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PALAEOMAGNETISM OF UPPER BHANDER SANDSTONES FROM CENTRAL INDIA AND IMPLICATIONS FOR A TENTATIVE CAMBRIAN GONDWANALAND RECONSTRUCTION*

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ABSTRACT

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A virtual geomagnetic pole position for the uppermost Vindhyan sediments in Central India, probably correlative with the Cambrian of the Salt Range (W. Pakistan), was obtained from 43 oriented cores (7 sites) drilled from the Upper Bhander sandstones in the Great Vindhyan basin.

Alternating field and thermal demagnetization resulted in a mean direction: $D = 207.5°$, $I = +9.5°$ ($k = 137.5$, $\alpha_{95} = 5.5°$) and a virtual geomagnetic northpole position: 146.5°W 48.5°N ($dp = 3°$, $dm = 5.5°$).

This pole position disagrees with the Cambrian palaeomagnetic results from the Salt Range. Implications of this disagreement for the pre-drift configuration of Gondwanaland, based on palaeomagnetic results, are discussed.

INTRODUCTION

During a recent palaeomagnetic sampling trip on the Indian subcontinent by a group from the Utrecht State University, oriented cores were drilled from the Upper Bhander sandstones of the Upper Vindhyan system in Central India. To these uppermost Upper Vindhyan beds a probable Early Palaeozoic age has been assigned (Ahmad, 1958; Gansser, 1964; Krishnan, 1968; Crawford and Compston, 1970).

In the present paper we present palaeomagnetic results from Upper Bhander sandstones beds, drilled about 80 km SW of Agra (Central India).

The uppermost Vindhyan beds of Central India are generally correlated with the Cambrian sequence of the Salt Range (W. Pakistan) on lithological grounds (Ahmad, 1958; Pascoe, 1959; Sahni, 1960a, b; Gansser, 1964; Krishnan, 1968). Therefore a comparison will be made with the palaeomagnetic results of the Lower- to Middle Cambrian Purple Sandstone beds from the Salt Range (McElhinny, 1969) and with the results of the slightly younger Salt Pseudomorph beds from the same Salt Range area (Wensink,

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1972 a, b), as a check whether the Salt Range area and the Indian subcontinent belong to the same rigid plate.

VINDHYAN GEOLOGY

The Vindhyan system comprises a series of unfossiliferous sedimentary rocks, and encompasses a long span of time from a maximum age of 1400 m.y. till may be the Early Palaeozoic (Crawford, 1969; Crawford and Compston, 1970). These Vindhyan rocks occupy a large arcuate basin in Central India (Fig. 1, 2). Formations correlated with the Vindhyan system (Fig. 2) are present throughout India and W. Pakistan (Ahmad, 1958).

The Vindhyan system of Central India is subdivided into four subunits: (1) Semri, (2) Kaimur, (3) Rewa, (4) Bhander (Table I).

The Semris or Lower Vindhyans are mainly argillaceous and calcareous. The lithology is varied, the thickness is variable up to 1000 m and the area of outcrop is limited. The Kaimur, Rewa and Bhander series, constituting the Upper Vindhyans, are up to 4000 m in thickness and cover a far greater area than the Lower Vindhyan beds. Locally an unconformable superposition is exposed. The Upper Vindhyans are mainly arenaceous, i.e., essentially red sandstones and shales with some limestone beds. Its subdivision is persistent over the entire outcrop with a remarkable uniformity, extending from east to west over 500 km.

The Vindhyans rest with marked erosional unconformity upon steeply dipping and metamorphosed Archaean rocks. Within the Vindhyan system itself there are distinct un-

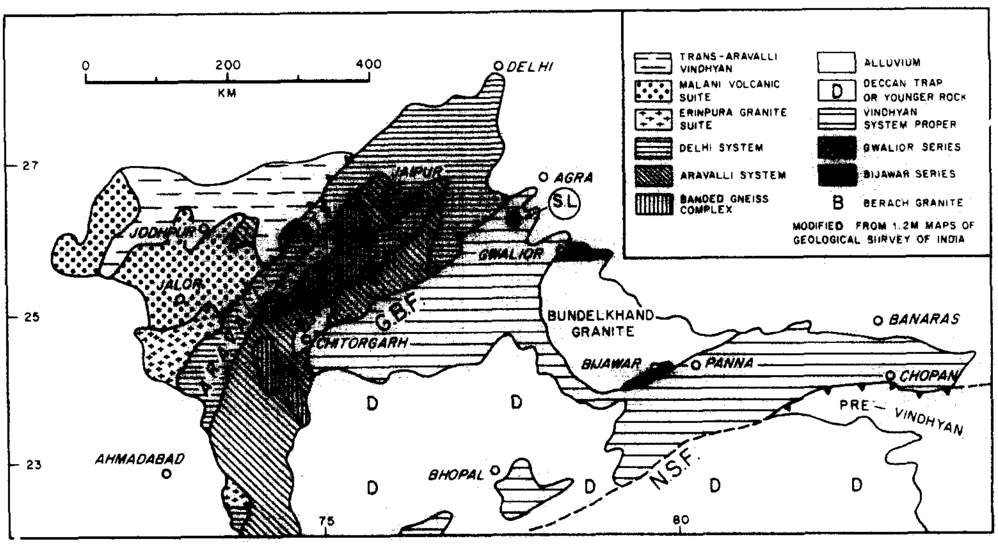

Fig. 1. Geological sketch map of Central India. *S.L.* = sampling localities, *G.B.F.* = Great boundary fault zone of Rajasthan, *N.S.F.* = Narbada–Son zone of weakness.

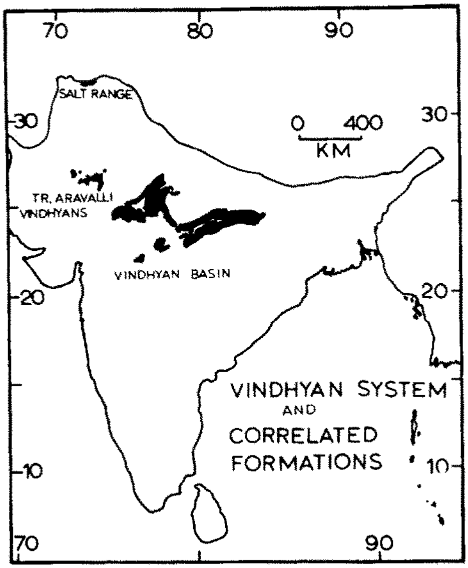

Fig. 2. Outcrops of rocks of the Vindhyan system and correlated formations in the northern part of the Indian subcontinent.

TABLE I
General stratigraphy in the area of the Great Vindhyan basin

DECCAN TRAP LAVAS			
			Upper Bhander sandstones
UPPER VINDHYAN	BHANDER SERIES		Sirbu shales
			Lower Bhander sandstones
			Ganurgarh shales
	– – – –	Diamond bearing conglomerate – – – –	
	REWA SERIES		
	– – – –	Diamond bearing conglomerate – – – –	
		UPPER KAIMUR BEDS	
	KAIMUR SERIES		
		LOWER KAIMUR BEDS	
	~~	(unconformity)	
LOWER VINDHYAN	SEMRI SERIES		
	~~	(unconformity)	
ARCHAEAN BASEMENT			

conformities, often marked by conglomerates. The Lower Vindhyan rocks are commonly disturbed, but almost everywhere the Upper Vindhyans are only gently folded and tilted and quite unmetamorphosed.

Generally the Vindhyan beds dip less than 10 degrees, they are practically undisturbed and subhorizontal in the sampling area.

