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LATE CRETACEOUS PALEOPOSITION AND POST COLLISIONAL CRUSTAL ROTATIONS OF SULAIMAN RANGE: A PALEOMAGNETIC STUDY OF SULAIMAN RANGE

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ABSTRACT

The Himalayan mountain system represents an active continent-continent collision extending westward from Burma through India and Nepal to Pakistan. The western margin of the Indian continent is oblique to direction of convergence between India and Eurasia. At this margin Sulaiman fold-and-thrust belt is formed because of the India-Eurasia collision. The magnetic mineral that serves as remanent carrier is magnetite. The ChRM directions yield mean directions of Dec/Inc=358/-35 with alpha-95=14.6 and k=13.5 in stratigraphic coordinates. The positive intra-formational conglomerate test indicates that the acquisition age of ChRM is close to the age of rock formation. Considering the mean paleolatitude (19S) of the present study, it can be concluded that at the time of formation of these volcanics, the area was close to the location of Reunion hotspot. Thus Bibai volcanics are probably a trace of Reunion hotspot. The mean declination values are deviating about 27 clockwise with respect to declination values calculated from Indian Apparent Polar Wander Path for the area. This clockwise rotation may be due to supra-crustal decollement over counter clockwise rotating and northward moving Indian continent. The paleomagnetic rotations are only observed in central part of the Sulaiman fold-belt showing that only central part moved over the decollement surface, which is further supported by structure trends. In the central part of the Sulaiman fold-belt the structure trends are E-W and in eastern and western parts these are N-S or NNE-SSW. Keeping in view the change of structure trend, it appears that central part of the fold-belt has moved towards southeast and these rotations occurred along different strike-slip faults in area. Although exact age of these rotations cannot be constrained by the present study, but regional tectonics indicates that these rotations are related with Plio-Pleistocene oblique collision of NW margin of Indian continent with Afghan plate.

INTRODUCTION

Foreland thrust and fold belts related with the convergent continental boundaries are important areas for the exploration of the hydrocarbons. The Sulaiman fold-belt is one of the active tectonic features of the Himalayan orogenic belt. Structural studies were done on the Sulaiman fold-belt and foredeep by Humayon et, al, 1991[1]; Jadoon et, al., [2] Petroleum prospects studies were performed by Raza et al., (1989)[3].

Paleomagnetism is one of the important tool to solve tectonic and structure problems related with translational and rotational movements of plates and blocks. Several paleomagnetic studies have been carried out in northwestern Himalaya and Hindukush ranges [4; 5; 6; 7 and 8], but very few paleomagnetic data are available for Sulaiman fold-belt. Most of the paleomagnetic data from internal Himalayan zone are complex with numerous overprints and do not reveal primary paleo-latitudinal position of the Indian plate. The paleomagnetic data from un-metamorphosed rocks of Sulaiman range offer promising prospects for indicating details of India's drift. Therefore this paleomagnetic study was carried out to get better paleo-latitudinal control of Indian continent. Moreover this work also attempts to document the amount and sense of block rotation in western part of the Sulaiman Range. In this paper we present the results of paleomagnetic investigation carried out on Bibai Volcanics of Sulaiman Range.

GEOLOGY

The northwestern margin of the Indian continent is in contact with Eurasian continent (Afghanistan-Helmand block) [9 and 10]. The suture zone between two continents is marked by ophiolites and melanges (Fig.1). A set of volcanic rocks occurs interstratified with the continental shelf sediments of the northwestern margin of the Indian continent [12]. These volcanics are termed as Bibai Volcanics [11]. These are exposed near Zhob, Muslim Bagh, Quetta, Khuzdar, Bela and Karachi areas. The maximum thickness (2km) of these volcanics is near Muslim Bagh town. These volcanics consist of pillow basalts, agglomerates, tuffs and volcanic conglomerates. Tuffaceous sandstone, mudstone, shale and marl occur as intercalation in all localities [12]. On the basis of geochemical analysis it has been interpreted that these volcanic rocks are within-plate basalts and these volcanic units represent passage of Tethyan ocean floor over the Reunion hotspot [13 and 14]. Moreover McCormick [14] correlated these volcanics with Deccan tholeiites. The age of Bibai Volcanics is estimated by various paleontological and radiometric data. The underlying Parh Limestone is rich in foraminifers of Campanian age [15]. The Bibai Volcanics is conformably overlain by marly shales, which are dated as Late Campanian by the nano fossil assemblages [16]. A 71+3.4 Ma K-Ar whole rock age is reported from Bibai Volcanics [17]. Therefore the most probable age of the Bibai Volcanics is middle-Campanian. These volcanics were obducted on the Indian continent in Paleocene time when plate motion changed to northwest from north direction [14].

