liu, Q., Roberts, A.P., Larrasoana, J.C., Banerjee, S.K., Guyodo, Y., Tauxe, L. and Oldfield, F. (2012) Environmental magnetism: Principles and applications. Reviews of Geophysics, v.50, RG4002.

Misra, K.S. (1971) Note on the geology of the area around Dwarahat, Almora district, U.P. Himalayan Geology, v.1, pp.261-265.

Sagar, W.W. and Hall, S.A. (1990). Magnetic properties of black mud turbidites form ODP leg 116, distal Bengal fan, Indian Ocean. In: J.R. Cochran and D.A.V.O. Stow, D et al. (Eds.), Proc. Ocean Drilling Program. Scientific Results, v.116, pp.317-336.

Sangode, S.J., Sinha, R., Phartiyal, B., Chauhan, O. S., Mazari, R.K., Bagati, T.N., Suresh, N., Mishra, S., Kumar, R. and Bhattacharjee, P. (2007). Environmental magnetic studies on some Quaternary sediments of varied depositional settings in the Indian sub- continent. Quat. Int., v.159, pp.102-118.

Sangode, S.J., Suresh, N. and Bagati, T.N. (2001) Godavari source in the Bengal fan sediments: results from magnetic susceptibility dispersal pattern. Curr. Sci., v.85(5), pp.660- 664.

Taloor, A.K., Ray, P.K.C., Jasrotia, A.S., Kotlia, B.S., Alam, A., Kumar, S.G., Kumar, R., Kumar, V. and Roy, S. (2017) Active tectonic deformation along reactivated faults in Binta basin in Kumaun Himalaya of north India: Inferences from tectono-geomorphic evaluation. Zeitschriftfür Geomorphologie, v.61(2), pp.159- 180.

Thompson, R. and Oldfield, F. (1986) Environmental Magnetism. Allen & Unwin, London, 20-22, 227.

Valdiya, K.S. (1980) Geology of Kumaun Lesser Himalaya. Wadia Institute of Himalayan Geology, Dehradun, 291.

Walden, J., Slattery, M.C. and Burt, T.P. (1997) Use of mineral magnetic measurements to fingerprint suspended sediment sources: approaches and techniques for data analysis. Jour. Hydrology, v.202(1-4), pp.353-372.

Walling, D.E., Woodward, C. and Nicholas, A.P. (1993) A multiparameter approach to fingerprinting suspended sediment sources. Tracers in Hydrology. Proceedings of the Yokohama Symposium, v.215, pp.329-338.

Yu, L. and Oldfield, F. (1989). A multivariate mixing model for identifying sediment source from magnetic measurements. Quat. Res., v.32, pp.168-181.

Yu, L. and Oldfield, F. (1993) Quantitative sediment source ascription using magnetic measurements in a reservoir catchment system near Nijar, SE Spain. Ear. Surf. Proc. Land., v.18, pp.441-454.

Manuscript received: 13-05-2022
Manuscript accepted: 28-06-2022