AGE OF THE SYSTEM

The radiometric datings from Vinogradov et al. (1964), Tugarinov et al. (1965), and Crawford and Compston (1970) showed that the lower part of the Vindhyan system is much older than had previously been believed (Table II).

Tugarinov et al. (1965, as quoted by Crawford and Compston, 1970), obtained the following K/Ar ages from glauconites:

Upper Kaimur series: 910 m.y.; Lower Kaimur series: 940 m.y.

Upper Semri series: 1140 m.y., whereas sediments correlated with the Lower Semri series gave an age of 1400 m.y.

Regarding these K/Ar ages as minimum ages they do not conflict with a Rb/Sr dating of 1140 m.y. by Crawford and a corresponding K/Ar dating by McDougall on the Majhgawan pipe, which intrudes into the Kaimur sandstones.

Radiometric datings from the Upper Vindhyan Rewa and Bhander beds are not available. However, the Jodhpur sandstones in Western Rajasthan (Fig. 1, 2, Table II), which are correlated with the uppermost part of the Vindhyans, overlie the Malani volcanic rocks, which are dated by Rb/Sr methods at 745 m.y. (Crawford and Compston, 1970).

The age of the Vindhyan system thus extends over a very long period – from at least 1200 m.y. and possibly 1400 m.y. to a Late Precambrian, and probably a Cambrian age (Table II). This upper age is not confirmed by radiometric datings, and the palaeontological data are somewhat doubtful, but recently salt pseudomorph shales have been recognized in the Sirbu shales sequence of the Upper Vindhyan Bhander series (Table I; Banerjee, 1964; Krishnan, 1968). Such shales were formerly only known from the Cambrian Salt Pseudomorph beds in the Salt Range. These outcrops strongly support the generally accepted correlation on lithological grounds of the uppermost Upper Vindhyan beds with the well-known Cambrian from the Salt Range (Ahmad, 1958; Pascoe, 1959; Sahni, 1960 a, b; Gansser, 1964; Krishnan, 1968).

SAMPLING

The samples (cores) were collected from seven sites in Upper Bhander sandstones beds, the highest stage in the Upper Vindhyan system, at two localities about 80 km SW of Agra (Central India).

The Upper Bhander beds in general are fine-grained, thin-bedded, somewhat flaggy sandstones with a characteristic deep red colour, sometimes with white specks. These beds appeared to be very important as building stone in northern India and the material

TABLE II

Age comparisons (after Crawford, 1969)

Rajasthan	Age (m.y.)	Vindhya-Bundelkand
	400	
	500	
		-------- ? *Bhander series*
Jodhpur sandstones ------------- (Trans Aravalli Vindhyans)	600	
	700	
Malani volcanic suite ------------	800	
		-------- ? Rewah series
	900	
Granites, pegmatites ------------	1000	
	1100	
	1200	-------- Majhgawan Kimberlite
Pegmatites -----------------------		-------- Base of Upper Vindhyan
	1300	
	1400	-------- ? Base of Lower Vindhyan
	1500	
	1600	
Bairat Granite -------------------		
	1700	
Delhi system --------------------	1800	
		-------- Gwalior lavas
	1900	
	2000	
Post-Aravalli, Pre- Delhi granite ------------	2100	
	2200	
Aravalli system -----------------	2300	
	2400	-------- Bijawar lavas Chopan dykes
	2500	
Berach granite ------------	2600	-------- Bundelkhand Granite
	2700	
? Older metasediments ---------		-------- ? Older metasediments
	2800	

was used for many historic buildings, e.g., the famous Taj Mahal at Agra; quarries are found in several places.

In a small quarry along the road, halfway between Dholpur and Bari (26.68°N 77.75°E), six samples were drilled from each of three sites (*IDHA* to *IDHC*) in three succeeding beds of red to purple-red fine-grained sandstones. At the small village of Rerigoan, just east of Balauri (26.55°N 77.42°E), another four sites (*IBAA* to *IBAD*) yielded six samples each, drilled from red-coloured fine-grained thinly bedded sandstones on a hill which had been partly quarried.

The sampled beds dip 2°NNE in the Dholpur locality and 3°W in the Balauri locality.

The cores were drilled with a portable drill and orientation was performed using a specially designed orientation apparatus in connection with a normal compass and clinometer.

LABORATORY TREATMENT AND METHOD OF ANALYSIS

The cores, 43 altogether, were sawn in the laboratory into 61 specimens with a diameter of 2.5 cm and a height of 2.2 cm.

After measurement of N.R.M. and initial susceptibility, at least one pilot specimen per site was subjected to a progressive A.C.-cleaning in 12–14 steps up to 3200 Oe peak value, and moreover, at least one pilot sample per site was subjected, in a furnace described by Mulder (1971), to a progressive thermal demagnetization in 18–22 steps up to the Curie point. At least five specimens per site were progressively cleaned by A.C.-methods in five steps from 1800–3000 Oe peak value. In order to check the efficiency of A.C.-cleaning, 14 pre-A.C.-treated specimens and the remaining uncleaned specimens were thermally cleaned in 8–12 steps from 640° C up to the Curie temperature.

All measurements were carried out with the Utrecht astatic magnetometers and the directional analysis was performed according to Zijderveld (1967).

All computations and the plotting of demagnetization graphs in orthogonal projection, density distribution figures, palaeolatitude maps, etc. were carried out by means of the Philips Electrologica X-8 computer of Utrecht State University, to which an off-line Calcomp 507 incremental plotter had been attached. The X-8 was programmed in ALGOL-60 (Klootwijk, 1971).

An attempt was made by the present author to reconstruct the ancient position of the Indian subcontinent with respect to other Gondwanaland continents, purely based on palaeomagnetic data. For this reason two special programs were written in ALGOL-60. One of the programs enables a rotation of separate continents in such a way that the palaeomagnetic northpoles become coincident with the present geographical northpole. If one assumes that a secular variation has been averaged out in the palaeomagnetic data, and if one assumes that the earth's magnetic field was to be represented by the central axial dipole field formulae during the acquisition of the characteristic magnetization, then such a rotation relocates the continents in their ancient geographical orientation and latitudinal position (plotted in equal-area projection; polar view). The longitudinal positions of the continents are undeterminate from the palaeomagnetic data alone. The other program delivers a plot of the best visual reconstruction of Gondwanaland, which can be obtained by rotating the continents around the centered palaeomagnetic northpole into their ancient relative geographical position.

RESULTS

The intensity of initial remanent magnetization of the Dholpur samples (series *IDHA–C*) varied between 2 and $10 \cdot 10^{-6}$ e.m.u./cm^3, that of the Balauri samples (series *IBAA–B*) between 9 and $12 \cdot 10^{-6}$ e.m.u./cm^3. However, the samples from the other two Balauri

