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Magnetic properties of dolerite dykes and lamprophyre sills from Jharia coal fields, Damodar valley basin, India

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ABSTRACT

The Gondwana (Early Permian to Early Cretaceous) basins of eastern India have been intruded by ultramafic-ultrapotassic and mafic (dolerite) dykes. Total 35 samples from 7 sites of dolerite dykes and lamprophyre sills have been collected from the Jharia coal field of the Damodar valley basin for rock magnetic studies. The investigations mainly comprise of magnetic susceptibility measurement, isothermal remanent magnetization (IRM), Lowrie-Fuller (L-F) test and thermomagnetic (K-T) experiment. The natural remanent magnetization (NRM) intensities measured on 450 specimens of dolerite dykes and lamprophyre sills show a mean value of 4.06 A/m and 0.003 A/m. Magnetic susceptibility values indicate mean values of 30.93 x 10^{-3} and 0.41 x 10^{-3} SI units. The Koenigsberger ratio (Q_n) value of dykes and sills show mean value of 3.47 and 0.19, respectively. Rock magnetic studies indicate that titano-magnetite/ magnetite of pseudo single domain (PSD)/ single domain (SD) type are the main magnetic minerals present in the studied samples of the Damodar valley basin.

INTRODUCTION

Cretaceous potassic dykes and sills at Jharia area intrude the Permo-Carboniferous coal-bearing Gondwana sediments of the Eastern Damodar Valley, Singhbhum craton. These intrusives are widely regarded as a part of the Mesozoic alkaline and Rajmahal flood basalt magmatism in the Eastern Indian shield (Srivastava et al., 2009). The Gondwana basins of Peninsular India are located along prominent river valleys, namely the Son, Damodar, Mahanadi, Godavari, and Satpura rivers. Some of these Gondwana basins are characterized by prominent lineaments, faults and high heat flow values (Acharya, 2000; Shankar et al., 1991). Geochemical studies on Precambrian mafic dyke swarms in the Chotanagpur gneissic complex (basement in the Damodar Valley) indicate a derivation from a lithospheric extensional environment (Kumar and Ahmad, 2007). Role of extension is also well understood in the evolution of the Gondwana sedimentary basins in the Damodar Valley (Chakraborty et al., 2003). Therefore, the alkaline potassic magmatism in the Jharia region is clearly sited in a "thin spot" - a region of pre-existing lithospheric extension. Geophysical studies involving heat flow and seismic methods demonstrate that the present day average lithospheric thickness (~65 km) beneath the Singhbhum craton is the thinnest amongst all the Indian cratons (Pandey and Agrawal, 1999). Therefore, the thinned lithosphere, its location at the margin of the Singhbhum craton and the inheritance of an ancient (Archaean) subducted component played a significant role in deciding the diverging characters of Jharia intrusives which contain a cratonic signature (lamproites and orangeite) as well as rift-related signature (exhibited by aillikites). The basic dykes of the Gondwana coalfields were dated 110-75 Ma by K-Ar method (Agrawal and Rama, 1976). These ages may be low due to sample alteration or analytical difficulties. However, these ages supported a continuum in the volcanic episodes between the earlier Rajmahal and the later Deccan volcanism. Recent Ar-Ar dating has confirmed two distinct age groups of 113.4±1.0 Ma and 64.4±0.03 Ma (Kent et al., 1997). Detailed rock magnetic studies have been performed and the magnetic minerals responsible for the remanent magnetization and their domain state have been reported for dolerite dykes and lamprophyre sills of the Jharia coal field of the Damodar valley basin in the present paper.

