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PALAEOMAGNETISM AND THE STRATIGRAPHIC CORRELATION OF CERTAIN PRECAMBRIAN FORMATIONS OF INDIA

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One of the applications of the palaeomagnetic data is its use in the stratigraphic correlations of the geological formations (Khramov, 1958; McElhinny, 1969; Irving, 1971). The absence of sufficient radiometric age data however considerably hinders such attempts for the Precambrian formations, although several workers (Brock and Piper, 1972; Irving and Park, 1972) have recently shown an effective use of the palaeomagnetic data in the correlation of the African and the Canadian Proterozoic rocks. In the case of the Indian geological column, the efforts made so far in this direction have been limited. Prasad and Reddy (1972) have, for instance, interpreted the palaeomagnetic data in support of the contemporaneity of lower Cuddapahs and lower Vindhyans with the Bijawars, a correlation originally suggested by Dubey (1950). An attempt is made here to show that this palaeomagnetic correlation is rather erroneous and is also modified when the relevant radiometric age data are taken into cognisance. A magnetostratigraphic correlation of the Indian Precambrian rocks is also attempted here.

It will be pertinent to mention at the very outset that, as pointed out by Crawford and Compston (1970), the palaeomagnetic result reported by Athavale *et al*, (1963) as belonging to the Bijawar traps does not pertain to the Bijawars at all and was actually based on studies conducted on the Gwalior lavas which were erroneously called Bijawar traps. In the following discussion, the term Bijawar traps used in the earlier palaeomagnetic work is therefore replaced by 'Gwalior lavas'.

The remanent magnetic directions of the lower Cuddapahs and B.H.Q. and B.H.J. have an approximate mean of 287° declination (E of true N) and $-9°$ (+ve down) inclination. Reversed of this direction will be 107° declination and $+9°$ inclination. Not a single Gwalior lava sample showed this direction even though these rocks showed a high scatter of the remanent magnetic directions (A_{95}, i.e. the radius of 95% circle of confidence = 18°) ranging from 30° to 90° declinations and $+10°$ to $-5°$ inclinations. The palaeomagnetic inference of Prasad and Reddy (1972) that the Gwalior lavas are magnetically reversed with respect to the lower Cuddapahs and the lower Vindhyans, the latter represented by B.H.Q. and B.H,J., is thus questionable.

Further, the lower Vindhyans are now believed to be about 1200-1400 m.y. old (Crawford and Compston, 1970) which is also the age of the lower Cuddapahs (Aswathanarayana, 1964 a, b; Crawford, 1969). The Gwalior lavas, on the other

hand, are found to be much older with the Rb-Sr isochron age of 1830±200 m.y. and the Bijawars are about 2500 m,y. old (Crawford and Compston, 1970). Thus, while both palaeomagnetic and radiometric age data suggest the contemporaneity of lower Cuddapahs and lower Vindhyans, these formations can neither be correlated with the Gwaliors nor with the Bijawars.

The other Precambrian formations for which palaeomegnetic as also radiometric age data exist are Malani rhyolites, Mundwara complex and the upper Vindhyan Kaimur sediments. The Malani rhyolites were reported by Sarkar *et al* (1964) to be about 600 m.y. old (mineral age) but the Rb-Sr isochron age of 745±10 m.y. (Crawford and Compston, 1970) is a more reliable estimate. The mean remanent magnetic direction of these rocks is 353° declination and +56° inclination (Athavale *et al*, 1963). The Mundwara complex, with a mean remanent magnetic direction of 329° declination and −24° inclination (Athavale *et al*, 1963), is believed to be contemporaneous with the Erinpura granite. The age of the Mundwara complex can then be taken to be about 950 m.y. on the basis of the age of 900±50 m.y. reported for Erinpura granite (Vinogradov *et al*, 1966). Besides, the granites of Aravalli axial zone, at Chhapoli and Ajmer, gave isochron age of 950±40 m.y. (Crawford, 1970) and Untala Granite, correlated with Erinpura granite by Heron (1953), has an age of 955±50 m.y. on Rb-Sr isochron (Crawford, 1970) which is also corroborated by the age of 959±24 m.y. reported for carbonatite intrusive in it (Deans and Powell, 1968).

