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Palaeomagnetic data about southern Tibet (Xizang) – I. The Cretaceous formations of the Lhasa block

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Summary. A palaeomagnetic study of Middle to late Cretaceous redbeds from Linzhou basin (Lhasa block), north of the Yarlung Zangbo suture zone, gives a stable palaeomagnetic direction of magnetization with a positive fold-test: six sites, 57 samples, $D = 333°$, $I = 38°$, $k = 78$, $\alpha_{95} = 8°$, pole 64°N, 348°E. We discuss the problem of a possible remagnetization but consider that this direction of magnetization gives a good approximation for the palaeolatitude of the Lhasa block during Middle to late Cretaceous time. Results from more recent Tibetan formations are also presented: late Cretaceous to Palaeocene sediments and volcanics give a lower palaeolatitude of 10° N and but more recent andesites have emplaced about 30° N, close to the present-day latitude. An interpretation is proposed whereby the Lhasa block, which was a part of Asia in the early Cretaceous, has undergone first a southward motion accompanied by an anticlockwise rotation and then, after the Palaeocene, a northward motion under the constraint of the colliding India.

1 Introduction

The actual location of the India–Asia suture zone is thought to lie at the surface within the Yarlung Zangbo suture zone. As the convergence between Asia and India has a strong northward component, the palaeomagnetic method is the best suited for improving geodynamical models.

During the first joint French–Chinese geological and geophysical field-work, palaeomagnetic sampling was undertaken both north and south of the Yarlung Zangbo suture zone.

We present here the results obtained on Cretaceous volcanics and sediments from the Lhasa block, north of the Yarlung Zangbo. This work documents a very brief account of a part of the results given elsewhere (Pozzi *et al.* 1982) and presents new results from more recent Tibetan formations.

2 Geological setting of the Lhasa block

The metamorphic basement of the Lhasa block is covered by Carboniferous tillites with Gondwanian affinities (Tapponier *et al.* 1982; Colchen *et al.* 1982; Academia Sinica 1980). From the Permian to the Jurassic, shallow marine sedimentation predominates, but during the Jurassic the deposits become increasingly detrital and consist of Upper Jurassic clastic series, Lower Cretaceous clastics similar to the Himalayan formations, and rythmic shale–limestone sequences of Aptian age. On the top of this sequence, red sandstones and siltstones with volcanic intercalation become more and more continental, giving rise to the Takena formation with a thickness of about 1000 m. The age of this series spans from Albian–Cenomanian at the base to an unknown age at the top.

The Gangdise plutonic belt intrudes the folded Mesozoic series. The folded Takena and older formations are overlain unconformably by red conglomerates with an intercalation of tuffs and thick volcanics (Lingzizong formation).

The age of this formation is only known by two radiometric datings: 60 Ma (Maluski, Proust & Xiao Xuchang 1982) and 48 Ma (Montigny, private communication, see below).

3 Sampling and measurements

3.1 SAMPLING

The sampling localities are given in Fig. 1. The Takena formation was sampled between Lhasa and Yangbajing (sites 1 and 2) and in the Linzhou region near Peng Po farm, north-east of Lhasa (sites 4, 5, 7, 8 and 12). Three sites (3, 6 and 9) were sampled on the Lingzizong volcanics between Lhasa and Yangbajing near Linzhou. Between six and 25 samples were drilled or hand sampled on each site spreading over 10–300 m. The orientation was done with both a sun compass and a magnetic compass.

3.2 PALAEOMAGNETISM

The measurements of the remanent magnetization were made with a Digico and a Schönstedt spinner magnetometer. All the sedimentary specimens were demagnetized by step heatings of up to 650 or 660°C in a field compensated space (residual field lower than 20 nT). Volcanics were mainly demagnetized in alternating magnetic fields of peak value up to 100 mT.

3.3 RESULTS

We present first the results from sediments of the Takena formation, in chronological order up to uncomformity between Takena and Lingzizong formations and then the results from Lingzizong's volcanics. The characteristic magnetic directions are given for all sites in Table 2.

