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THE PALEOMAGNETISM OF THE SALT PSEUDOMORPH BEDS OF MIDDLE CAMBRIAN AGE FROM THE SALT RANGE, WEST PAKISTAN

H. WENSINK
Geological Institute, Oude Gracht 320, Utrecht, The Netherlands

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Oriented cores for a paleomagnetic investigation were collected from ten sites in the sedimentary redbeds of the Salt Pseudomorph Beds of Middle Cambrian age in the Salt Range near Khewra. All samples were subjected to progressive, thermal demagnetization procedures which revealed the characteristic direction of magnetization.

The material of ten sites with a total number of 71 specimens was included in the analysis, giving an overall mean direction with $D = 215.9°$, $I = +42.4°$, $\alpha_{95} = 13.7°$. In the ultimate analysis the material of six sites was included, because four sites show fairly strong deviations from the mean direction. The virtual magnetic pole position is located at 26.6° S, 33.5° E, with $A_{95} = 5.1°$. A Phanerozoic polar wander curve is given for India-Pakistan. The result presented here supports the view that in Gondwana reconstructions the west coast of the Indian subcontinent is best fitted alongside the northeast coast of Africa.

1. Introduction

In the Salt Range of West Pakistan, where excellent outcrops are available of sediments of Cambrian and Permo–Carboniferous age, oriented samples were collected from the Salt Pseudomorph Beds of Middle Cambrian age for paleomagnetic research. In this area McElhinny [1] collected material from the Purple Sandstones of Lower Cambrian age which revealed reliable characteristic directions of magnetization.

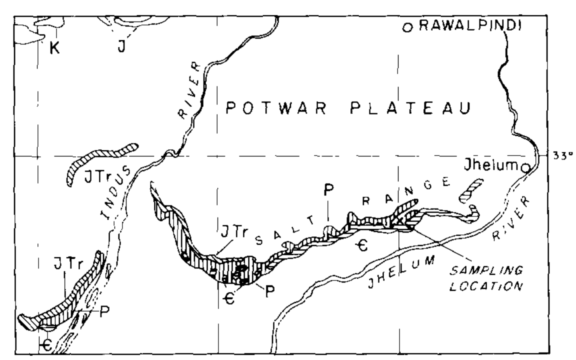

Fig. 1. Geological map of the Salt Range, West Pakistan, with sampling locality.

2. Geology of the area

The Salt Range is situated in West Pakistan between the rivers Indus to the west and Jhelum to the east (fig. 1). The range is little more than the scarped southernly margin of the Potwar plateau where sediments of mainly Tertiary age are met with. There are a number of deep ravines facing towards the south, which offer excellent outcrops.

The basal series, the Saline Series, which has an Upper Precambrian to Lower Cambrian age, consists of gypseous marls, marls, and salt deposits; the minimum thickness is 450 m. The Saline Series is overlain by the Jhelum Series of Lower to Middle Cambrian age with a thickness up to 360 m. The Jhelum Series is subdivided into four stages (fig. 2): the Purple Sandstone, the Neobolus Shales, the Magnesium Sandstone, and the Salt Pseudomorph Beds successively [2].

The Purple Sandstone consists of fine-grained, maroon to reddish, jointed sandstones with thin bands of shale. The unfossiliferous sediments have some ripple-marks. The Neobolus Shales have dark shales

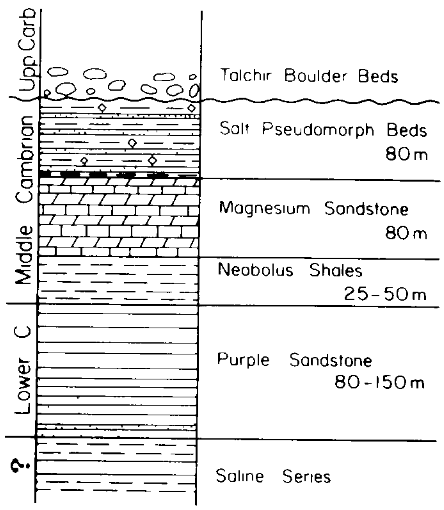

Fig. 2. Stratigraphical column of the rocks of Cambrian age from the Salt Range.

associated with sandy and calcareous beds. Fossils are found, including trilobites of the genus *Redlichia*. The Magnesium Sandstone is a cream-coloured or white massive sandy dolomite with some intercalated clay beds. At this stage fossils are met with as well.