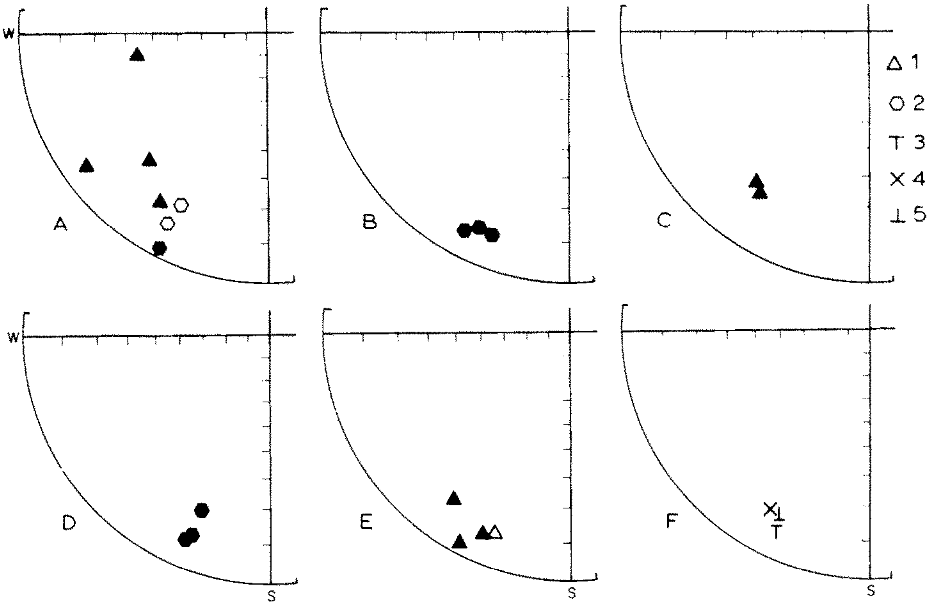

Fig. 3. Mean directions of remanent magnetization in stereographic projection. A. N.R.M. site-mean directions. B. A.C.-cleaned site-mean directions, Dholpur sites. C. Idem, Balauri sites. D. Thermally cleaned site-mean directions, Dholpur sites. E. Idem, Balauri sites. F. Mean of A.C.- and thermally cleaned directions.

Explanation of symbols: open symbols denote upward pointing directions; full symbols denote downward pointing directions. *1* = Balauri sites, *2* = Dholpur sites, *3* = mean direction of thermally cleaned results, *4* = mean direction of A.C.-cleaned results, *5* = mean direction of A.C.- and thermally cleaned results. *3*, *4* and *5* are pointing downwards. The present local field direction at the sampling area is denoted in Fig. 5.

sites *IBAC* and *IBAD*, which showed less consistent results, were less in intensity by a factor of 5 to 10. This might result from a lower amount of magnetic minerals, as the initial intensities of induced magnetization (H = 0.44 Oe), were also much lower: 0.1 to $0.7 \cdot 10^{-6}$ e.m.u./cm^3 in contrast to 0.8 to $2.1 \cdot 10^{-6}$ e.m.u./cm^3 for the other two Balauri and all Dholpur sites. The Q-values greatly exceeded unity, ranging from 1 to 9 with a mean range from 3 to 6.

The initial directions were grouped in the SW quadrant, with low and both positive and negative inclinations (Fig. 3A). Sites *IBAC* and *IBAD* were notable exceptions. Specimen directions of these two sites showed a greater scatter and the site *IBAD*-specimens in particular showed a streaking towards the present local field direction (Fig.4A).

A.C.-cleaning

From the Dholpur specimens (Fig.3A, 3B, 4A, 4B, 5) and from site *IBAA* and *IBAB* (Balauri) specimens (Fig.3A, 3C, 4A, 4C, 5) in general a soft upwards and NW-directed secondary component of small intensity could be removed in A.C.-fields of 1000–1500 Oe

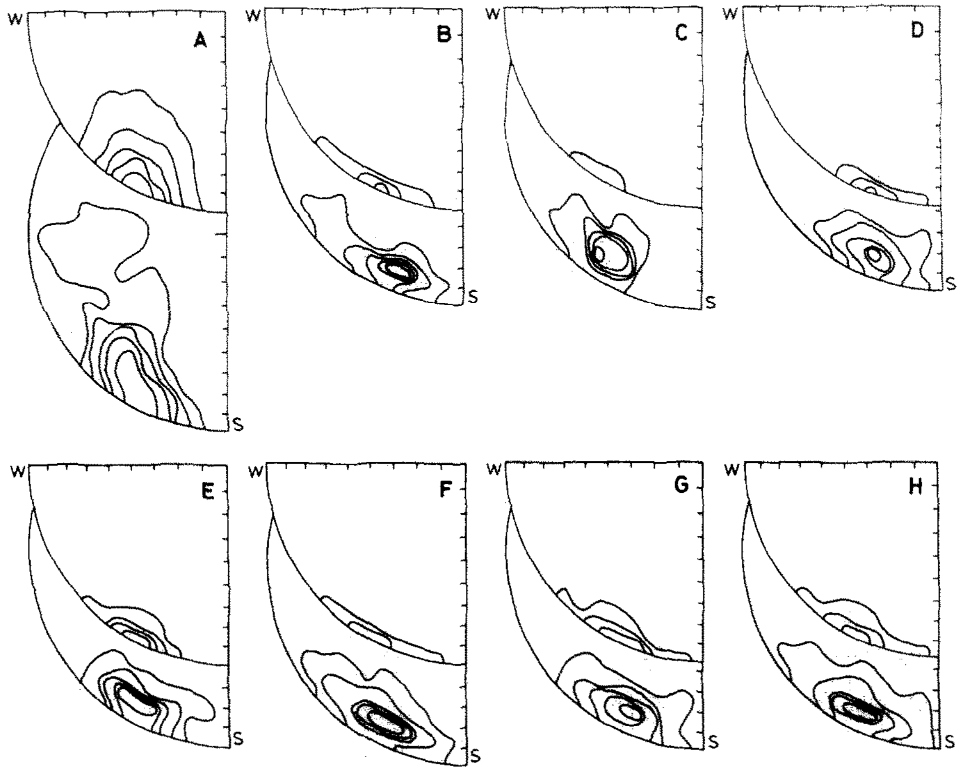

Fig. 4. Density distribution of remanent magnetization directions in equal-area projection. Only southwesthern quadrants of upper and lower hemisphere are shown. The upper quadrant denotes directions pointing upwards, the lower quadrant denotes directions pointing downwards.
A. Initial directions. B. A.C.-cleaned directions, Dholpur specimens. C. A.C.-cleaned directions, Balauri specimens. D. Thermally cleaned directions, Dholpur specimens. E. Thermally cleaned directions, Balauri specimens. F. Combined A.C.-cleaned directions, Dholpur and Balauri specimens. G. Combined thermally cleaned directions, idem. H. Combined A.C.- and thermally cleaned directions, idem.
A circular counting area of 2% of the hemisphere area has been applied in 4A, in all other figures a counting area of 1% has been applied. Frequency intervals: A:4, B:2, C:1.6, D:2.2, E:2, F:2.8, G:4, H:6.8. The present local field direction at the sampling area is denoted in Fig.5.

peak value. Specimens from sites *IBAC* and *IBAD* could not be fully cleaned by A.C.-methods.

For all sites, except *IBAC* and *IBAD*, the A.C.-cleaning resulted in a distinctly improved mean direction and better grouping of the site mean directions (Fig.3A, 3B, 3C, 3F, Table III): $D = 209°$, $I = +11.5°$, $k = 113$, $\alpha_{95} = 7°$, $N = 5$. The density distribution of remanent-magnetization directions clearly shows the cleaning effect of the A.C.-demagnetization (Fig.4A, 4B, 4C, 4F). The stable directions were obtained during cleaning with A.C.-fields between 1800 and 3000 Oe peak value (Fig.6, 7, 8).