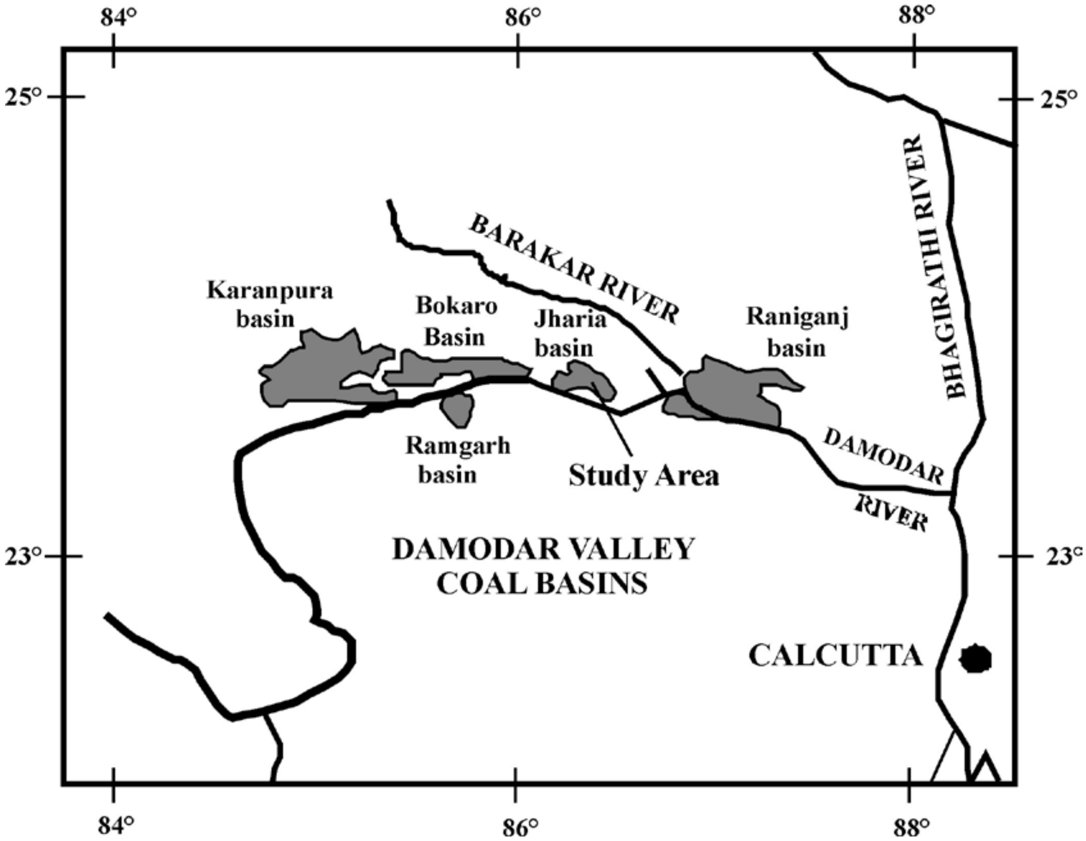

Figure 1. Generalized geological map showing the distribution of Gondwana Supergroup sediments of the Damodar valley, eastern India

GEOLOGY OF STUDY AREA

The east-west trending Damodar valley belt of Gondwana basins lies within the Chotanagpur granite gneiss belt at the northern most margin of the Singhbhum craton, eastern India (Fig-1). The Damodar valley hosts major Gondwana coal fields such as Ranigunj, Jharia, Bokaro and Karanpura (Mukherjee and Ghose, 1999; Mahadevan, 2002; Srivastava et al., 2009). Intrusion of two suites of igneous bodies, namely ultrapotassic–ultramafic and mafic rocks have been taken place. The ultramafic suite is represented by lamprophyres, lamproites and orangeites, while the mafic suite consists of dolerite dykes. All the dykes are showing NW-SE trend. The ultramafic suite has been studied by a number of researchers (Sanyal, 1964; Sarkar et al., 1980; Paul and Potts, 1981; Middlemost et al., 1988; Rock et al., 1992; Basu et al., 1997; Kent et al., 1998).

Jharia intrusives display a wide petrographic diversity; olivine, phlogopite and carbonate are the predominant phases whereas apatite and rutile constitute important accessories. Large scale intrusions of lamproites and lamprophyres are present as east-west trending dykes and sills, confined to the basin. Contemporaneous dolerite dykes occur within and external to the basin.

SAMPLING AND MEASUREMENTS

A total of 35 samples were collected from 7 intrusives (5 dolerite dykes and 2 lamprophyre sills), intruded into the Jharia coal fields of the Damodar valley. Samples have been collected from road cuttings, quarries and mines. These areas are selected aue to availability of dykes and sills and good exposures as shown by Athavale and Verma, 1970.