The Salt Pseudomorph Beds consist of shales with intercalated thin-bedded flaggy sandstones. The flags are sometimes sun-cracked. The shales are characterized by their deeply red colour and by the numerous pseudomorph casts of salt crystals which cover the bedding surface. The origin of the crystals must be due to the evaporation of salt water and the subsequent covering of the crystals by sediment. The unfossiliferous beds must have been laid down under arid conditions.

The exact age of the Jhelum Series was discussed by several authors. On account of the assemblage of fossils Schindewolf and Seilacher [3] place the units in the Lower Cambrian; Opik [4], on the other hand, has shown that the occurrence of the trilobite species *Redlichia noetlingi* points to a late early as well as early Middle Cambrian age.

The Upper Carboniferous Talchir Boulder Bed overlies the Cambrian sediments. In the Salt Range the Boulder Bed transgresses westwards over ever older stages of the Jhelum Series.

Apart from southward directed overthrusting at various places at the margin of the range, also dome structures can be observed, that are due to the local thick development of the salt of the Saline Series.

3. Field sampling

Along the road from Khewra to the north there are excellent exposures of the Salt Pseudomorph Beds. In an almost undisturbed sequence of about 15 m thickness, immediately overlain by the Talchir Boulder Bed, samples were collected for paleomagnetic research. Cores were sampled with the aid of a portable diamond drill; at each site 8 to 10 independently oriented cores were drilled. In fig. 5 the sites are indicated at their respective elevations in the section.

4. Laboratory studies

The material collected was treated at the Paleomagnetic Laboratory of the Utrecht State University. The cores with a diameter of about 25 mm were sawn into cylinders of 22 mm length.

The measurements for the detection of the intensities and directions of the natural remanent magnetization were carried out on astatic magnetometers. The initial natural remanent magnetization (n.r.m.) nearly always is, however, composite. For the elimination of the secondary component(s) of magnetization, the specimens were subjected to progressive thermal demagnetization which was carried out in a furnace, positioned

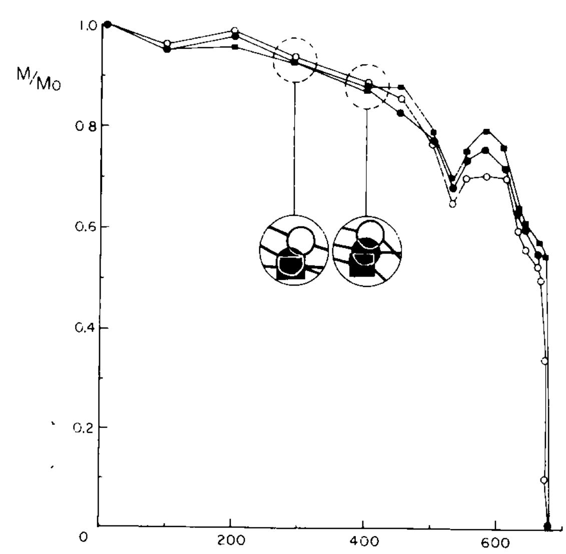

Fig. 3. Curves showing the normalized intensities of natural remanent magnetization from specimens of the Salt Pseudomorph Beds during thermal treatment.

in a set of Helmholtz coils. A minimum of ten successive steps of heating was applied; after each step the specimens were remeasured

The decrease in the intensity of the n.r.m. during thermal treatment can be presented in a diagram, where the normalized intensities, i.e. the ratio of the remaining to the initial intensity, are plotted to the applied temperatures. In fig. 3 the thermal decay curves are given for three specimens from three different sites. These curves are strikingly consistent with slight increases in the intensity at about 200°C and at about 530°C. An increase in the intensity can be attributed to the complete demagnetization of one of the components of magnetization. Above about 580°C the intensities drop rapidly [6]; this is the characteristic magnetization of which the direction remains unchanged. It is fairly certain that haematite is an important carrier of the n.r.m. of these redbeds. One can infer from fig. 3 that the n.r.m. is composite and consists of a characteristic component and two secondary components of magnetization.