For the present study, the volcanics exposed in Muslim Bagh area have been selected. The Muslim Bagh area is situated on the northwestern margin between the Indian continent and Eurasian continent. The area is divided in to three main geologic units from north to south; the ophiolite complex, the melange zone, and the calcareous zone [18]. The ophiolite complex is mainly composed of ultra-mafic to mafic igneous rocks. The melange zone contains Triassic to Cretaceous volcono-sedimentary sequences. The calcareous zone comprised of calcareous and pelitic rocks. In the upper part of the calcareous zone pillow lavas, tuffs, and volcanic conglomerates of Bibai Volcanics are intercalated with the sediments.

SAMPLING AND METHODOLOGY

Paleomagnetic samples were collected from pillow lavas of Bibai Volcanics (Fig.2). The determination of accurate paleo-horizontal plane is of great importance in all paleomagnetic studies. The paleo-horizontal plane was determined with confidence by observing the bedding plane of associated sediments as well as pillow structure. Four to ten samples were collected from each site. The intra-formational conglomeratic facies presence allows a paleomagnetic conglomerate-test. Nine samples were collected from the conglomerates. In order to know the magnetic mineralogy thermomagnetic analysis and isothermal remanent (IRM) experiment were carried out for representative selected samples. Natural remanent magnetization (NRM) was measured on Natsuhara/SMD-88. A progressive thermal demagnetization (THD) technique was performed in 8~16 steps to all samples. Demagnetization results were plotted on Zijderveld diagrams [19]. NRM components were obtained by principal component analyses [20].

THERMOMAGNETIC RUNS AND IRM ANALYSES

An EIKO/EB-4 automatic magnetic balance was used to measure saturation magnetization versus temperature. The experiments were performed under defused air condition (~10^{-3} mmHg) by applying a steady magnetic field of 200-250 mT. Curie temperature of about 580C is observed (Fig. 3). The heating and cooling curves are almost reversible. A Curie temperature of 580C corresponds to pure magnetite (Fe_3O_4).

IRM was imparted by using TOKIN electromagnet up to maximum available field of 700 mT. The IRM acquisition curve demonstrates saturation at about 100~200 mT (Fig.4). This also confirms the presence of low coercive magnetic mineral such as magnetite.

PALEOMAGNETIC MEASUREMENTS

Vector component plots for THD of the samples indicate the presence of ChRM component having 570~580C unblocking temperature (Fig. 5). In some of the samples a low temperature component (up to 200 or 300C) is also observed (Fig. 5; e.g. sample MBG020-E). This may be a viscous remanent magnetization. ChRM component is observed from 400 to 580C. There is no significant difference in statistics of mean direction of ChRMs before and after bedding-tilt correction, possibly because bedding attitudes are not divergent enough (Table 1, Fig. 6). Data of site MBG022 is not used because of large α-95 (36.8).

Table-1 : Site mean and formation mean directions of ChRMs. N= number of samples used for site mean calculation. Dg & Ig are declination and inclination in geographic coordinates, whereas Ds and Is are declination and Inclination in stratigraphic coordinates. The site marked with * is not used for the calculation of mean direction.

	N	Dg°	Ig°	Bedding°/°	Ds°	Is°	α-95°	k
Sampling Sites:								
MBG06	5	25.8	32.0	348/62	35.0	-12.3	19.6	16.0
MBG018	6	320.0	-9.0	223/52	327.0	-60.0	6.0	91.0
MBG020	7	348.0	14.0	265/62	345.0	-47.5	6.0	100.0
MBG021	4	342.0	14.0	255/52	341.0	-38.0	30.0	5.0
MBG029	7	9.5	37.0	268/57	7.7	-19.2	9.6	40.0
MBG030	5	357.2	9.0	273/55	354.5	-45.6	17.7	20.0
MBG039	6	346.0	38.5	280/58	350.5	-16.5	12.5	30.0
MBG040	9	0.0	20.5	262/58	1.4	-37.0	8.0	45.0
MBG031	9	357.0	28.0	284/58	357.0	-27.6	11.0	25.0
MBG022*	5	317.0	56.0	255/64	330.0	-4.0	36.8	5.0
Mean:		**353.0**	**21.0**	**(k=13, α-95=15)**	**358.0**	**-35.0**	**14.6**	**13.5**
Conglomerate Test:								
MBG035	9	269.0	3.9				78.4	1.4

Paleo Pole Position:

Paleo Latitude=40.2° **Paleo Longitude=250.5°** **(dp = 9.7, dm = 16.8)**

CONGLOMERATE TEST AND AGE OF THE MAGNETIZATION

Paleomagnetic samples were collected from the conglomerates, which directly overlies the pillow basalts. These volcanic conglomerates are mainly composed of rounded to sub-rounded fragments of basalt and are embedded in tuffaceous sandy matrix. These may be derived from underlying basaltic rocks of Bibai Volcanics. The ChRM directions of conglomerate samples are widely scattered (Fig. 7). Hence the conglomerate test is positive. This means that the area did not suffer any remagnetization after the deposition of the conglomerates. The positive intra-formation conglomerate test indicates that the acquisition age of the ChRM is close to the age of the rock formation, which is middle Campanian.

