Magnetic properties of mafics and ultramafics from Eastern Ghats

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Abstract. Magnetic properties, namely intensity of natural remanent magnetisation (NRM) and magnetic susceptibility, of mafic and ultramafic formations of Eastern Ghats belt in the Godavari Districts, Andhra Pradesh are studied. The formations sampled for the study are, iron-ore, chromite-ore, amphibolite, gabbro, charnockite and khondalite gneiss. Mineralogical differences in iron-ore and the degree of martitisation are reflected in magnetic susceptibility. NRM and susceptibility of chromite-ore are feeble. The gabbro exhibits strong magnetic properties because of its contiguity with iron formation. The Koenigsberger ratio is found to indicate relative palaeomagnetic stability.

Keywords. Natural remanent magnetisation susceptibility ; Koenigsberger ratio ; volume percent magnetite ; palaeomagnetic stability ; mafics and ultramafics.

1. Introduction

Different ultramafic bodies and their associated rocks occur in the southern Indian peninsula along major planes of weakness in the crust. In the Eastern Ghats belt they are represented by, among others, magnetite bearing gabbro and chromite bearing pyroxenites. They are associated with charnockites.

The evolutionary history of the charnockite-khondalite system is marked by succeeding geosynclinal facies of sediments and volcanic effusives with associated syntectonic mafic and ultramafic intrusives. The last phase of the Eastern Ghats orogeny culminated in a series of basement controlled NE-SW shear zones along the margins of the charnockite-khondalite belt. The tectonic evolution of the Precambrian provinces in South India has brought out many manifestations of the upper mantle during the Archaean-Proterozoic orogenies. The ultramafics localised along NE-SW shear zones in the margins of the charnockite belts, probably represent late tectonic intrusives during the Eastern Ghats orogeny (Narayanaswamy 1970). They might have been emplaced into the Eastern Ghat suite of rocks prior to the upliftment (Karunakaran 1970).

The samples are collected from four localities namely Addatigala, Devipatnam, Tekuru and Eleswaram (Figure 1a) for laboratory measurements in conjunction with magnetic prospecting for iron-ore (Lakshmi pati Raju 1977)

2. Geological setting

According to Ray (1967), the Eastern Ghats region is a portion of the oldest Precambrian crust in India. Khondalites, which are characteristically of granulite facies have charnockites as their almost constant companion. Granitic gneisses and anorthosites prevail in many parts. Ultramafic and related rocks occur as magnetite-ore bearing gabbro-norite types and chromite bearing pyroxenites.

The country rocks in the area, in general, are khondalite gneisses and schists, charnockite rocks, pink granites and pegmatites. In the localities of Addatigala, Devipatnam and Tekuru, the ultramafic rocks comprise variants of pyroxene, hornblende and plagioclase including pyroxenite, gabbro and amphibolite. At Addatigala the iron-ore bands are within the gabbroic zone trending NE-SW with a dip of 60° SE and conformable with the country rock gneisses. At Devipatnam the ore occurs as reefs and veins exhibiting both concordance and discordance with the country rock formations and with nearly vertical dips. At Tekuru also the mafic-ultramafic assemblages are associated with iron-ore. Chromite is enclosed within pyroxenites, showing a gradational sequence, as bands in conformable relationship with the khondalite gneisses. It strikes at $N 60^\circ E$ with a dip of 75° SE.

3. Sample collection and laboratory measurements

The various formations sampled from different localities are listed in table 1. Locations of sampling sites are shown in figure 1b. In the laboratory, cores of 2.5 cm diameter, are drilled from the samples with a diamond drill and specimens (2.5 cm long) are cut.

Figure 1a. Index map.

Table 1. Details of formations sampled.

Locality	Formation sampled
Addatigala	Iron-ore Gabbro Charnockite
Devipatnam	Iron-ore Amphibolite Biotite granite gneiss Charnockite
Tekuru	Iron-ore Chromite-ore Khondalite gneiss
Eleswaram	Charnockite

Figure 1b. Locations of sampling sites : [1] Iron-ore, [2] Chromite-ore, [3] Amphibolite, [4] Gabbro, [5] Charnockite, [6] Biotite granite gneiss, [7] Khondalite gneiss.

Intensity and direction of NRM are measured with an astatic magnetometer having a sensitivity of 1×10^{-6} oe/mm. Magnetic susceptibility is measured with a susceptibility meter (Likhite and Radhakrishna Murthy 1965) in which the Helmholtz coil assembly produces an alternating magnetic field of variable strength, up to a maximum of 10 oe, at a constant frequency of 576 Hz. The measurements are made at a field strength of 0.5 oe. Specific gravity of all the specimens is determined and polished sections of the ore samples are examined under an ore microscope to identify the opaque minerals. Some representative ore samples are analysed chemically.

4. Results of measurements

All the measured values of NRM intensity (J) and magnetic susceptibility (k) are presented in the form of frequency histograms for both normal and log normal distributions in figure 2. The ranges in J and k are listed in table 2. Among all the types listed only iron-ore exhibits a wide range of values for J and k . The higher values of J ($1021 - 2658 \times 10^{-3}$ e.m.u.) are shown by four specimens of enriched ore from Devipatnam. In general, the

Figure 2. Histograms of: [a] intensity of natural remanent magnetisation, [b] Susceptibility and [c] Koenigsberger ratio.

Tabl 2. Ranges and average values of J , k and Q .