In general, the demagnetization graphs showed an anomalous tendency of the magnetization vector path to bypass the center (Fig.7, 8, 9). We might attribute this bypassing ef-

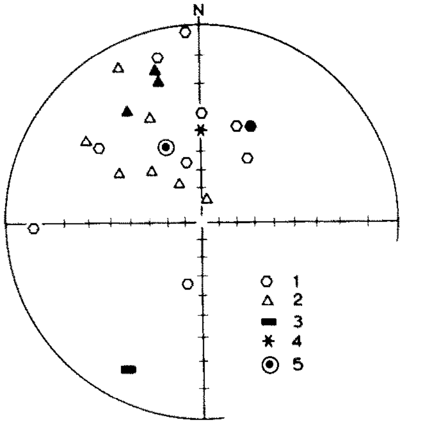

Fig. 5. Secondary remanence directions, eliminated during A.C.- or thermal cleaning in stereographic projection. Explanation of symbols: open symbols denote directions pointing upwards, full symbols denote downward-pointing directions. *1* = Dholpur specimens, *2* = Balauri specimens, *3* = mean direction of Upper Bhander sandstones, pointing downwards, *4* = present local field direction at the sampling area, pointing downwards, *5* = normal Deccan-Trap direction, pointing upwards.

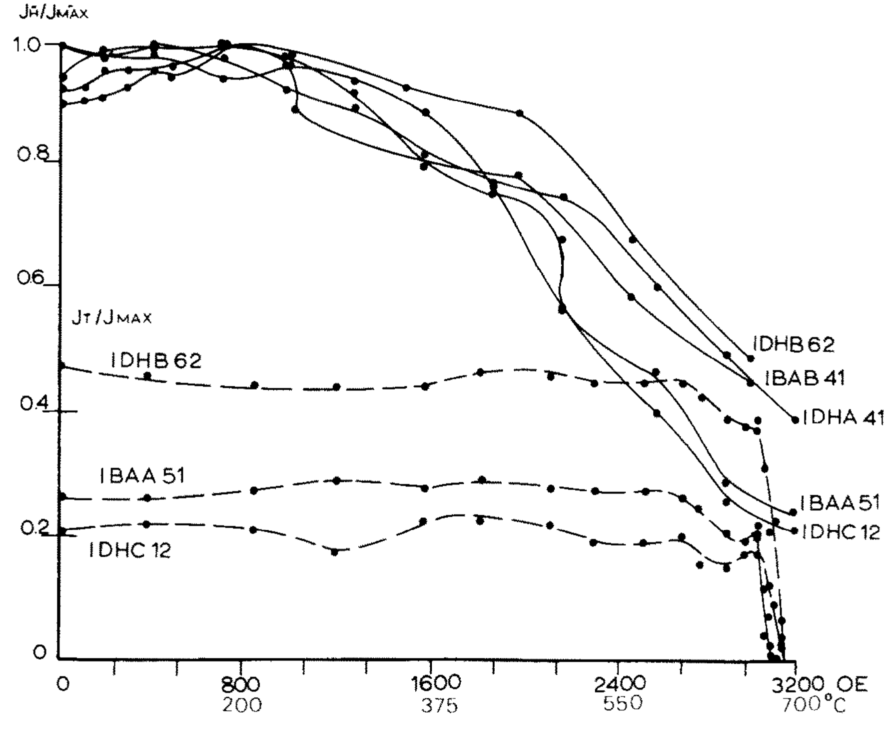

Fig. 6. Normalized curves, showing the decrease in intensity of total remanent magnetization, during A.C.-cleaning (full lines). Broken lines show the continued decrease in intensity during thermal demagnetization of specimens, cleaned already before by A.C.-methods.

TABLE III

Natural remanent magnetization

Site	Samp.	Spec.	Site mean direction (degrees)		K	α_{95} [*1] (degrees)	Intens [*2]	M [*2]	Q-value [*3]
IDHA	6	9	207.5	−15	29	10.5	20– 98	10–15	2–8
IDHB	6	8	208.5	− 9	90	6	30– 74	9–20	2–4
IDHC	6	11	207.5	+ 2	132	4	51– 73	8–12	4–7
IBAA	6	12	223.5	+20.5	232	3	95–123	11–21	4–9
IBAB	6	10	213	+12.5	226	3	93–121	12–18	6–9
IBAC	6	7	234.5	+ 6	19	14	5– 27	2– 7	1–4
IBAD	7	14	260.5	+34.5	25	15.5	21– 31	1– 7	3–6

		After A.C.-demagnetization				After dip correction		Pole position			
Site	Sp. [*4]	Site mean direction (degrees)		K	α_{95} (degrees)	Site mean direction (degrees)		Longitude (degrees)	Latitude (degrees)	DP (degrees)	DM (degrees)
IDHA	6	201	+ 7	61.5	8.5	201	+ 9	138.5 W	53 N	4.5	8.5
IDHB	6	208	+ 5	74	8	208	+ 7	148.5 W	49.5 N	4	8
IDHC	6	205	+ 7.5	78	7.5	205.5	+ 9.5	144.5 W	50 N	4	7.5
IBAA	7	216.5	+18.5	63	7.5	217.5	+17	153.5 W	39.5 N	4	8
IBAB	7	213.5	+15.5	115	5.5	214.5	+14	152 W	42.5 N	3	6
IBAC	1	––	––	––	––	––	––	––	––	––	––
IBAD	1	––	––	––	––	––	––	––	––	––	––

After thermal demagnetization						After dip correction		Pole position			
Site	Spec.[*5]	Site mean direction (degrees)		*K*	α_{95} (degrees)	Site mean direction (degrees)		Longitude (degrees)	Latitude (degrees)	*DP* (degrees)	*DM* (degrees)
IDHA	6	202.5	+ 6	69	8	202.5	+ 8	140.5 W	52.5 N	4	8
IDHB	6	202.5	+ 5	252.5	4	202.5	+ 7	141 W	53 N	2	4
IDHC	6	202	+14	69	8	202	+16	137 W	49 N	4.5	8.5
IBAA	7	216.5	+12.5	160.5	5	217	+11	156 W	42 N	2.5	5
IBAB	7	204	+ 7.5	82	6.5	204	+ 7	144 W	52 N	3.5	7
IBAC	6	202	− 7.5	70.5	8	202	− 8	149 W	59.5 N	4	8
IBAD	5	208.5	+ 4	57	10	208.5	+ 3	151.5 W	50.5 N	5	10

Combined results dip correction applied						Pole position		Corresponding direction at Nagpur[*6]			
	Site mean direction (degrees)		*N*	*K*	α_{95} (degrees)	Longitude (degrees)	Latitude (degrees)	*DP* (degrees)	*DM* (degrees)	Declination (degrees)	Inclination (degrees)
Mean A.C.	209	+11.5	5	113	7	148 W	47 N	4	7.5	210.5	+19
Mean therm.	206	+ 8.5	6	123	6	145.5 W	50 N	3	6	207	+17
Mean A.C. and therm.	207.5	+ 9.5	6	137.5	5.5	146.5 W	48.5 N	3	5.5	208.5	+18

[*1] Only the specimens selected for demagnetization treatment were used in the determination of the semi-angle of Fischer's cone of confidence.
[*2] Intens: range of initial remanent magnetization per site in 10^{-7} e.m.u./cm^3.
M: range of initial induced magnetization per site in 10^{-7} e.m.u./cm^3.
[*3] *Q*-value: range of *Q*-values per site.
[*4] Number of specimens used for A.C.-demagnetization.
[*5] Number of specimens used for thermal demagnetization.
[*6] Corresponding direction at Nagpur (21.06°N 79.23°E), according to the dipole hypothesis.