TECTONIC IMPLICATIONS

The mean paleolatitude (19S) of ChRMs of Bibai volcanics is reasonably consistent with the previously reported paleomagnetic data of the Sulaiman Range. The Aptian-Albian to Santonian-Campanion paleolatitude of the area is 23+2S [20]. This has been calculated on the basis of primary magnetizations of underlying Parh Limestone and Goru Formation. Geochemical data such as Zr vs Nb and La/Ta, Hf/Ta, and Th/U values of Bibai Volcanics are similar to that of Reunion island basalts [14]. The mean paleolatitude of Bibai Volcanics is close to the position of Reunion hotspot. Moreover paleolatitude (23+2S) of underlying formations also support that in Early Campanian the position of the area was also close to the location (21S) of Reunion hotspot. Hence paleomagnetic data from northwestern margin of Indian continent supports the idea that Bibai Volcanics were formed on the western margin of Indian continent, when it was passing over a Reunion hotspot.

The comparison of VGP for the Bibai Volcanics with Indian APWP indicates that it is distinct from APWP trend (Fig. 8). The calculated mean declination value (358) is about 27 clockwise deflected with respect to declination values calculated from 70 Ma pole of Indian APWP for the area (Table 2). About 50 clockwise rotation is also observed in Sanjawi area of central Sulaiman range (Fig. 9)[20]. This rotation may be due to supera-crustal decollement over the counter-clockwise rotating and northward moving Indian continent. Moreover on the basis of seismic reflection profiles, drill hole and surface geology it has been reported that Sulaiman Lobe is underlain by a detachment fault and most probably Eo-Cambrian evaporites are decoupling zone [1 & 2]. Reference 21 quantify the velocity gradient tensor field that accommodates total India-Eurasia plate motion in the area by using geologic, geodetic, and seismic information, along with velocity boundary constraints. They suggested that that the Sulaiman Range involves both strike-slip and dip-slip (thrust) deformation and all material between the Sulaiman Lobe and Chaman Fault moves southeastward relative to Indian continent. The observed clock-wise rotation of paleomagnetic declinations with respect to Indian continent is consistent with this southeastward movement. The above mentioned paleomagnetic rotations are only observed in central part of the Sulaiman fold-belt indicating that only central part moved over the decollement surface, which is further supported by the structure trends of the area. In the central part of the Sulaiman fold-belt the structure trends are E-W and in eastern and western parts these are N-S or NNE-SSW. Keeping in view the change of structure trend, it appears that central part of the fold-belt has moved towards southeast and these rotations occurred along different strike-slip faults in area. Although exact age of these rotations cannot be constrained by the present study, but regional tectonics indicates that these rotations are related with Plio-Pleistocene oblique collision of NW margin of Indian continent with Afghan plate.

Table - 2 : Declination and Inclination values calculate for the study area (30.5N, 68 E) from Indian APWP [22] from 100 Ma to 50 Ma.

Age of pole	Declination n°	Inclination °	Paleolatitude
100 Ma	316.0	-50.7	31.5°S
90 Ma	320.5	-47.6	28.7°S
80 Ma	325.4	-44.6	26.2°S
70 Ma	331.5	-33.2	18.1°S
60 Ma	336.8	-15.5	7.9°S
50 Ma	346.3	20.2	10.4°N

CONCLUSIONS

1) Magnetic mineralogical studies reveal that the potential remanent carrier of these volcanics is magnetite.

2) The positive intraformation conglomerate test indicates that the acquisition age of the ChRM is close to the age of the rock formation, which is middle Campanian.

3) According to mean paleolatitude the ChRM was acquired at about 19S. Considering the present and previously reported paleomagnetic data of underlying formations, it can be inferred that at the time of formation of Bibai Volcanics the northwestern margin of Indian continent was close to the Reunion hotspot. Thus the Bibai Volcanics are probably a trace of the Reunion hotspot activity in Campanian.

4) Paleomagnetic data show clock-wise rotation with respect to Indian APWP. This clock-wise movement in the Sulaiman Range is due to the southeastward movement of the Sulaiman Range after the collision.