3.3.1 Takena sediments

The oldest Takena samples were taken a few kilometres east of Peng Po on an isolated characteristic hill (site 12) formed of an intercalation of limestones with orbitolinas, sand-

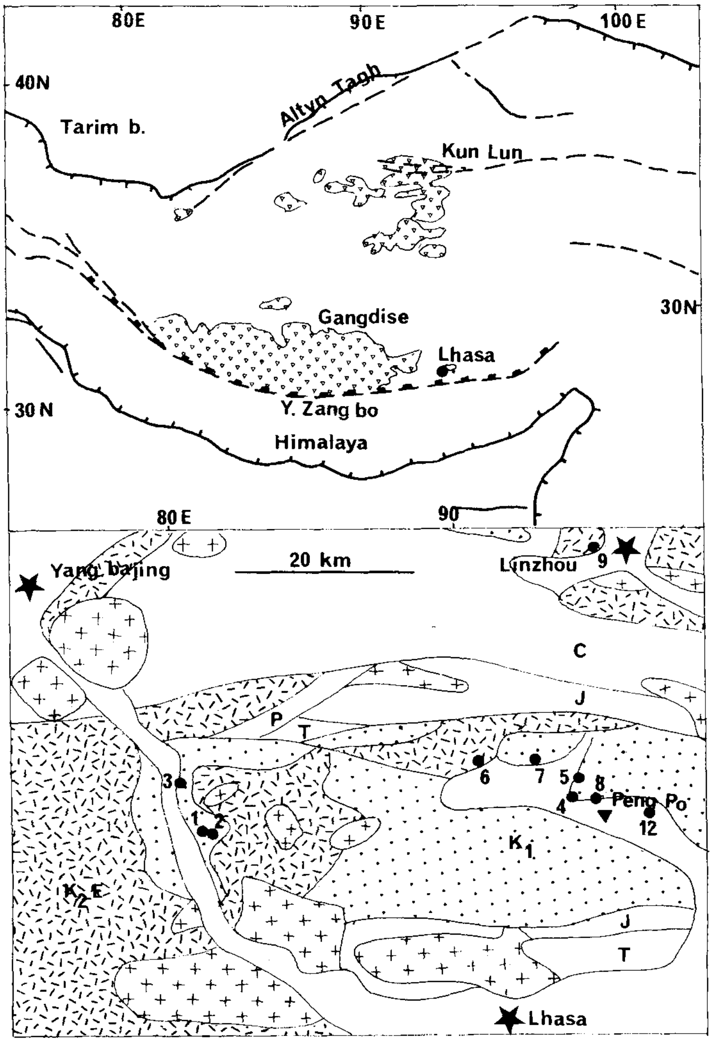

Figure 1. Top: general overview of Tibet. Bottom: geological structure of the Lhasa region and sampling areas (numbered dots). Crosses: granites and granodiorites. C: Carboniferous, T: Trias, J: Jurassic, K_1: Cretaceous up to the Takena formation. K_2E: Lingzizong and younger formations.

stones with ripplemarks and siltstones. It is older than sites 4, 5 and 8, probably of Barremian age. Twenty-three samples were taken in different levels (subsites 12/1 to 12/5). The thermal behaviour of subsites 12/1, 12/3 and 12/2, 12/4, 12/5 are different. Subsites 12/1 and 12/3 have a blocking temperature of 590°C and their IRM acquisition curve shows a quick saturation characteristic of magnetite. On the other hand, subsites 12/2, 12/4 and 12/5 have a higher blocking temperature ($>650^\circ$C).

The characteristic magnetization of the different subsites and before tectonic correction are given in Fig. 2 and in Table 1.