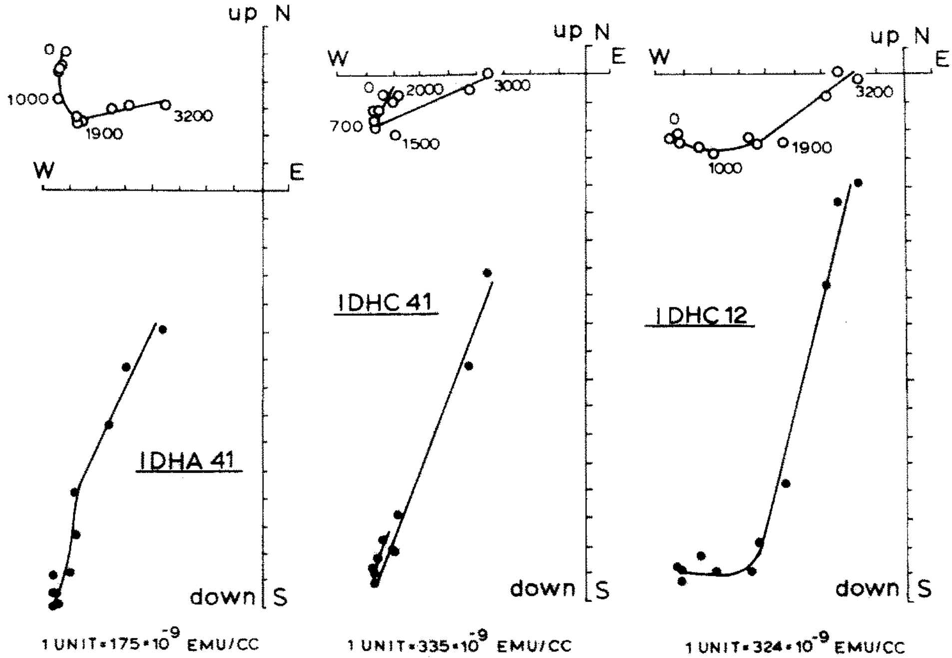

Fig. 7. Dholpur specimens. Orthogonal projection figures of the vector path of the total remanent magnetization vector during A.C.-cleaning. Circles denote projections in the vertical east–west plane, dots denote projections in the horizontal plane. Numbers denote Oe-peak values of the applied alternating fields.

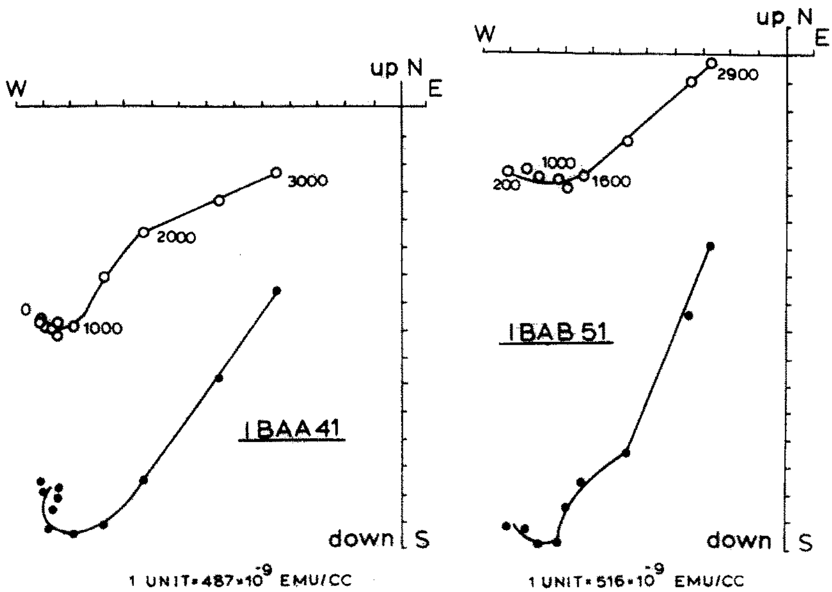

Fig. 8. A.C.-cleaned Balauri specimens. Explanation as under caption to Fig.7.

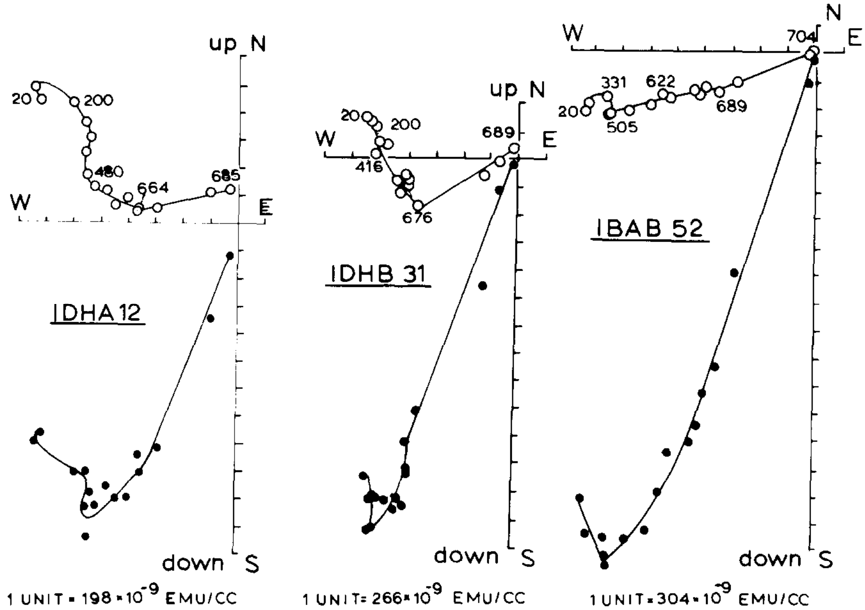

Fig. 9. Thermally cleaned specimens. Explanation as under caption to Fig.7. Numbers denote successive peak values of the applied temperatures.

fect to an inhomogeneous magnetization of the samples. The obtained directions, as represented in Table III, are certainly not hampered by this bypassing effect, as only the first derivative of the vector path was calculated.

Thermal demagnetization

Thermal demagnetization of the Dholpur specimens and site *IBAA* and *IBAB* specimens (Fig.9) eliminated in analogy to the A.C.-cleaning the NW- and upwards directed component completely at about 650–660°C. (Fig.6, 10). It should be remarked here that this upwards and NW-directed component does not represent the present local field direction, dipping 30 degrees downwards at the sampling locality. In contrast, in specimens from site *IBAC* and *IBAD* a slight downdipping direction with N–NW declination was eliminated at 640–650° C. We attribute the latter aberrant magnetization vector to a simultaneous decay of the above-mentioned upwards-directed component and a present field component.

Stable directions very similar to the A.C.-results were obtained during cleaning at temperatures above 650–660° C (Fig.3, 4, 7, 8, 9).

The thermal demagnetization graphs showed, although to a lesser extent, the same bypassing effect as the A.C.-demagnetization graphs. The resulting characteristic directions group well in the SW quadrant with a slight downwards inclination (Fig.3, 4).