Formation	$J \times 10^3$ e.m.u.		$k \times 10^3$ e.m.u.		Q		Number of samples
	Range	Average	Range	Average	Range	Average	
Iron-ore	1.6—2658	1 5(a) 131(1)	2—130	15.8(a) 124	0.4 — 2.2	1 2.1(1)	24
Chromite-ore	<2	...	<0.2	0.15	...	...	6
Amphibolite	...	...	0.6—2.4	1.9	...	...	5
Gabbro	3—9.2	5.6	10.3—23.4	17.8	0.4 — 1	0.7	5
Charnockite	0.1—6.7	0.8(2) 1.74 0.6(3) 2.2(4)	0.1—12.5	1.3(2) 5.1 3.4(3) 6.7(4)	0.03—3.9	1.3(2) 1 0.4(3) 1(4)	20
Biotite granite gneiss	0.2—1.8	1	5.2—13.5	10.7	0.03—0.6	0.2	5
Khondalite gneiss	3.3—4	3.7	2 — 2.9	2.5	—	...	4

(1) Enriched ore including higher values of J .

(2), (3) and (4) for samples collected from Addatigala, Devipatnam and Eleswaram respectively.

enriched ore specimens, from Addatigala, Devipatnam and Tekuru, have intensities in the range 25×10^{-3} — 138×10^{-3} e.m.u. with an average of 131×10^{-3} e.m.u. Low values in the range 1.6×10^{-3} — 8.7×10^{-3} e.m.u. with an average of 5×10^{-3} e.m.u. are exhibited by samples collected from the contact zone with the gabbroic rocks. The susceptibilities of enriched ore are in the range, 80×10^{-3} — 130×10^{-3} e.m.u. Chromites have low values of J as well as k . The values for gabbro and khondalite gneiss are on the high side. The Koenigsberger ratios (Q) are calculated from measured values of J and k . Q is expressed as $Q = J/kH$ where H is strength of the earth's field. The values of Q also are presented as frequency histograms in figure 2 and the ranges are indicated in table 2.

5. Discussion of results

In view of the wide range of values it appears from figure 2 that log normal distribution is better suited. The average values of J , k and Q are listed in table 2. Averages for J and k corresponding to iron-ore (a) and gabbro are of the same order. This may be explained by the fact that the ore occurs in gabbro and that the sampling locations are juxtaposed. The NRM intensity and susceptibility of chromites are feeble. From the table it is evident that charnockites from Eleswaram have higher average values of J and k than those from other localities, which are associated with iron-ore.

Susceptibilities are plotted against specific gravities in figure 3. The points for iron-ore form into four distinct groups named as A, B, C and D. Groups

Figure 3. A plot of susceptibilities against specific gravities.

A, *B* and *D* correspond to the ore from Addatigala, samples of group *D* being from the site closer to the village (figure 1b). Group *C* corresponds to the enriched ore from Addatigala, Devipatnam and Tekuru. Groups *A* and *B*, with average specific gravities of 3.4 and 3.6 respectively, represent samples from a single site and the former group has lower susceptibility values than the latter. Group *C* with average specific gravity approaching that of pure magnetite has higher values of k . These differences in susceptibility are probably reflecting the mineralogical differences observed in polished sections and chemical analysis.

In group *B* magnetite occurs as irregular bands in the host rock. Exsolved lamellae of ilmenite and spinel are seen in magnetite. Most of the magnetite grains are unaltered and few have been subjected to martitisation. Patches of unreplaced magnetite are seen in a network of haematite. Magnetite represents the major portion. In group *A* magnetite is extensively martitised and patches of relict magnetite are rarely seen. Haematite is the predominant constituent. Samples of group *D* contain roughly 70% of haematite and 30% of magnetite. The mineralogical character of enriched ore collected from the three different localities is not as varied. The ores from Addatigala contain unaltered magnetite as the only constituent. More than 95% of the ore from Devipatnam contains magnetite. Slender scales of exsolved ilmenite are observed. Though few of the magnetite grains are in the initial stages of martitisation, alteration is negligible. The ore samples collected from Tekuru contain mostly magnetite with subordinate amounts of intergrown euhedral grains of ilmenite. Regularly oriented thin blades of exsolved ilmenite are seen in magnetite. Magnetite is rather unaltered, though few grains are seen to be replaced by fine scales of haematite, amounting to more than 95%.

The extensive martitisation in group *A* may be responsible for low susceptibilities while low magnetite content explains group *D*. Close points in group *C* which represent the enriched ore from Addatigala, Devipatnam and Tekuru, probably reflect the mineralogical similarity of the ores as is clear from the above discussion.

Many expressions, for the relationship between susceptibility and magnetite content, deduced by Slichter (1929), Grenet (1930), Nagata (1940), Kato (1941), Werner (1945), Mooney and Bleifuss (1953), Rao (1956), Balsley and Buddington (1958) Sauck (1972), Bath (1962), Jahren (1963), Hood (1964) and others are available. Werner's expression (Hansen, 1966) for magnetite ores is used in computing the line in figure 3 and for this a value of 1.7 is substituted for the susceptibility of magnetite. The line appears to be a reasonable fit to the data.

It was pointed out by Radhakrishna Murty and Mishra (1966) that high values of Q are generally associated with high stability of magnetisation in rocks. Magnetisations with Q values of one or more are usually considered as stable. Biotite granite gneisses and charnockites from Devipatnam (table 2) have low Q values. As anticipated from these low values the behaviour of charnockites during a. c. demagnetisation was not satisfactory and biotite granite gneisses did not give stable directions (Lakshmipati Raju 1977). On the other hand iron-ore, gabbro and other charnockites, with Q values around one, gave stable directions.

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