In the laboratory, 450 cylindrical specimens were prepared from 35 samples of standard size 2.5 cm diameter and 2.2 cm height to carry out the rock magnetic studies. The study comprises of NRM intensity and magnetic susceptibility (χ) measurements, isothermal remanent magnetization (IRM) and thermomagnetic (K-T) experiment. Natural remanent magnetization intensities were measured using Minispin Molspin spinner magnetometer (Molspin, UK). Magnetic susceptibilities were measured using Kappabridge MFK1-FA (Agico, Czech Republic). IRM studies have been carried out using pulse magnetizer and alternate field (AF) demagnetizer (Molspin, England).

ANALYSIS AND RESULTS

NRM Intensity (J_n)

The Natural Remanent Magnetization (NRM) intensity of all the specimens was measured on Minispin Molspin spinner magnetometer. The remanent magnetic intensity of dolerite dykes show a variation in values and range from 0.90 to 11.37 A/m with mean value of 4.06A/m, whereas, lamprophyre sill specimens range from 0.001 to 0.013 A/m with mean value of 0.003A/m. The NRM range and mean values (site-wise) are shown in Table 1 and their distribution is shown as a histogram in Figure 2 (a & d). The dyke specimens show a strong magnetization due to lightning strike. The sill specimens show a very low intensity.

Magnetic Susceptibility (χ)

Magnetic susceptibility is the 'magnetizability' of a material in the natural environment mainly tell us about Fe-bearing minerals that are found in soils, bricks, rocks, dust and sediments (Thomson and Oldfield, 1986). Magnetic susceptibility is a function of the concentration and mineralogy of the ferromagnetic (magnetite, maghemite, Fe-sulphides) minerals present, but can also depend on the strength of the applied magnetic field and the particle size distribution of the magnetic grains. In the absence of ferromagnetic minerals χ can be due to antiferromagnetic, paramagnetic and diamagnetic minerals. Magnetic susceptibility (χ) is also dependent on sample size and therefore, it is customary to present susceptibility as a mass normalized susceptibility (Mooney et al., 2002). The