Subsites 12/2, 12/4 and 12/5 have stable, single magnetization with similar directions. The magnetic directions of subsites 12/1 and 12/3 are different. The magnetization of subsite 12/1 is very weak (0.3×10^{-3} A m^{-1}) and the dispersion of magnetic direction even after

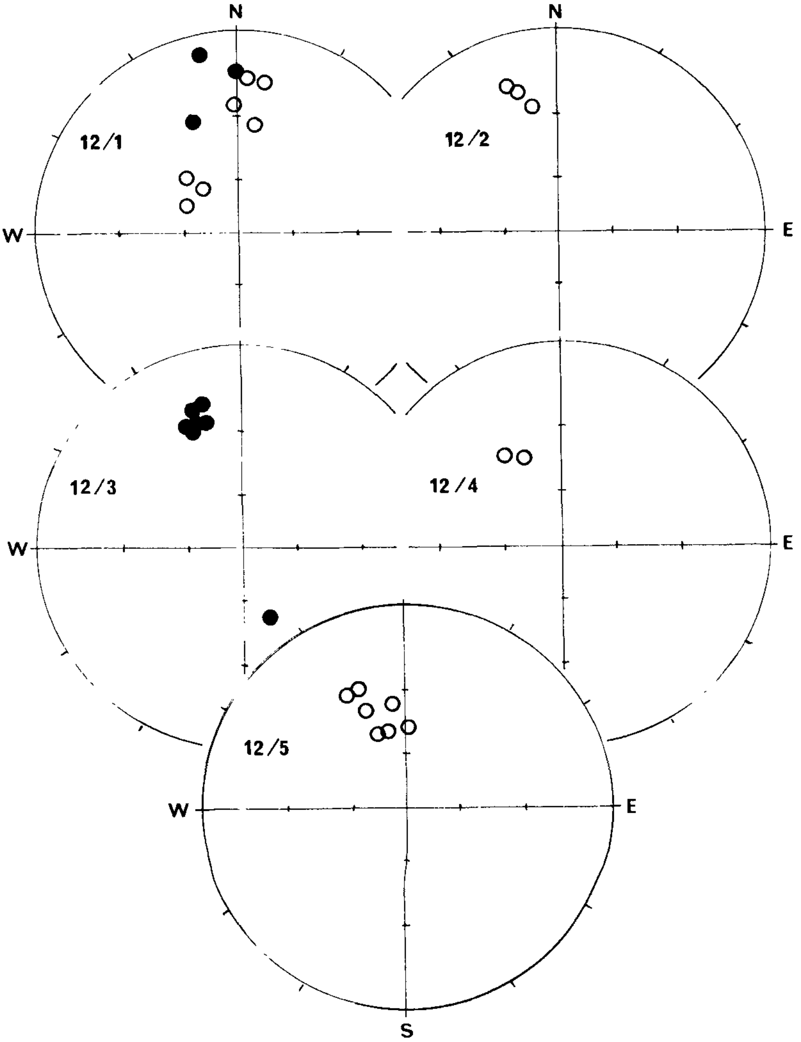

Figure 2. High blocking temperature magnetic directions for subsites 12/1 to 12/5 (before tectonic corrections).

thermal cleaning is high. The scatter is larger in inclination (from –60° to +30°) than in declination, probably reflecting two magnetic components with comparable blocking temperature spectra. Before tectonic corrections, subsite 12/3's direction is comparable to the direction of subsites 2, 4 and 5 after tectonic correction. In fact the magnetic directions of subsites 1 and 3 before tectonic corrections are on the path of magnetizations of subsites 2, 4 and 5 between uncorrected and corrected positions. Subsites 1 and 3 should have been remagnetized during the folding phase. We think that only subsites 12/2, 12/4 and 12/5 have reliable magnetizations.

The next sampling sites are situated a few kilometres west of Peng Po farm (Fig. 1) and are noted sites 4, 5 and 8. The sediments consist essentially of red sandstones well silicified. Beds are compact and their thickness may reach 10 m. Cleavage is rare or absent in these sites, large regions (several kilometres wide) can be found without any intrusions.

Table 1. Characteristic magnetizations of site 12.

Subsite	*N*	D_m	I_m	D'_m	I'_m	k	α_{95}
1	10	351	-23	349	32	5.2	24
2	3	345	-21	342	32	210	9
3	6	341	24	285	67	375	4
4	2	334	-39	335	35	213	(17)
5	7	346	-37	342	47	48	9
Mean of samples of subsites 12/2, 12/4, 12/5							
	12	344	-33			43	7
	12			341	42	48	6

N: number of samples used in the statistic, D_m, I_m: mean declination and inclination before tectonic correction, D'_m, I'_m: mean after tectonic correction, k: Fisher precision parameter, α_{95}: confidence cone radius.