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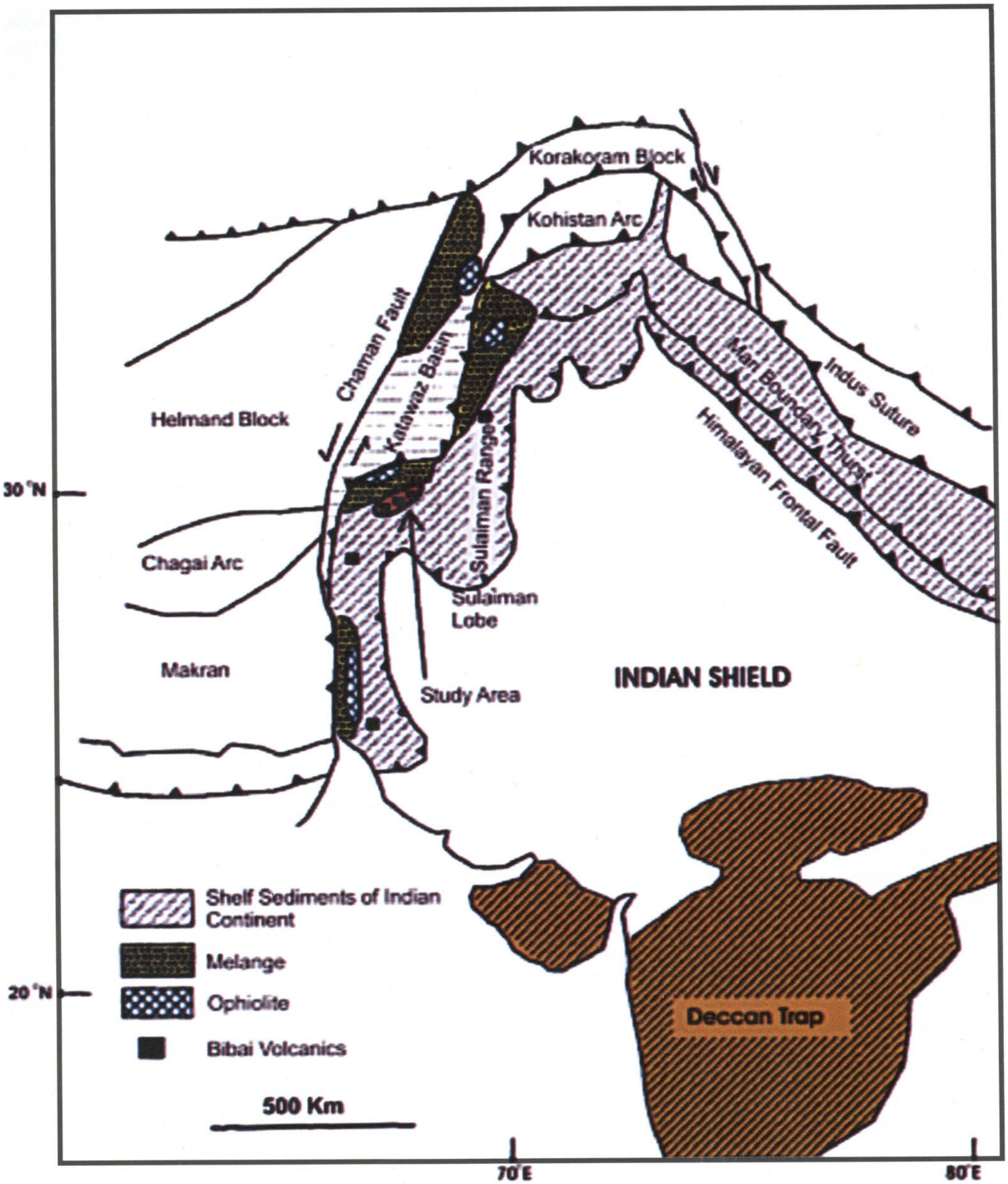

Fig. 1 - Tectonic map of Indian continent and surrounding terranes, showing the study area [1]