Most of the eliminated secondary directions in sites *IDHA*, *IDHB*, *IDHC*, *IBAA* and

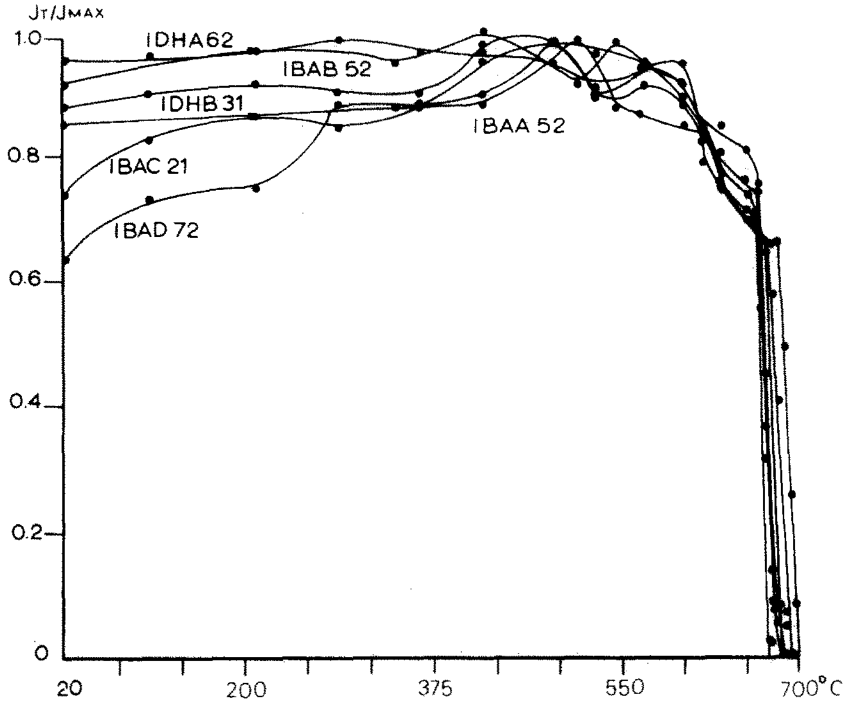

Fig. 10. Normalized curves, showing decrease in intensity of total remanent magnetization during thermal cleaning.

IBAB (Fig.5), coincide with the Deccan-Traps direction (normal magnetization), $D = 331.5°$, $I = -49.5°$ (Wensink and Klootwijk, 1971). So we assume that this secondary component was thermally induced by a former but now eroded layer of Deccan-Trap lavas. These lavas have at present a maximum thickness of 2000–3000 m in the Western Ghats near Bombay. The outcrop of these Early Tertiary flood basalts (60–65 m.y.; Wellmann and McElhinny, 1970) has now shrunk to a distance of at least 200 km from the sampling locality (Fig.2). Partial and total thermal remagnetization we also found in a number of Gondwana red beds in Central India (Klootwijk, in press). Examples of such secondary Deccan-Traps directions confirm the generally accepted idea that the original extent of the Deccan Traps greatly exceeded the present outcrop, maybe by a factor of 2 or 3 (Wadia, 1953; Pascoe, 1963; Krishnan, 1968).

Some specimens, especially from site *IBAC*, revealed after thermal cleaning SW directions with an aberrant upwards inclination (Table III). We believe that these specimens were too far remagnetized by the Deccan-Trap lavas, thus preventing the determination of the primary direction. We therefore disregarded the directions from site *IBAC*.

The resulting thermally cleaned site mean directions are closely grouped in the SW quadrant and do not show a marked deviation from the site mean directions obtained by A.C.-cleaning (Fig.3, 4, Table III). The mean site directions resulting after application of a slight correction for the local dip of the strata are (Table III): A.C.-cleaned direction: D = 209°, I = +11.5°, k = 113, α_{95} = 7°, N = 5. Thermally cleaned direction: D = 206°, I = +8.5°, k = 123, α_{95} = 6°, N = 6. In view of the very analogous A.C.-cleaned and thermally cleaned results, I suggest as the best fitting mean site direction a combination of the A.C.- and thermal results for each site: D = 207.5°, I = +9.5°, k = 137.5, α_{95} = 5.5°, N = 6.

INTERPRETATION

Application of a small correction for the local dip of the strata resulted in a slight improvement in α_{95} for the A.C.-cleaned site mean directions from 7.99° to 7.23°. However, α_{95} obtained for thermally cleaned site mean directions did not show any noticeable change. Application of the fold test to the combined A.C.- and thermal-results, gives a non-significant improvement of the α_{95}. These minor changes in α_{95} are due of course to the slight dip of the strata. The resulting pole position is 146.5°W 48.5°N (Table III). By taking this pole as a palaeomagnetic northpole we obtained a palaeolatitude pattern for the Indian subcontinent as shown in Fig.11A and an original position of the Indian subcontinent slightly to the south of the equator as shown in Fig.12A.

Palaeomagnetic data (D = 357°, I = +31°) were acquired from the Upper Vindhyan Kaimur series in Central India (Sahasrabudhe and Mishra, 1966, as quoted by McElhinny, 1968). These authors originally assigned a Cambrian age (540–580 m.y.) to their samples but the recent radiometric datings (Vinogradov et al., 1964; Tugarinov et al., 1965; Crawford and Compston, 1970) proved the age of the Kaimur series to be much greater, between 900 and 1200 m.y. So this Upper Vindhyan Kaimur result seems to be no longer representative for the Cambrian of India. Palaeomagnetic results from sandstones of the Bhander series, reported recently by Athavale (1972), were different from the present results. R.N. Athavale (personal communication, 1972) applied A.C.-cleaning up to 400 Oe peak value only. However, in my experience in the present case of the comparable Upper Bhander sandstones, A.C.-cleaning in fields higher than 1800 Oe or thermal cleaning at temperatures above 650–660° C was necessary in order to eliminate secondary (Deccan Trap) magnetization components (Fig.5).

Thus up till now the only comparable results from the Indian subcontinent seem to be those from the Salt Range area (McElhinny, 1969; Wensink, 1972a, b). However, the Salt Range area is situated in what is generally referred to as the Western Himalayan syntaxis, very close to the foothills of the great Himalayan mountain chains (Fig.1).

There are strong arguments that the Indian subcontinent has underthrust the Eurasian continent (Holmes, 1965; Dietz and Holden, 1970; Minato and Hanuhashi, 1970), so the northern border of the Indian shield is not clearly delineated. Generally the foothills of the Tertiary mountain chains are taken as its border, but it has been pointed out that the Lower- and Higher-Himalayas might be an activated portion of the Indian subcontinent (Wadia and Auden, 1939; Gansser, 1964; Wadia, 1966; Ahmad, 1968; Qureshy, 1968). The enormous extent and height of the Tertiary mountain chains and the Tibetan Plateau are suggestive for the great stresses caused by the northward movement of the Indian sub-

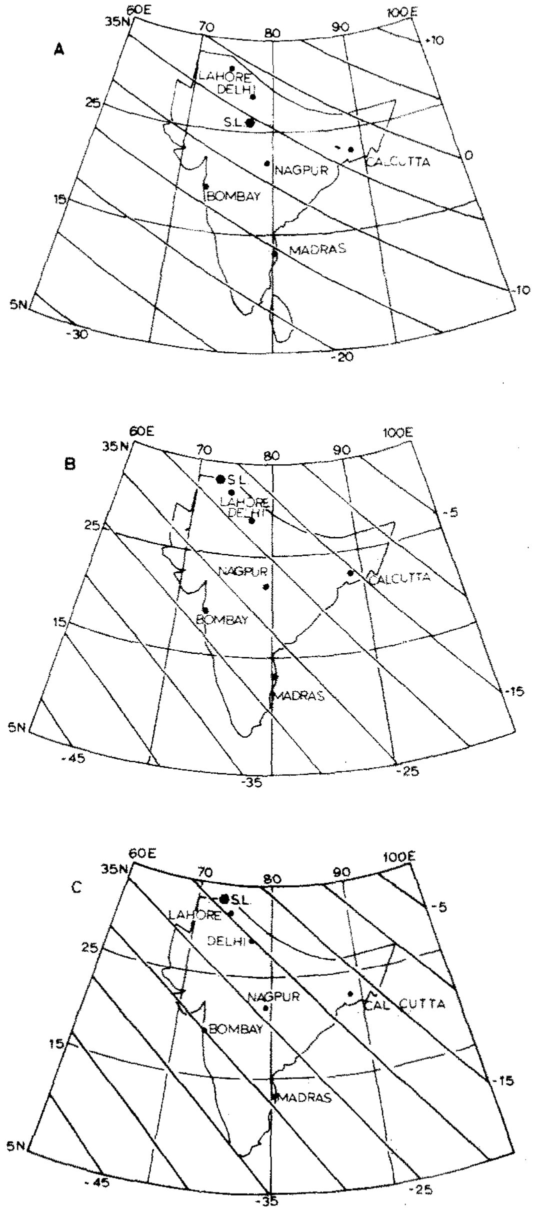

Fig. 11. Maps of palaeolatitudes, according to the Upper Bhander sandstones palaeomagnetic result (A, present study); the Purple Sandstone result (B, McElhinny, 1969). and the Salt Pseudomorph beds result (C, Wensink, 1972a, b). *S.L.* denotes sampling locality. The palaeolatitudes are computed according to the central axial dipole field formulae.