Sites 4 and 8 show a single, high blocking temperature component (Fig. 3c). In site 5, a first magnetic component is eliminated at 590°C (Fig. 3a). The high blocking temperature (>650°C) components are well grouped.

Another sampling area is located along the Lhasa–Yangbajing road (sites 1 and 2). Samples of red siltstones were taken in hard beds between more cleaved levels cut by a lot of dykes and sills of unknown age. A few samples were therefore also taken in a nearly diabase sill, about 1 m thick.

The mean magnetization is 5×10^{-3} A m^{-1} for the redbeds and is lower for the diabase samples. The thermal demagnetization of a siltstone sample (Fig. 3b) shows two magnetic components. The first one has a blocking temperature of 590°C and the second one a blocking temperature above 650°C (further heatings gave spurious results due to mineralogical transformations).

The first component is rather scattered (Fig. 4: s1 and 2), whereas the second one is better grouped (Fig. 4: 1). This second component is common to all samples for the site and is characteristic of it. The first component seems secondary. These secondary components are apparently stronger for the samples which are closer (1 m) to the sill than farther apart (10 m). This sill, along with the related hydrothermal circulations of fluids, may be responsible for the secondary components. The demagnetization behaviour of the samples shows that this effect of the sill has probably been eliminated.

The diabase samples have only widely scattered magnetizations, even for specimens cut in the same sample. No characteristic magnetization can be derived from the diabase.

The last sampling site of the Takena has been chosen just beneath the major unconformity between the Takena and Lingzizong formations (noted site 7). Both green and red sandstone levels were sampled. Thermal demagnetization shows only one component with a high blocking temperature (>650°C) but this component is normal for the red sandstone specimens and reversed for the green sandstones. These two directions are approximately antiparallel (Fig. 4):

normal samples: $N = 4$, $D = 14$, $I = 20$, $k = 67$, $\alpha_{95} = 11°$,

reversed samples: $N = 7$, $D = 187$, $I = -28$, $k = 97$, $\alpha_{95} = 6°$.