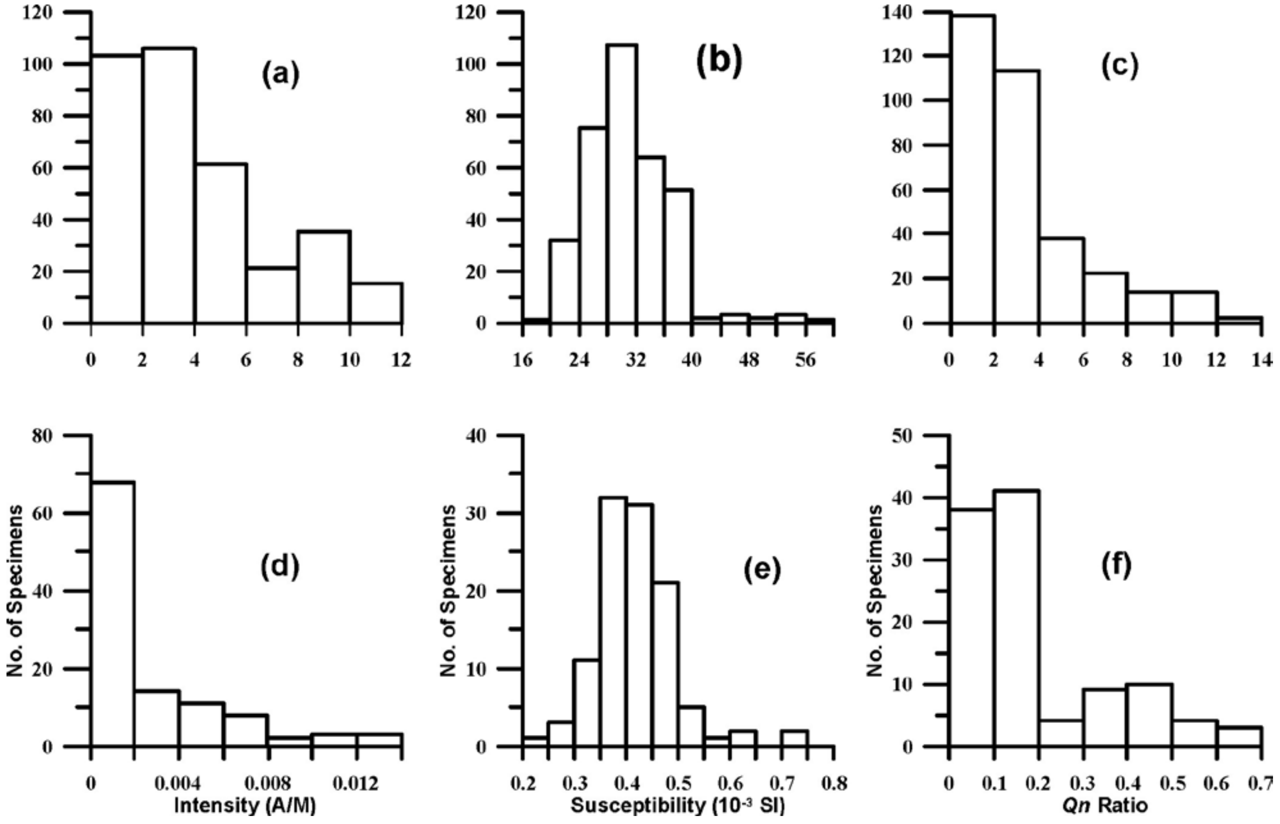

Figure 2. Histograms showing the variation of remanent Magnetic intensity, magnetic susceptibility and Koeningsberger Ratio of the dykes (a, b, c) and sill (d, e, f) samples

Table – 1. Table shows the rock magnetic properties of dykes and sills samples from Jharia coal field.

Site No.	N(n)	Rock Type	J_n (A/m)			χ x10^{-3} SI			Q_n		
			Range		Mean	Range		Mean	Range		Mean
MD1	6(75)	Dolerite Dyke	0.91	2.34	1.72	24.20	38.80	34.77	0.73	2.04	1.25
MD2	5(70)	Dolerite Dyke	3.21	6.93	5.07	21.49	38.74	30.76	2.64	7.26	4.21
SA3	5(63)	Dolerite Dyke	1.44	3.89	2.00	22.10	36.42	28.22	1.30	3.17	1.78
SA4	5(68)	Dolerite Dyke	3.22	11.37	8.50	20.56	58.27	32.22	1.51	12.44	7.42
KH6	6(65)	Dolerite Dyke	1.72	4.36	3.08	19.91	32.73	28.01	1.54	3.82	2.77
KG5	3(31)	Lamprophyre Sill	0.002	0.013	0.007	0.24	0.74	0.43	0.09	0.70	0.40
CD7	5(78)	Lamprophyre Sill	0.001	0.006	0.002	0.27	0.55	0.41	0.05	0.60	0.11

N = No. of samples, n = no. of specimens, Jn = NRM Intensity, χ = Magnetic susceptibility, Qn = Koenigsberger ratio

magnetic susceptibility value suggests the presence of ferromagnetic mineral concentration (Thomson and Oldfield, 1986; Dunlop and Özdemir, 1997).

The magnetic susceptibility of all the 450 specimens consisting dolerite dykes and lamprophyre sills were measured using MFK1A Kappabridge. These specimens show susceptibility values in the range of 19.9 – 58.2 x 10^{-3} SI units with mean value of 30.9 x 10^{-3} SI units and 0.2 – 0.7 x 10^{-3} SI units with mean value of 0.4 x 10^{-3} SI units, for dykes and sills, respectively. The susceptibility range and mean values (site-wise) are shown in Table 1 and their distribution is shown as a histogram in Figure 2 (b & e).

Koenigsberger Ratio (Q_n)

Koenigsberger ratio (Q_n), which gives the type of mineral and its domain state that produces a dominantly induced remanent magnetization and the value 0.5 Oe corresponds to a magnetizing force of 39.79 A/m (McEnore et al., 2001). The high Q_n values are characteristic of stable (thermoremanent) origin of natural remanent magnetization (NRM) while low values ($Q_n<1.0$) are for other non-stable remanence (Dunlop and Özdemir, 1997).