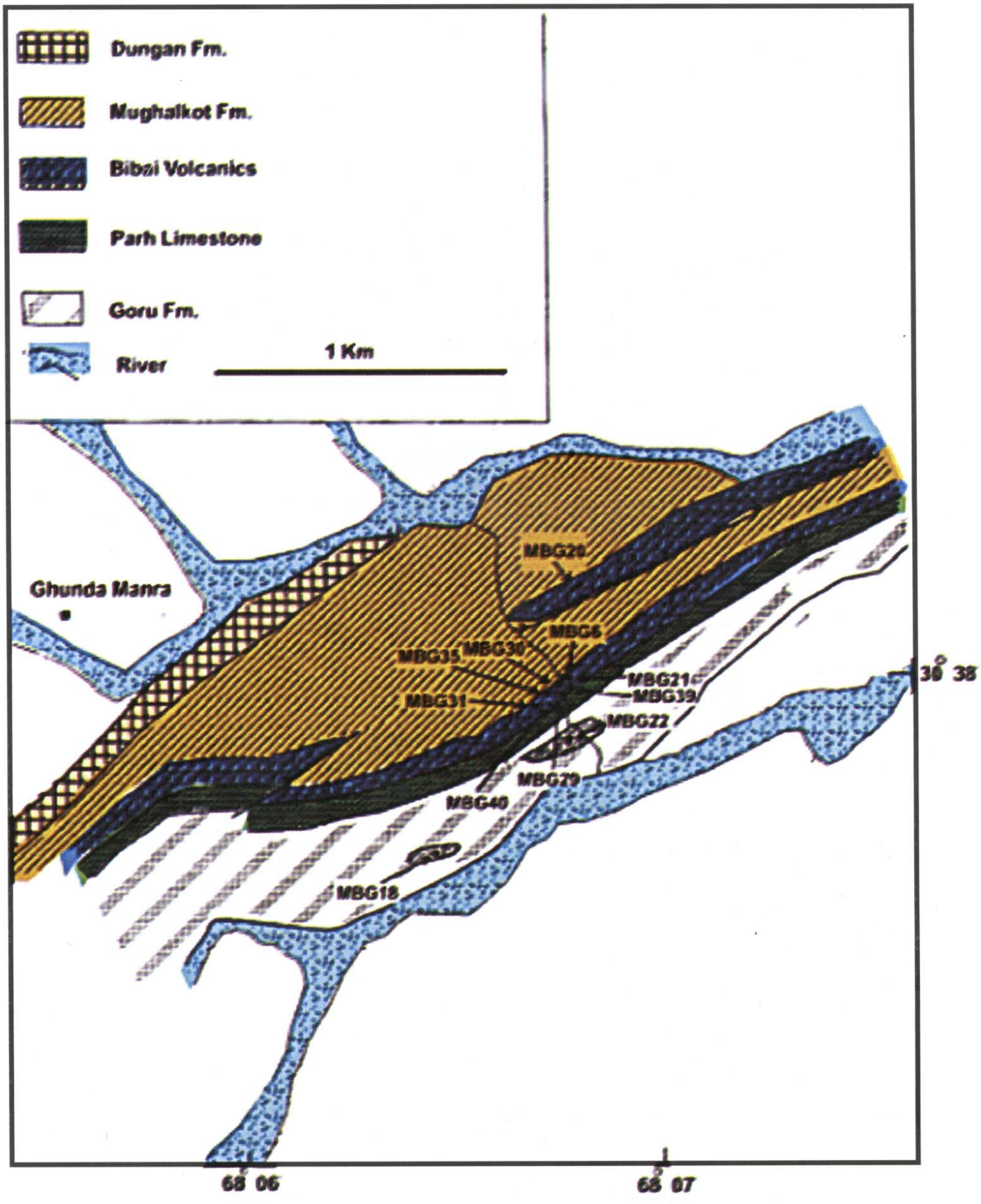

Fig. 2 - Sampling sites location of Bibai Volcanics. Geologic Sites are marked by filled circle. Geologic map is modified from [24]

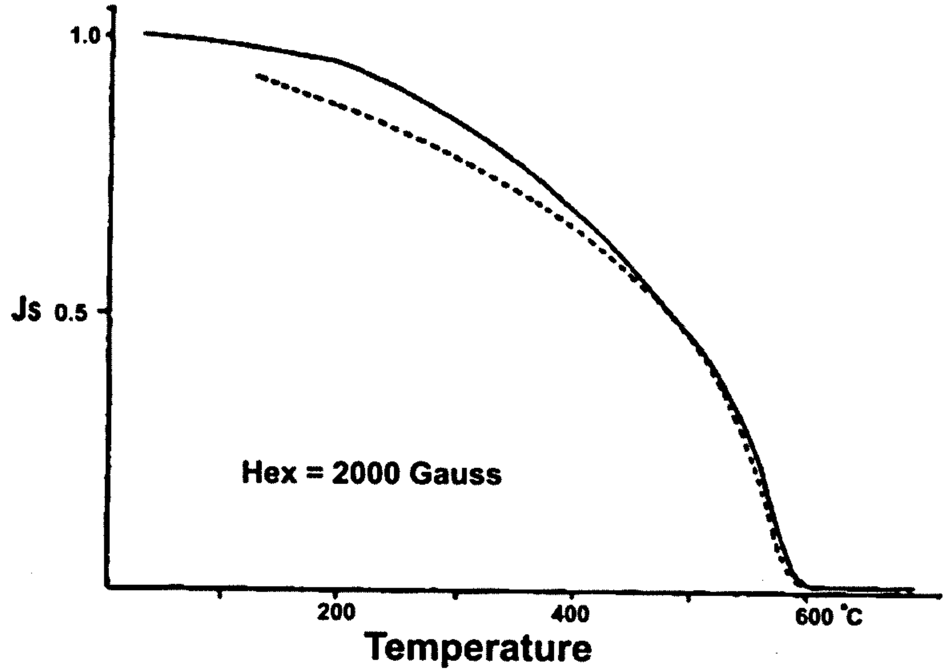

Fig. 3 - Thermomagnetic (Js-T) curves for Bibai pillow basalt specimen. Solid(dashed) line shows heating (cooling) curve