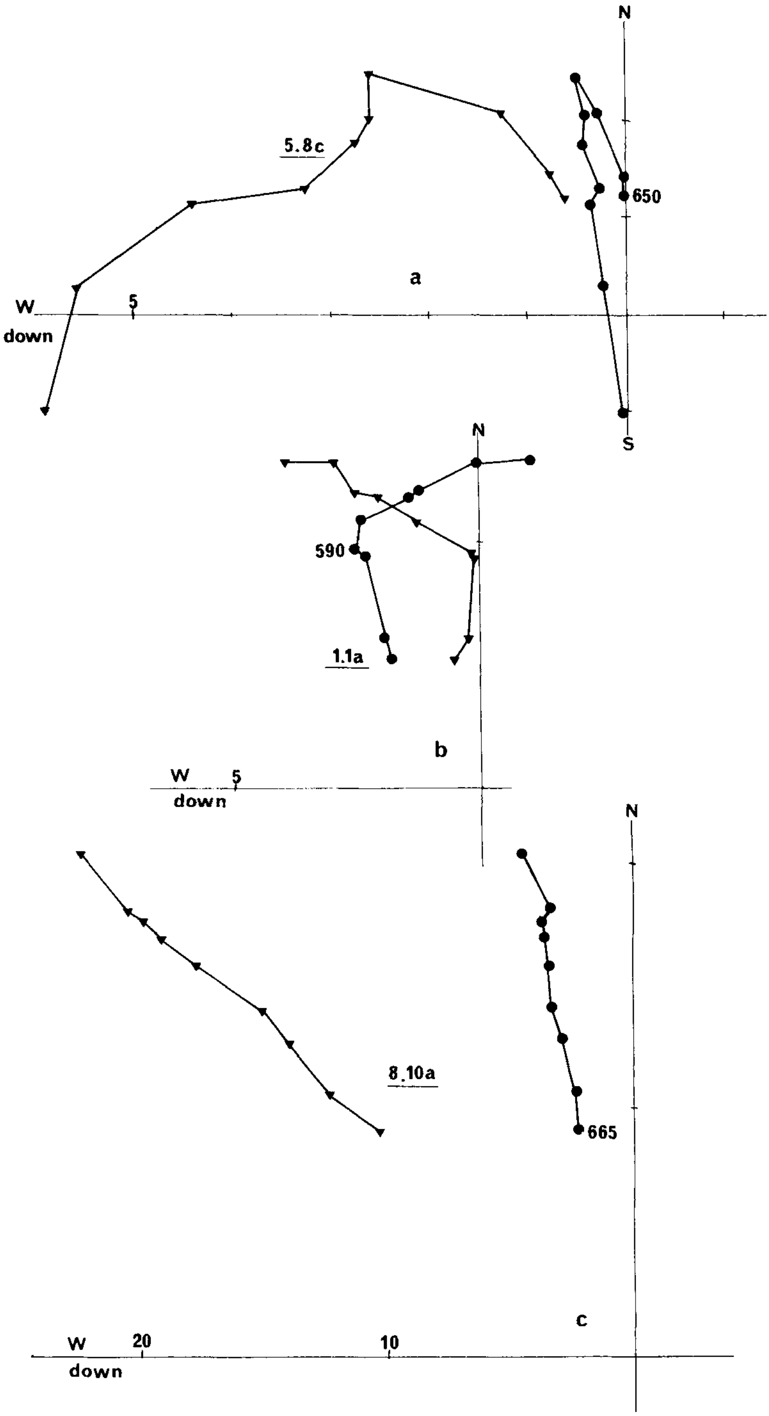

Figure 3. Vector projection diagram for thermal demagnetization diagrams for sediments (before tectonic corrections). Dots: vector end points in the horizontal plane, N: north, W: west, triangles: north–south, up-down place. Magnetization units are in 10^{-3} A m^{-1} (or 10^{-6} emu). Characteristic temperatures are also given beside the curves. The first number refers to the site, the second to the sample and the letter to the specimen.

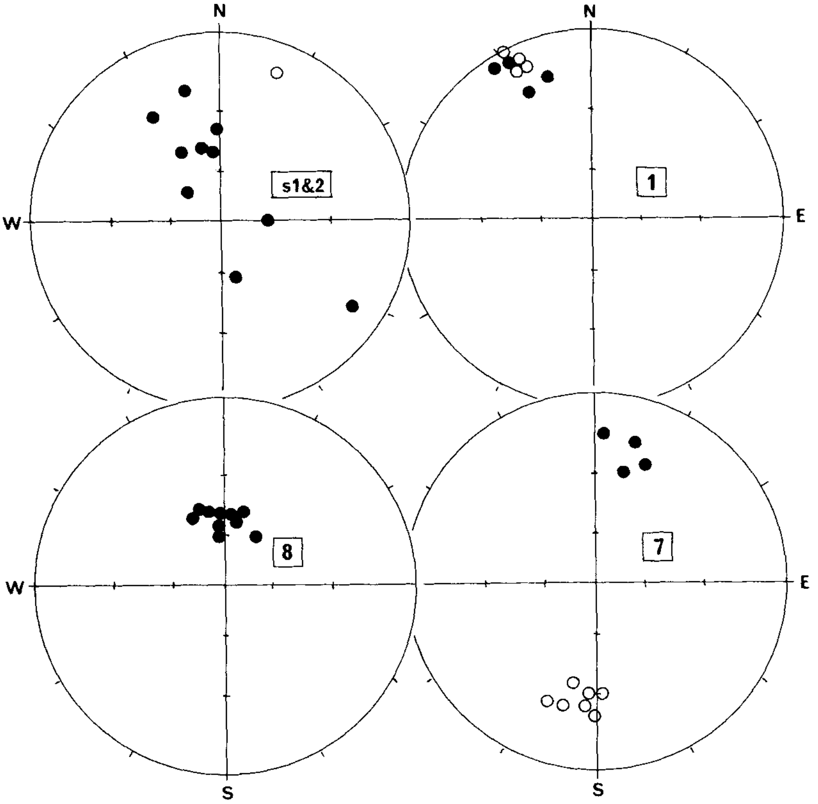

Figure 4. Stereogram for magnetization directions for typical sites (before tectonic correction). S1 & 2: secondary magnetizations of sites 1 and 2. 1, 8, 7: characteristic remanent magnetization for sites 1, 8 and 7.