5. Paleomagnetic results

The characteristic directions of magnetization of the specimens of three sites are plotted in individual equal area projections (fig. 4); the fourth projection, below to the right, shows the mean directions of the sites as well as the overall site-mean direction. The latter projection indicates that two sites have north-seeking directions upwards (negative inclinations) and eight sites north-seeking directions downwards (positive inclinations). Moreover, it appears that four sites, one with negative and three with positive inclinations, have fairly strongly deviating characteristic directions of magnetization with respect to the site-mean direction.

It can be seen from fig. 5 that the upper two sites have negative inclinations. The sites with deviating directions of magnetization are the sites E, G, I, and K. The declinations and inclinations of the successive sites at the polarity change in fig. 5 seem to indicate a gradual transition in direction. However, polarity transitions generally occur within a short interval of about 50 000 yr; in our section the distance between successive sites is too large, unless an extremely low rate of sedimentation has occurred.

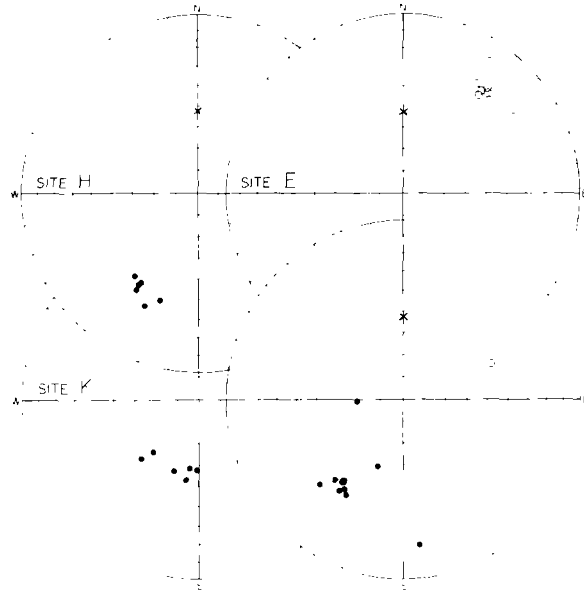

Fig. 4. Equal-area projections with the characteristic directions of magnetization after tectonic corrections of the specimens of three individual sites: site H and site E have positive and negative inclinations respectively; site K with positive inclinations has a mean value deviating from the overall mean. The projection below to the right shows the mean characteristic directions of magnetization of all ten sites and also the site-mean direction provided with its 95% circle of confidence. Full dots and open circles denote north-seeking directions pointing downwards and upwards respectively. Cross is the local direction of the axial geomagnetic dipole field.

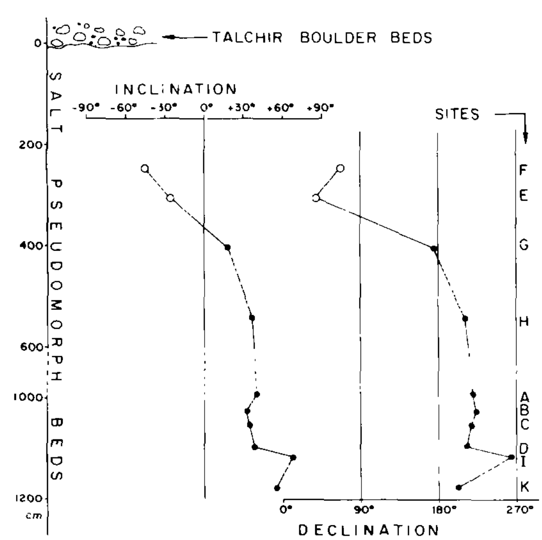

Fig. 5. Diagram showing the values of the declinations and inclinations of the characteristic directions of magnetization of ten successive sites in a Salt Pseudomorph Beds section.