The Kaimurs palaeomagnetically studied by Misra (1965) can be taken to be about 1150 m.y. old in view of the 1140±12 m.y. age (Crawford and Compston, 1970) of the diamondiferous Majhgawan pipe intruding these sediments, the glauconite age of 910-940 m.y. (Tugarinov *et al*, 1965) being a likely minimum estimate. A reversal of the geomagnetic field was recorded in these sediments.

A tentative palaeomagnetic scale of time can now be drawn for the Indian Precambrian column (Table I) which can be a useful aid in geological correlation as shown below.

Rao *et al* (1970) reported three sets of remanent magnetic directions in the nagnetite quartzites of Ongole of which one set showed a mean of 274° declination and −38° inclination. This is very similar to the directions of lower Cuddapahs. Palaeomagnetic studies on some magnetite quartzites near Khammam (17.3°N : 80.1°E) also gave identical directions (mean 263° declination and +6° inclination). In view of the reported radiometric age of 1160-1350 m.y. for the Ongole magnetite quartzites (Venkatasubramanian and Krishnan, 1960) this correlation is indeed striking. An inference can probably be drawn that the rocks in the Indian Precambrian column showing remanent magnetic directions of about 280° declination and ±20° inclination (or the opposite trend indicating polarity inversion) can possibly be classified in the age group of say about 1300 m.y. i.e., contemporaneous with the lower Vindhyans and the lower Cuddapahs.

Another set of remanent magnetic directions of the Ongole magnetite quartzites reported by Rao *et al* (1970) has a mean of 346° declination and −24° inclination. This is similar to the direction of 360° declination and −26° inclination reported by Rao and Murty (1967) for the Ongole magnetite quartzites, and compares well with the mean direction of Mundwara complex. The third set of remanent magnetic directions of Ongole magnetite quartzites (mean 171° declination, −3° inclination) is similar to the directions of Veldurthi haematites (191° declination, −1° inclination) studied by Sampath (1968) and can possibly be correlated with Kiamur sediments.

TABLE I

TENTATIVE MAGNETO-STRATIGRAPHIC CORRELATION OF INDIAN PROTEROZOIC FORMATIONS

Grouping of the Indian Proterozoics *		Palaeomagnetic data				
Age (m.y.)	Stratigraphic interval and rock suites	Assumed age (m.y.)	Rock suite	D°	I°	Reference
500 to 900	*Lr. Cambrian-Up. Proterozoic:* Cambrians of Salt Range Up. Vindhyans, Kurnools, Bhimas, Malani	500-600	Salt pseudomorph beds, Salt Range	216° (55°)	+42° (-35°)	Wensink (1972)
			Purple sandstone, Salt range	218° (33°)	+32° (-23°)	McElhinny (1970)
			Rewa sandstone (Up. Vindhyan)	32°	-37°	Athavale *et al* (1972)
			Bhander sandstone (Up. Vindhyan)	49°	-19°	Athavale *et al* (1972)
			Kondapalle charnockites	44°	-23°	Bhimasankaram (1964)
		750	Malani rhyolites	353°	+56°	Athavale *et al* (1963)
			M. Bhima limestone	328°	+50°	NGRI Ann. Rep. (1971-72)
			Lr. Bhima shale	349°	+25°	NGRI Ann. Rep. (1971-72)
900 to 1600	*Middle Proterozoic:* Cuddapahs, Lr. Vindhyans, Satpura, Aravalli and Delhi	950	Mundwara complex	329°	-24°	Athavale *et al* (1963)
		1150	Kaimur sandstone (Lr. Vindhyan)	186° (0°)	-32° (+30°)	Misra (1965)
		1300	B.H.Q., Pokhra (Lr. Vindhyan)	270°	-12°	Misra (1965)
			B.H.J., Parkhuri (Lr. Vindhyan)	280°	-9°	Misra (1965)
			Cuddapah sandstone	294°	-6°	Prasad & Reddy (1972)
			Cuddapah shales	295°	-10°	Prasad & Reddy (1972)
1600 to 2500	*Lower Proterozoic:* Satpura and Aravalli (in part), Eastern Ghats (Phase II)	1600	Charnockites-I, Visakhapatnam	280°	+35°	Bhimasankaram (1964)
		1800	Charnockites-II, Visakhapatnam	45°	+45°	Bhimasankaram (1964)
			Gwalior lavas	70°	+3°	Athavale *et al* (1963)
			Hyderabad dyke	44°	-3°	Verma *et al* (1968)

D°=Declination (east of true north); and I°=Inclination (positive downwards).