Koenigsberger ratio (Q_n) has been computed using the measured intensity and susceptibility values of all the 450 specimens by assuming a value of 0.05 mT for the inducing field that is equivalent to that of the Earth's magnetic field value. The computed Q_n values of these dolerite dykes and lamprophyre sills vary from 0.7 to 12.4 and 0.05 to 0.69 with mean values of 3.48 and 0.19, respectively. The dyke specimens had relatively higher values (mean = 3.4) than those of lamprophyre sill specimens (mean = 0.19). The Q_n range and mean values (site-wise) are shown in table 1 and their distribution is shown as a histogram in Figure 2 (c & f).

When the dyke specimens taken individually shows Q_n between 1 to 12, forming 95% of the total number of specimens, they also show presence of single domain or pseudo single domain magnetite grains, suggestive of retaining the original magnetization in these studied dyke samples. On the other side, all the sill specimens show $Q_n<1$, which suggests loss of original magnetization in the specimens. In general, Q_n values for dolerites ranges between 2 to 3.5 (Sharma, 1986) and for igneous rock it lies between 1 and 40 (Carmichael, 1989). It is generally considered that a value of $Q_n>1$ indicates the presence of stable directions, although very high values may indicate the effect of lightning strikes (Radhakrishnamurty, 1966).

Lowrie-Fuller Test (L-F Test)

To identify the domain character of the magnetic grains, representative specimens were subjected to Lowrie-Fuller test (Lowrie and Fuller, 1971). For

Lowrie-Fuller test, 14 specimens were subjected to AF demagnetizations in 14 steps like 3.6, 5, 7.5, 10, 15, 20, 25, 30, 35, 40, 50, 60, 80 and 100 mT and then imparted isothermal remanence magnetization (SIRM) at 1 Tesla. The AF demagnetization is repeated in the similar steps. The response of the NRM intensity to the applied field is compared with that of SIRM intensity. It is revealed from this study that the NRM intensity is harder than the SIRM intensity, indicating single domain (SD) nature in the dykes (fig. 3(a)). Sill specimens show an erratic behavior (fig.3 (b)). In general, magnetic minerals in single domain states reveal stable remanent magnetic directions (Goutham et al., 2008). The present study shows similarity with the results as obtained by Patil and Arora (2003) for the Deccan volcanic dykes of Mumbai region.

Isothermal Remanent Magnetization (IRM)

Isothermal remanent magnetization (IRM) is acquired by a sample after exposure to, and removal from a steady direct current (DC) magnetic field. IRM depends on the strength of the applied field, function of magnetic mineralogy and also grain size. The maximum remanence that can be produced in a sample is saturated (Hs) isothermal remanent magnetization (SIRM). IRM is often used as an indicator for the ferromagnetic and antiferromagnetic minerals such as haematite and goethite, which are capable of acquiring IRM (Mooney et al., 2002). After a sample has acquired an IRM, it is often possible to partially demagnetize the sample by exposing it to a magnetic field in reverse direction. Such a partial demagnetization can yield information about the ease of remanence acquisition or the coercivity (Hc) of the sample. Alva-Valdivia et al. (2003) reported that in IRM acquisition curves the saturation reached at low/ moderate fields of 150-200 mT. This indicates the ferromagnetic phase corresponding to some titano-magnetites or titano- maghemites. If the saturation is not reached even in the maximum available field, the behavior belongs to high coercivity minerals; titano-haematite and titano-maghemites.