Table 1
Site mean directions of magnetization after thermal cleaning with corresponding virtual pole positions*. The locality of the sites is 32.66°N lat., 72.97°E long.

Sites	N	Mean direction of magnetization				Pole position			
		D (deg)	I (deg)	k	α_{95} (deg)	Lat. S (deg)	Long. E (deg)	δp (deg)	δm (deg)
F	7	69.1	−45.6	19.3	14.1	1.2	16.6	11.4	17.9
E	8	39.8	−24.9	95.5	5.7	30.5	26.6	3.3	6.1
G	8	173.7	+19.4	83.6	6.1	46.9	82.1	3.3	6.4
H	6	210.6	+37.6	168.1	5.2	28.9	40.1	3.6	6.1
A	8	220.6	+40.1	17.2	13.7	22.3	32.6	9.9	16.6
B	8	224.1	+33.4	20.6	12.5	23.9	26.7	8.1	14.2
C	6	215.1	+37.5	18.7	15.9	26.7	36.0	11.0	18.7
D	8	212.7	+39.9	20.7	12.5	26.5	39.2	9.0	15.0
I	7	265.1	+68.9	298.1	3.5	−22.5	31.8	5.1	5.9
K	6	201.5	+57.1	57.7	8.9	16.8	55.3	9.4	12.9
All	10**	215.9	+42.4	13.4	13.7	23.3	37.5	10.4	16.8

* The locations of the sites are indicated on fig. 6; N is the number of samples; D and I are the declination and inclination of the magnetization direction; k is the precision parameter [17]; α_{95} is the semi-angle of the cone of 95% confidence; δp and δm are the semi-axes of the oval of 95% confidence for the pole position of the site.
** Number of sites included in the analysis.

Table 2
Pole positions calculated by combining positions of the sites*.

N	K	A_{95} (deg)	Latitude S (deg)	Longitude E (deg)
10	11	15.0	21.2	37.2
6**	176	5.1	26.6	33.5

* N is the number of site poles included in the analysis; K is the precision of the site poles; A_{95} is the semi-angle of the cone of 95% confidence for the mean pole position.
** Selected poles (see text).

The deviations in direction of magnetization of the sites E, G, I, and K are too large to be explained in terms of secular variation of geomagnetic field. But, the directions must have a primary cause as well, because the sampled section shows no inconsistencies. The strongly deviating characteristic directions can be due to short excursions of the geomagnetic field, such as was described by Watson [7].

The site-mean directions after thermal cleaning with their corresponding pole positions are listed in table 1. The site-mean pole position is given in table 2, where the paleomagnetic pole position computed from the poles of six selected sites is listed too. The latter pole is considered to be representative for the Salt Pseudomorph Beds.

6. Discussion

The results of a paleomagnetic study on the Lower Cambrian Purple Sandstone of the Salt Range in Pakistan [1] are in very good agreement with those presented in this paper. In fig. 6 the polar wander curve is drawn for the India-Pakistan subcontinent during the Phanerozoic. The selected virtual magnetic pole positions obtained from Phanerozoic rocks of India and Pakistan, which were used in fig. 6, are listed in table 3. The polar wandering curve is very similar to that of McDougall and McElhinny (1970). A few positions often used have been omitted: the pole position acquired from Kamthi beds of Upper Permian age [18], which considerably deviates from