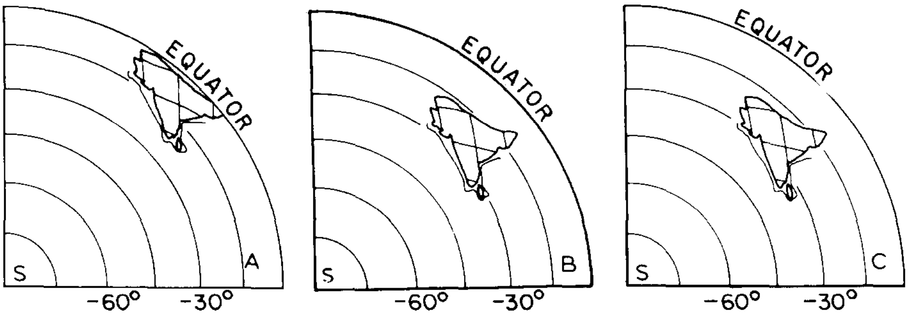

Fig. 12. Ancient orientation of the Indian subcontinent with respect to the equator, according to the Upper Bhander sandstones result (A, present study); according to the Purple Sandstone result (B, McElhinny, 1969); and according to the Salt Pseudomorph beds result (C, Wensink, 1972a, b). The longitudinal position of the subcontinent is indeterminate. Equal-area projection (polar view) of the southern hemisphere.

continent. So we should be aware of the possibility of internal distortions of the Indian subcontinent.

In comparing the palaeomagnetic results from correlative formations of the Salt Range area (McElhinny, 1969; Wensink, 1972a, b), in the utmost northwest of the Indian subcontinent, and from Central India (present author), we might test the rigidity of the Indian plate. We confine this Indian plate to the area west of the Ninety-East ridge as suggested by Francheteau and Sclater (1969), in contrast to the original definition of Le Pichon and Heirtzler (1968), and to the east of the Owen-Murray fracture zone.

McElhinny's results from both normal and reversed magnetized samples (10 samples, $D = 218°$, $I = +31.5°$, $\alpha_{95} = 11°$; Pole: 148°W 28°N, Fig.11B, 12B) for the Purple Sandstone beds, which are also supported by recent data from both normal and reversed samples from Wensink (71 samples, $D = 217.5°$, $I = +35.5°$, $\alpha_{95} = 6°$; Pole: 146.5°W 26.5°N, Fig.11C, 12C) for the slightly younger Salt Pseudomorph beds from the Salt Range area are not entirely in agreement with the Upper Bhander results (43 samples, $D = 207.5°$, $I = +9.5°$, $\alpha_{95} = 5.5°$; Pole: 146.5°W 48.5°N). The lower inclinations for the Upper Bhander results correspond to a pole position situated about 20 degrees to the south of the Salt Range poles. Interpreted in accordance with the axial dipole field hypothesis, this aberrance in results might have consequences in attempts to reconstruct pre-drift configurations of Gondwanaland.

McElhinny (1970), McElhinny and Luck (1970, a, b) and McElhinny and Briden (1971) tentatively placed India adjacent to the Somali coast of East Africa in Gondwanaland reconstructions, based upon the fitting of polar wandering curves. Such a reconstruction is in analogy to the geometrical computer fit from Smith and Hallam (1970).

A computer fit study of the Gondwanaland continents for the Cambrian was carried out by the present author. The continents were rotated in such a way that selected Cambrian palaeomagnetic northpole positions were made coinciding with the geographi-

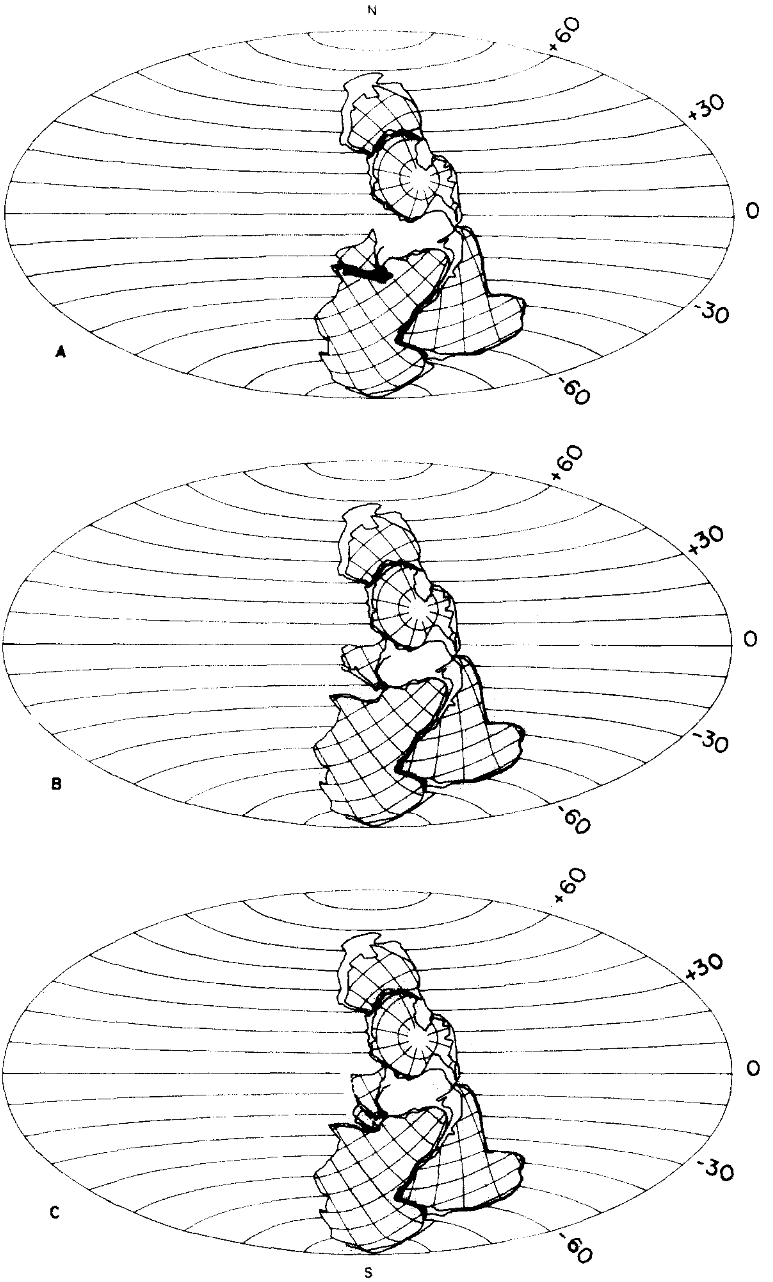

Fig. 13. Cambrian Gondwanaland configuration, as deduced from palaeomagnetic results only. Longitudinal position of the continents is indeterminate. Areas of overlap are denoted in black. Aitoff projection. Palaeomagnetic results applied:

A. Ntonya Ring structure (Africa; Briden, 1968), Red Beds Argentine (South America; McElhinny and Briden, 1971), Antrim Plateau volcanics (Australia, Antarctica; McElhinny and Luck, 1970b), Purple Sandstone (India, McElhinny, 1969).