* After Sarkar (1968). Upper limit for the first group arbitrarily extended from Sarkar's 600 m.y. to 500 m.y. by the author, indicating that the Proterozoic-Phanerozoic boundary in Indian stratigraphy does not bear any one-to-one correspondence with the established international stratigraphic nomenclature (George *et al*, 1967).

Veldurthi haematites gave two other sets of directions in addition; one with 160° declination, – 38° inclination and 133° declination, – 37° inclination, reported by Sampath (1968) and Verma *et al* (1966) respectively which can be correlated with the Malani rhyolites, and the other with 321° declination, – 21° inclination which can be correlated with Mundwara complex.

The three sets of remanent magnetic directions in the charnockites of Ongole (Rao *et al*, 1970) can be similarly explained. The charnockites of Visakhapatnam gave two sets of remanent magnetic directions (Bhimasankaram, 1964) one of which (45° declination, + 45° inclination) can probably be dated with Gwalior lavas at about 1800 m.y. while the other one (280° declination, + 35° inclination) can be dated at about 1600 m.y. (Aswathanarayana, 1964a, Crawford, 1969).

Results of palaeomagnetic study on diamondiferous pipe rocks of Anantapur (Anand, 1969) are interesting in this regard. The pipe at Lattavaram (14.9°N; 77°.3°E) gave a mean direction of 159° declination and + 42° inclination which can be correlated with Mundwara complex. The mean direction (104° declination, – 39° inclination) of the other pipe at Wajrakarur (15°N : 77.4°E) can be probably considered contemporaneous with 1600 m.y. old Visakhapatnam charnockites, or with the 1300 m.y. old lower Cuddapahs, if some allowance is made for the inclination parameter. Crawford's (1970) interpretation of the age of these pipes as about 1340 m.y. supports the latter possibility. The charnockites of Kondapalle (16.5°N : 80.6°E) were palaeomagnetically correlated by Bhimasankaram and Pal (1970) with the Purple sandstone of Salt Range (McElhinny, 1970) and other Cambrian formations which corroborates well with the radiometric age data (Aswathanarayana, 1964a, Grasty and Leelanandam, 1965).

The above discussion reveals that the Precambrian formations of Peninsular India contain remanent magnetic directions of different ages. This is not inconsistent with the hypothesis of recurrent tectonic episodes, and the consequent metamorphism, in the Eastern Ghats and Cuddapah basin between 1600 and 500 m.y. age (Aswathanarayana, 1964a; Crawford, 1969; Sarkar, 1968). In the absence of the necessary details, however, the above mentioned palaeomagnetic inferences should be regarded as strictly tentative.

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STRUCTURAL STATE OF PLAGIOCLASES FROM BASIC CHARNOCKITES

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The structural state (degree of order/disorder) of plagioclases is believed to have petrogenetic significance by Christie (1962), Hunahashi *et al* (1968) and by many others, but their conclusions are tentative and more data from diverse rock types are needed before any definite conclusions can be drawn. Therefore in the present study, plagioclases from the basic charnockites were selected because of the following reasons: (i) petrogenetically charnockites are the most interesting rock types in the world; (ii) the geology and chemistry of these rocks is comparatively well known; (iii) consistency in K_D values of pyroxene pairs from these rocks from widely different localities indicate that the rocks are in equilibrium and that they have equilibrated to the same pressure-temperature conditions; and (iv) basic charnockites yield fresh and unzoned plagioclases.

After careful evaluation, four samples of the basic charnockites were selected for final study, out of which three (4/161, 4/167, 4/169) are from the type area Pallavaram (Madras), and one (4/1) from Gangineni (Andhra Pradesh). No. 4/169, with andesinic plagioclase, is a hypersthene diorite belonging to intermediate charnockite series of Holland (1900) while the rest are norites. The detailed petrography of these samples has been described by Mall and Singh (1972).

Optic axial angles measured for several grains of orthopyroxene, clinopyroxene and hornblende from these samples show remarkably close and consistent values for each of the minerals from the same rock. In contrast, it is found that plagioclases of widely different composition coexist in these samples in as small an area as a thin section (Mall and Singh, 1972). Between 5 to 8 different fractions of plagioclases