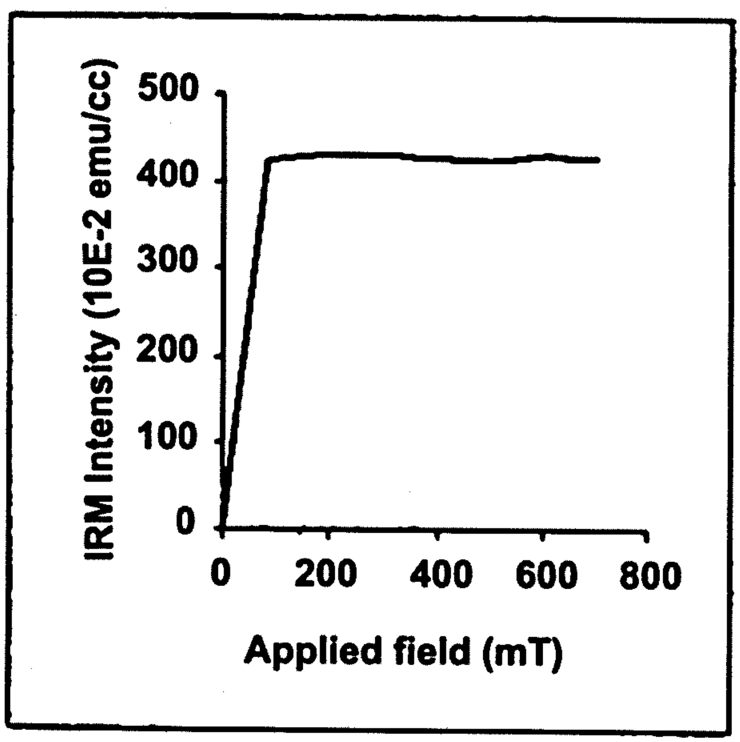

Fig. 4 - IRM acquisition curve for Bibai pillow basalt specimen

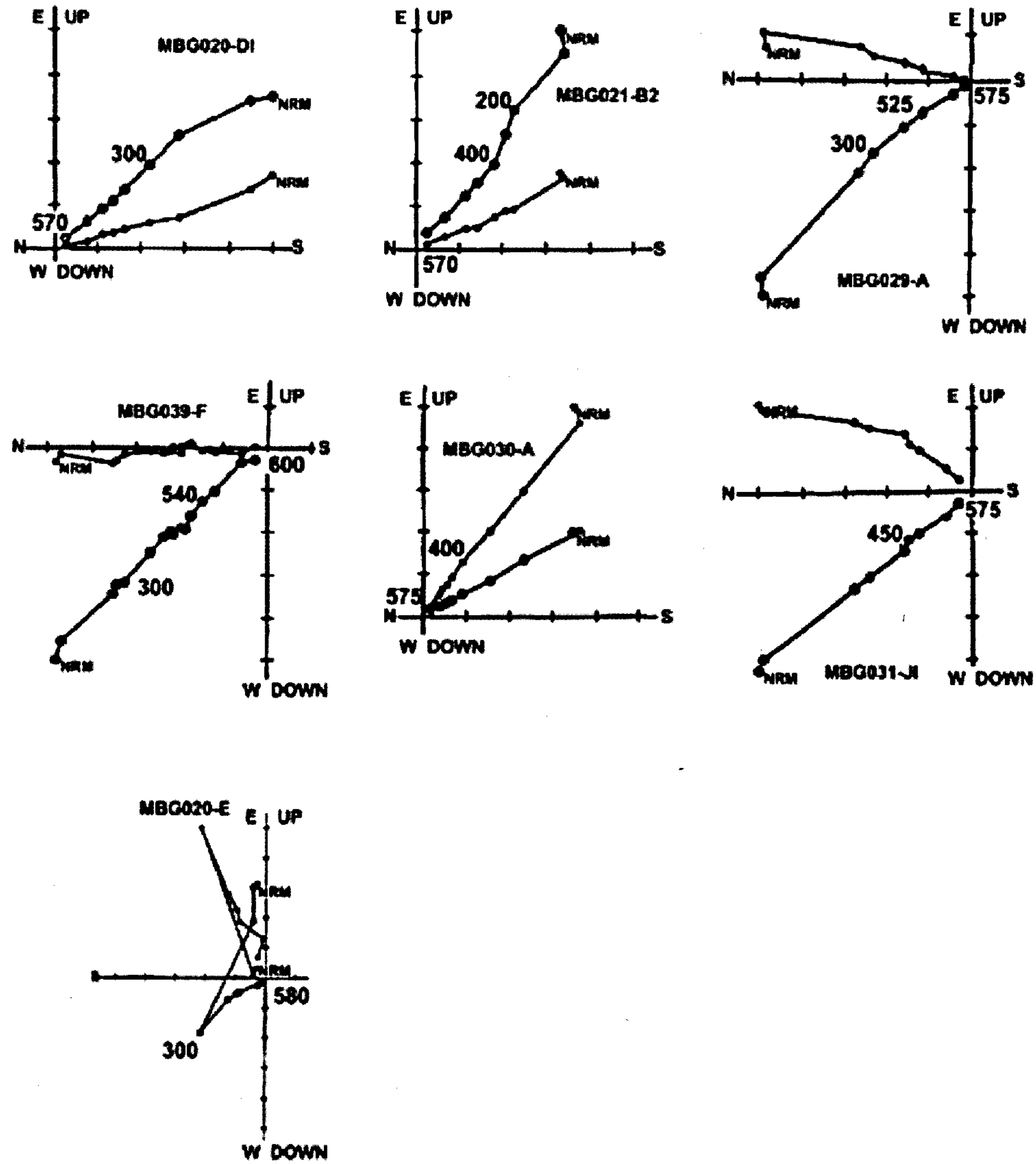

Fig. 5 - Zijderveld orthogonal projections of magnetizations vctor and points during progressive THD for samples of Bibai volcanics.

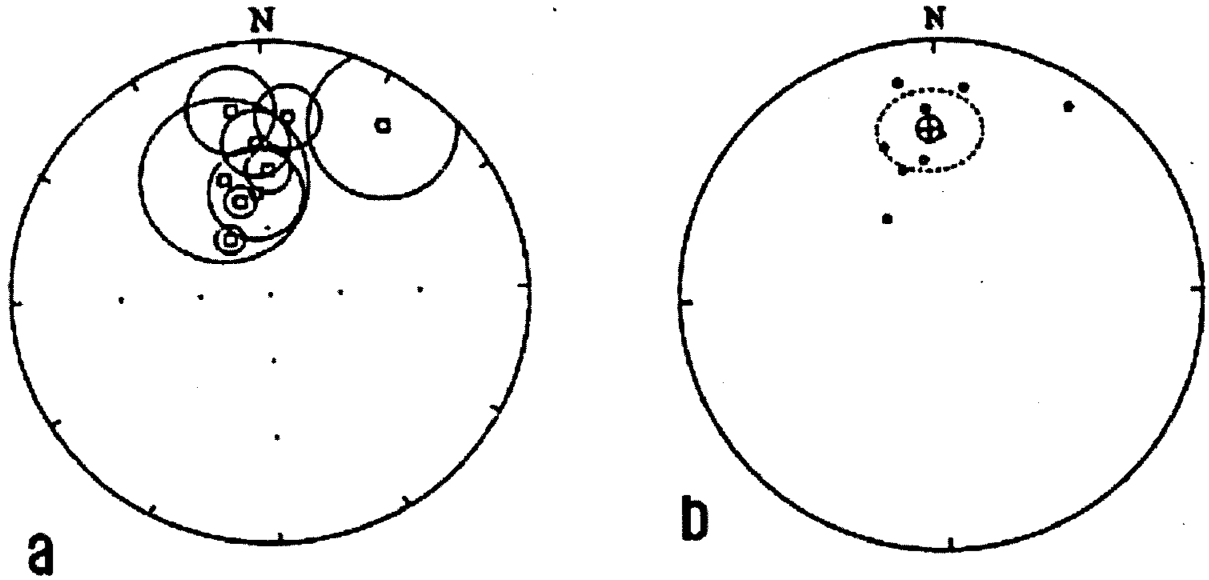