B. Upper Bhander sandstones (India, present study). Same results applied to other continents.

C. Purple Sandstone ("Indus subplate"), Upper Bhander sandstones (Indian subcontinent s.s.). Reconstruction proposed by the author.

cal northpole. According to the data used several tentative reconstructions can be obtained (Fig.13):

(1) Application of McElhinny's (1969) data for the Lower- to Middle Cambrian Purple Sandstone of the Salt Range area (India) and Briden's (1968) result for the Precambrian to Lower Cambrian Ntonya Ring structure (Africa) leads to an overlap of about 10 degrees of arc of Western India and the African East Coast of Tanganjika, Kenya and Somaliland (Fig.13A).

(2) Application of the Indian Upper Bhander pole and the African Ntonya Ring structure pole, leaves a sublatitudinal aligned gap between the African East Coast and the Indian West Coast (Fig.13B).

(3) The deviation of the Salt Range poles from the hereby presented pole from Central India can be attributed to an independent northward movement of an Indus subplate, comprised between the Baluchistan ranges in the west and the Aravalli range in the east (Fig. 13C).

Comparison of the palaeolatitude maps, compiled for the Salt Range poles and the Upper Bhander pole (Fig.11A, 11B, 11C), suggests a Cambrian position of the Salt Range area (part of the Indus subplate) off Bombay. Klootwijk (in preparation) gives much geological and geophysical evidence for such an independent northward movement of the Indus subplate relative to the Indian subcontinent s.s., e.g., the northward convex syntaxial junction of the Hindu Kush–Pamir–Karakorum–Himalayan belt and the anomalous northern position of the Pamir knot, bordered by sinistral shear systems in the west and dextral shear systems in the east. Moreover, there is a clear relationship between the movement of this Indus subplate and the huge dextral offset of the northern Carlsberg ridge with respect to the Southeast branch of the Mid-Indian Ocean ridge. McKenzie and Sclater (1971) and Fischer et al. (1971) suggested such a dextral offset along a formerly active Chagos–Laccadive megashear. The Owen–Murray zone with its continuation through the Baluchistan ranges up to the western Pamir shear system and the Chagos–Laccadive–Cambay zone, connected maybe with the eastern Pamir shear system, can be taken as the Indus subplate megashear boundaries.

The position of the Indus subplate with respect to the Indian subcontinent s.s., as indicated by the Salt Range and Upper Bhander palaeomagnetic data, yields a very satisfactory reconstruction of this part of Gondwanaland, closing the gap between the Indian subcontinent and the African East Coast of Kenya and Tanganjika (Fig.13C).

The available Lower Palaeozoic palaeomagnetic results from India and Australia, i.e., from the Purple Sandstone, the Salt Pseudomorph beds, the Upper Bhander sandstones and the Antrim Plateau volcanics, disagree with reconstructions placing southeast India in juxtaposition to northwest Australia. Such a juxtaposition, during at least part of the Phanerozoic was proposed on Permian palaeogeographical grounds by Ahmad (1961) and Veevers et al. (1971), on geophysical grounds by Qureshy et al. (1968) and on radiometric-age determinations by Crawford (1969). However, Crawford (1971) reformed his earlier ideas in the light of the recently available palaeomagnetic data, which suggest a juxtaposition of western India to East Africa, at least during the Palaeozoic and part of the Mesozoic.

The proposed reconstruction (3, Fig.13C) is in accordance with a palaeoposition of Madagascar to the south of the Somali basin (Baker and Miller, 1963; Flower and Strong, 1969; Wright and McCurry, 1970; Heirtzler, 1971 (as quoted by Heirtzler and Burroughs, 1971); Tarling, 1971; Green, 1972) and prevents a palaeoposition in the Somali basin, as advocated by Du Toit (1937), McElhinny (1970), Smith and Hallam (1970) and McElhinny and Briden (1971).

Definite Cambrian results for Antarctica are not available. For this reason we placed Antarctica adjacent to Australia, according to the geometrical computer fit of Sproll and Dietz (1969). According to marine magnetic anomalies, Australia separated from Antarctica in the Early Tertiary (Le Pichon, 1968; Le Pichon and Heirtzler, 1968; McKenzie and Sclater, 1971). Palaeomagnetic results are somewhat contradictary, as the Cretaceous poles of Antarctica and Australia are compatible with the Sproll and Dietz (1969) fit, whereas the Jurassic poles do not (Creer, 1970; McElhinny, 1970). Anyhow the juxtaposition seems justified in the tentative Cambrian reconstructions. A rotation according to the Australian Antrim Plateau volcanics pole (McElhinny and Luck, 1970 b), was applied to both continents in juxtaposition.

The rotation according to this pole, however, resulted in a rather large gap between South America, Africa and India on one side and the fitted Australian and Antarctican continents on the other. The reliability and extent of this gap is strongly dependent upon the accuracy of the Australian Antrim Plateau volcanics pole which has a large α_{95} of 16 degrees. ($N = 14$; 29 sites, 13 sites rejected).

So it is possible that this gap between West- and East-Gondwanaland, if representing a reality, will be modified to a certain extent when other Lower Cambrian data become available for Australia. A rather similar gap is also visible in other reconstructions of Gondwanaland during the Palaeozoic, e.g., the reconstruction of Vilas and Valencio (1970), based upon the fitting of apparent polar wandering curves and the Late Palaeozoic glacial facies study of Frakes and Crowell (1968). This debatable gap might, however, partly be filled up by the microcontinents in the Indian Ocean, i.e., the Mascarene Plateau, Madagascar, the Agulhas Plateau and Mozambique and Madagascar ridges, and probably the Kerguelen- and Crozet Plateau (Laughton et al., 1971). It is of interest, however, that any remaining gap, if a reality and forming an extensive waterbody, might invalidate some of Meyerhoff's main arguments against continental drift (Meyerhoff and Teichert, 1971; Meyerhoff and Harding, 1971), i.e., the advocated physical impossibility of extensive glaciation and subsequent coal formation in interior Gondwanaland, because of the absence of moisture. In Meyerhoff's somewhat roughly outlined Gondwanaland reconstructions the central part of this super-continent is 3000–4000 km away from the nearest ocean moisture source.

Late Palaeozoic glacial facies were studied by Frakes and Crowell (1968) in Antarctica, Africa, South America and the Falkland Islands. They produced a Late Carboniferous–Early Permian palaeogeographical reconstruction of these continents, based largely on the geodetic fit of the 500-fathom isobath (Bullard et al., 1965) and could nicely relate the remaining broad gap at the joint area to the distribution of three glacial facies, distinguished by them throughout Gondwanaland, i.e.: (1) terrestrial till, (2) shallow water glacial, and associated continental deposits, (3) glacial marine and marine deposits. The marine facies distribution reveals a good match with the gap in the reconstruction of Frakes and Crowell (about $5 \cdot 10^6$ km^2), and might be related with the remaining gap (the microcontinents relocated) in the present reconstruction. Frakes and Crowell emphasized in particular the importance of this gap as an extensive waterbody, for the onset of the Late Palaeozoic glaciation, pointing to adverse conclusions to those from Meyerhoff and Teichert (1971) and Meyerhoff and Harding (1971).

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