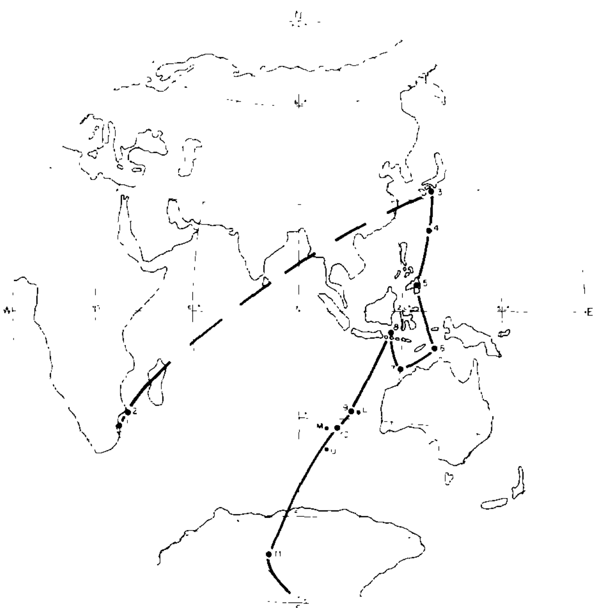

Fig. 6. Map showing the Phanerozoic polar wander curve for the India-Pakistan subcontinent. The poles are numbered as in table 3. The positions L, M, and U near pole no. 10 are the pole positions from the respective Lower, Middle, and Upper Deccan traps.

Kamthi pole, no. 4 in table 3, is not listed, because, in our opinion, the secondary magnetizations were not completely removed; the poor correlation can also be due to a difference in time. There is some controversy on the ages of a number of Gondwana beds [15] ; the ages, presented in table 3, are not irrevocable.

The question may be posed whether it is warranted to use indiscriminately the paleomagnetic data from India and Pakistan in the same configuration. It is not certain that since the early Phanerozoic the Salt Range has had the same relative position with respect to the Indian part of the subcontinent.

Paleomagnetic studies on rocks of a particular age which are found both in India and in the Salt Range may resolve this problem. In India Paleozoic rocks older than Upper Carboniferous in age are virtually absent. In the Salt Range the Talchir Boulder Bed is overlain by reddish and purplish sandstones of the Speckled Sandstone Stage which has an Upper Carboniferous age; paleomagnetic research on these rocks are in progress. Here, the covering sediments mainly are marine limestones of Permian age.

Recently it was pointed out [19] that at the reconstructions of Gondwanaland for the Lower Paleozoic the India–Pakistan subcontinent should be placed near East Africa rather than alongside Western Australia. The paleomagnetic results presented in this paper strongly support this view. This arrangement is not fully in agreement with the computer fit of the southern continents proposed by Smith and Hallam [1, 20]. The Upper Paleozoic paleomagnetic data of the subcontinent do not support a position near East Africa [9]. More research is needed to conclude whether this discrepancy is significant.

Table 3
Phanerozoic paleomagnetic results from India and Pakistan.

Pole no.	Formation	Age	Site locality		Pole position			Ref.
			Lat. N	Long. E	Lat.	Long.	A_{95}	
1	Purple sandstone	Lower Cambrian	32.7°	73.0°	28°S	32°E	11°	[1]
2	Salt pseudomorph beds	Middle Cambrian	32.7°	73.0°	27°S	33°E	5°	this paper
3	Talchir shales	Upper Carbonif.	21.4°	79.0°	31°N	134°E	3°	[8]
4	Kamthi redbeds	Upper Permian	20.0°	79.0°	22°N	130°E	10°	[9]
5	Mangli redbeds	Lower Triassic	20.5°	79.0°	7°N	124°E	9°	[9]
6	Pachmarhi sandstones	Upper Triassic	22.4°	78.4°	10°S	129°E	13°	[9]
7	Sylhet traps	Jurassic-Cret.?	25.3°	91.4°	16°S	120°E	8°	[10]
8	Rajmahal traps	Middle Cret. 105–100 my	24.6°	87.4°	7°S	117°E	7°	[11, 15]
9	Tirupati sandstones	Upper Cretaceous	16.4°	81.1°	28°S	107°E	5°	[12]
10	Deccan traps	Lower Eocene 60 my	16°–25°	72°–79°	34°S	101°E	4°	[13, 16]
11	Siwalik redbeds	Miocene	32.8°	73.0°	72°S	69°E	–	[14]

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