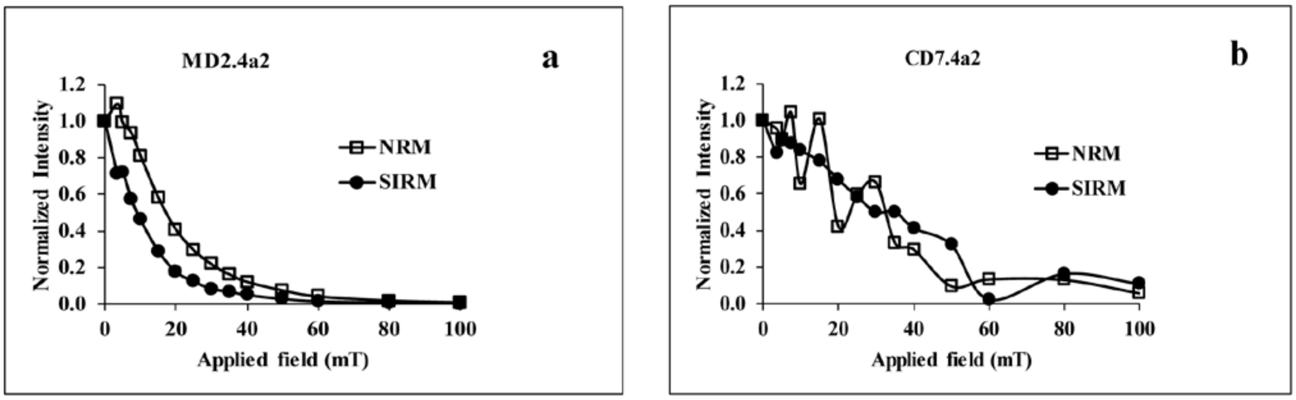

Figure 3. Lowrie-Fuller test showing the NRM and SIRM Af demagnetization curves for dyke (a) and sill (b) samples

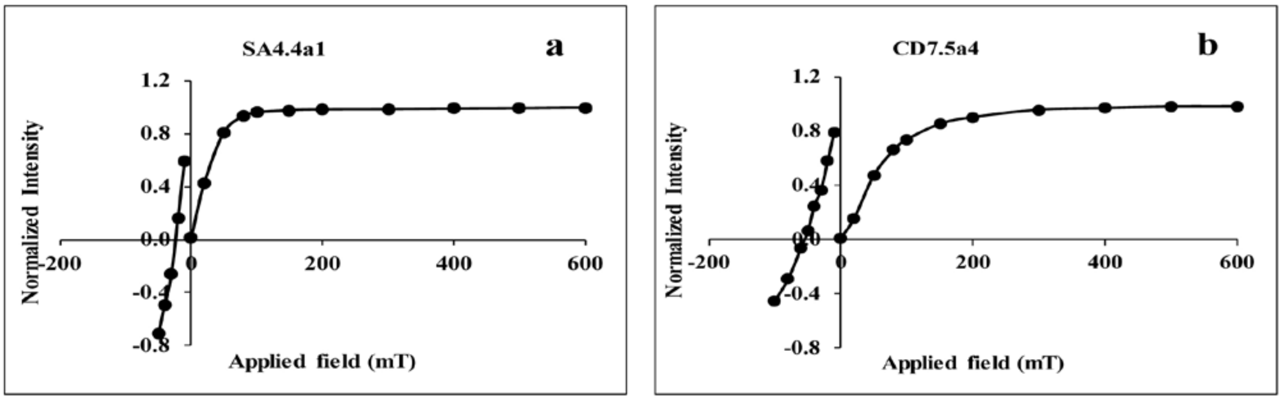

Figure 4. Normalized IRM acquisition curves for dykes (a) and sills (b)