Fig. 6 - Equal area projection a ChRM of different sites after bedding correction along with the circle of confidence (alpha-95) ChRM of different sites along with calculated mean after bedding tilt correction. Dashed ellipse represents circle of confidence on the calculated mean

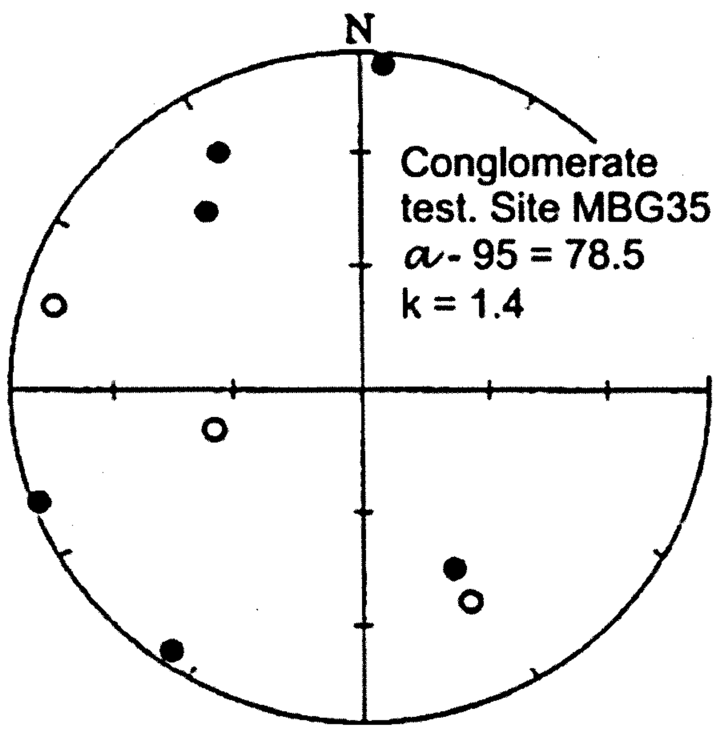

Fig. 7 - Equal area stereographic projects of ChRM components of samples of conglomerate bed at the site MBG35.