3.2.2 Volcanics from the Lingzizong formation

The first site (site 3) is a thick massive ignimbrite overlain by volcanic tuffs and pyroclasts, between Lhasa and Yangbajing. R. Montigny dated for us a sample of the massive body of K/Ar on a plagioclase separate. The results are: K_2O: 0.936 per cent, radiogenic Ar: 6.655×10^{-11} mol g^{-1}, radiogenic Ar/total Ar: 40 per cent, age: 48.5 ± 1.5 Ma (= Lutetian).

The massive body has a single, normal remanent magnetization with a blocking temperature of 590°C (Figs 5 and 6a) and a median destructive field of about 35 mT. The tuffs and pyroclasts have a more complex magnetization (Fig. 6b). They usually show a soft normal component destroyed at 300°C and then a harder reversed component for higher temperatures. Alternating field and thermal demagnetization give identical results. The reversed component is somewhat scattered but approximately antiparallel to the normal one.

Massive, fresh andesites, west of the Peng Po sampling area (site 6) give a very clear mean direction with a single component of magnetization (Figs 5 and 6c). The blocking temperature is 590°C and the median destructive field is about 30 mT. The mean direction before tectonic correction is different from the present field. After tectonic correction, the declination is 335° and the inclination corresponds to a palaeolatitude of 31°N. This andesite is very fresh and it may be rather recent.

The last andesitic body (site 9) near Linzhou shows pronounced alteration and has widely scattered directions. The magnetization is multicomponent, but even the different specimens

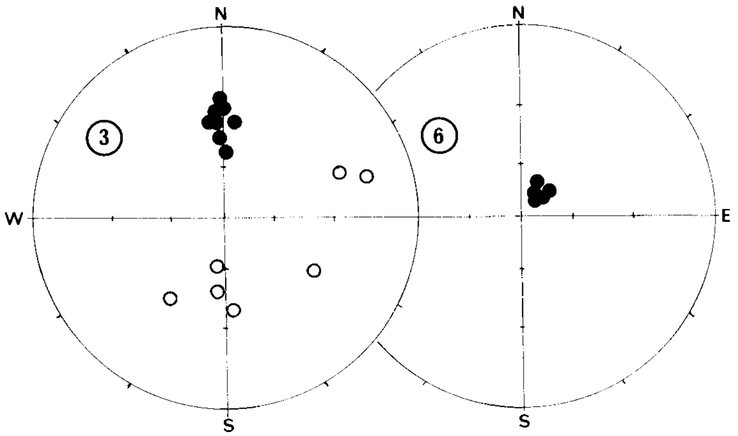

Figure 5. Characteristic remanent magnetic direction for sites 3 and 6 (before tectonic corrections).