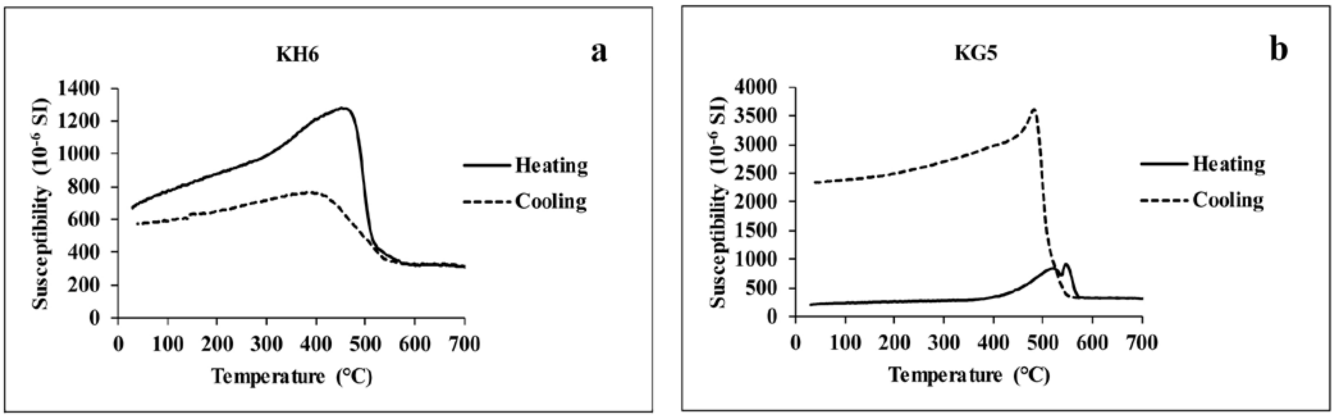

Figure 5. Thermomagnetic curves for the representative dyke (a) and sill (b) samples. Solid line indicates heating and dashed lines indicate cooling

For the identification of the main magnetic minerals, which are carrying the remanent magnetization in these dykes and sills, representative specimens were subjected to isothermal remanent magnetizations (IRM). For IRM test, a pulse magnetizer with a maximum field of 9T has been used for the remanence acquisition. Total of 14 specimens were imparted the magnetization at increasing fields in 12 steps from 20, 50, 80, 100, 150, 200, 300, 400, 500, 600, 800 and 1000mT, and the induced magnetization acquired by the specimens is measured after each step of induction. Then the specimens were subjected to opposite field to get the coercivity of remanence (Hcr). All the IRM curves appear to be saturated around 100 to 300 mT and the remanent coercive force (Hcr) is around 20 to 50mT (fig 4 (a & b)), suggesting that the magnetic carrier in these rocks is titano-magnetite/ magnetite. The present study on the dyke and sill samples of Damodar valley basin shows similar results as shown by Patil and Arora, (2003) for the dykes of Mumbai region, Deccan volcanics.

Thermomagnetic Analysis

The temperature-susceptibility measurement is meant to monitor the variations of the susceptibility, to determine the Curie temperature and to identify magnetic minerals that are responsible for acquiring ancient geomagnetic field and nature of mineral transformation, if any. The heating and cooling curves also reveal chemical and structural changes that can occur as a result of thermal treatment (Atkinson and King, 2005). Jordanova et al., (2001) reported that the enormous increase in susceptibility values during cooling is most probably due to breakdown of clay minerals and formation of new strong ferrimagnetic phase, indicating that these materials are not burnt to high temperatures during baking.

7 samples (5 dolerite dyke and 2 lamprophyre sill) were selected and powdered using agate motor for the thermomagnetic analysis. The real time magnetic susceptibility was measured while heating from room temperature to 700°C and cooling from 700°C to room temperature. For the measurement, Kappabridge KLY2-CS3 furnace apparatus (Agico, Czech Republic) was used. High-temperature behavior of magnetic susceptibility has been studied in order to determine the Curie temperature of main magnetic minerals, responsible for magnetic enhancement. During heating process, temperature drops after reaching ~580°C, which shows the presence of titano-magnetite/magnetite. The curves shown in Figure 5 (a & b) indicate that titano-magnetite/magnetite are the main magnetic remanence carrier minerals in the dolerite dykes and lamprophyre sills, respectively.

CONCLUSIONS

Rock magnetic studies on dolerite dykes and lamprophyre sills associated with Jharia coal fields of Damodar valley basin is successful in identifying the magnetic minerals and their domain state. Magnetite/ titano-magnetite are the main remanence carrier in these studied samples. Lowrie-Fuller test reveals the SD/ PSD domain state present in the studied dyke samples, whereas sill samples show the erratic behavior. As such it is not possible to identify the domain state present in the sill samples. IRM study shows the presence of titano-magnetite/magnetite as a major magnetic mineral in the dykes and sills samples. The thermomagnetic analysis curve shows a drop at ~580°C. This reveals the presence of magnetite in dykes and sills samples of Jharia coal fields of Damodar valley.

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