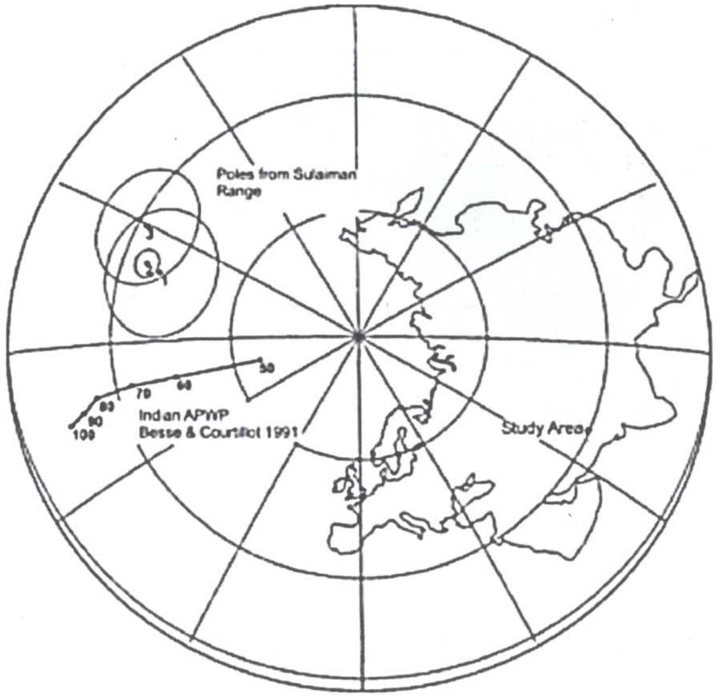

Fig. 8 - Comparisson of poles of Sulaiman range with that of Indian APWP. The pole marked as 1) is calculated from the present study 2) Aptian/Albian to Santonian/Campanion combined pole [20]. 3) early Campanion pole calculated from Parh Limestone[20]. The poles of Indian APWP are marked with ages in Ma.

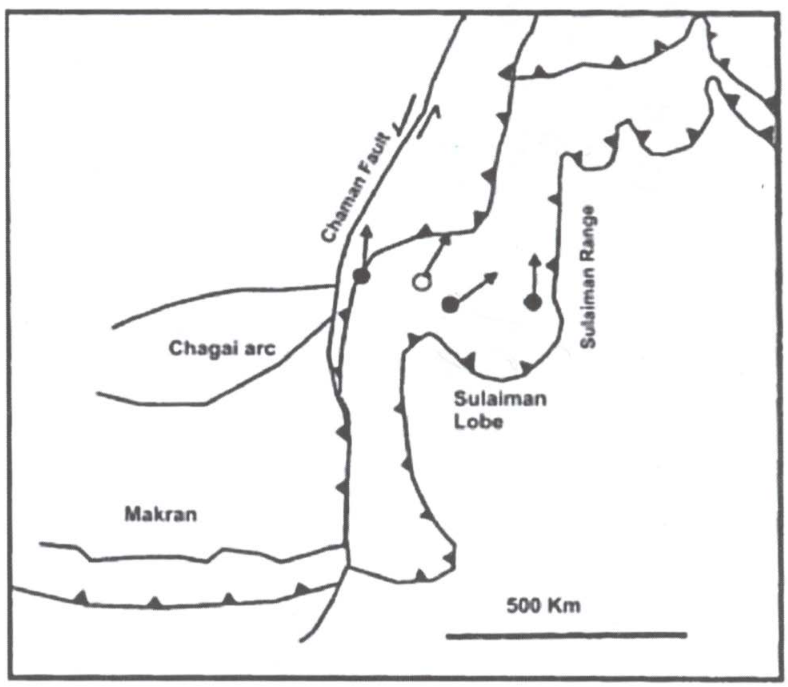

Fig. 9 - Rotations with respect to Indian Continent, deduced from paleodeclination values with western margin of the Indian continent. The direction of ChRM of the present study is shown by unfilled circle. The other rotations are marked after[20].

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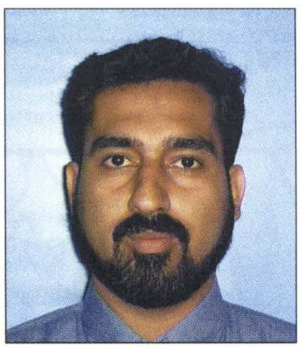

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