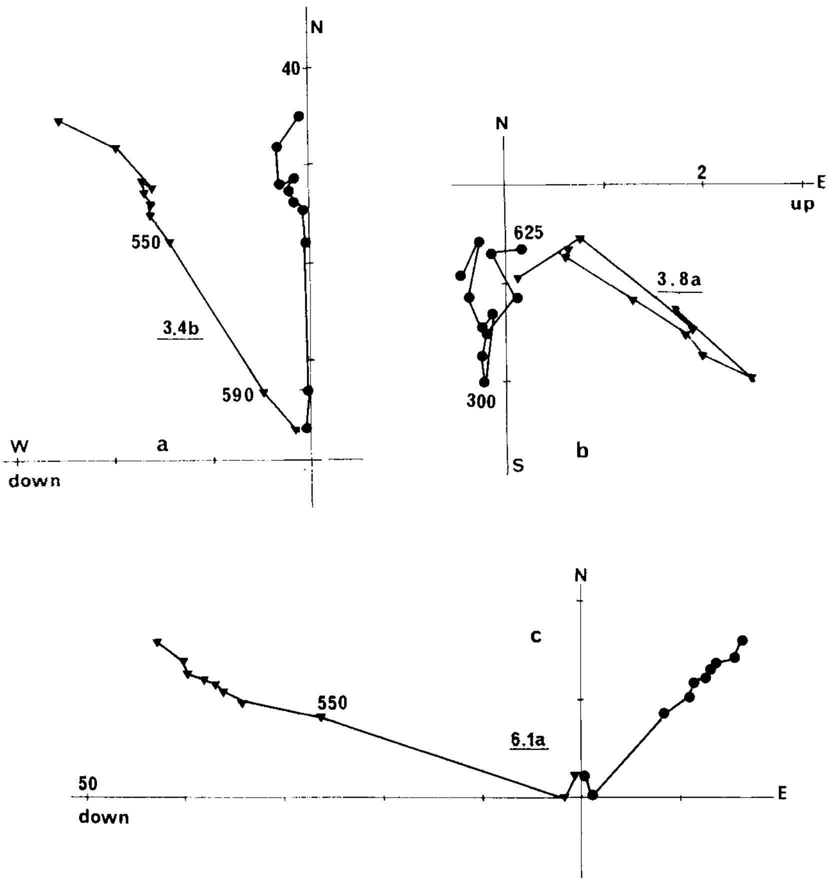

Figure 6. Vector projection diagram for thermal demagnetization behaviour of volcanics (same conventions as for Fig. 3).

from the same sample show both soft and hard components scattered. No characteristic mean direction could be derived from this site.

3.4 ROCK MAGNETISM

In addition to the information drawn from the thermal and AF demagnetization, we have also studied the IRM acquisition behaviour of some samples. First the IRM acquisition curves were drawn from 0 up to 1.3 or 2.0 T. Some specimens were then stepwise demagnetized by AF up to 0.1 T and the magnetization remaining was thermally analysed. After successive heatings, a new IRM curve was drawn. This new curve shows the mineralogical modifications induced by the heatings. The IRM curves for the redbeds show a slow increase and are initially concave upwards. The saturation IRM is not reached before 1.3 T (Fig. 7a, b and c). The AF demagnetization is inefficient (highest field: 0.1 T) and the Curie point is above 660°C. We could see no differences between samples bearing only a single magnetic component (Fig. 7a and c) and samples bearing two components (Fig. 7b). After successive heatings, the IRM at the highest field is strongly increased, 10 to 100 times the initial IRM. This strong increase easily explains the final spurious results obtained above 660° during NRM demagnetization. The magnetic carrier of the NRM should be hematite.

The IRM curves for the volanics are different. The beginning of the curve is very steep and saturation is rather quickly obtained (at 0.2–0.3 T) (Fig. 7d and e). Half of the saturated IRM is destroyed by fields of 60 mT. The Curie points are about 590°. Magnetite should be the main magnetic carrier. IRM curves are more complicated for site 12. There are two kinds of curves: steep and quickly saturated (Fig. 7g) and concave, unsaturated curves (Fig. 7f, h). In fact subsites 12/1 and 12/3 have saturated curves together with NRM Curie points of 590°C and subsites 12/2, 12/4, 12/5 have unsaturated curves with higher Curie points. A sample of subsite 12/1 shows a steep beginning and after a sharp bend at 0.15 T keeps on slowly and regularly increasing (Fig. 7h). The presence of two magnetic phases in this subsite is clearly shown. Hematite should be the main magnetic carrier of subsites 12/2, 12/4 and 12/5 and magnetite for subsites 12/1 and 12/3. In subsite 12/1, the two phases can be present and explain the strong dispersion of magnetic direction. The remagnetization of subsites 12/1 and 12/3 are probably linked with the intrusion of the dyke.

4 Discussion and conclusions

The present state of the magnetostratigraphic time-scale (Lowrie & Alvarez 1981; Larson & Hilde 1975) shows a long interval of normal polarity from Barremian (anomaly M0) to Campanian–Santonian (anomaly 34–33). Sites 3 and 7 show reversals and as they are situated respectively above and just below the major unconformity between Takena and Lingzizong, they are probably of the same age, between Campanian and Eocene. On the other hand, sites 1, 2, 4, 5, 8 and 12 are all of normal polarity and probably belong to the long normal interval. They are indeed locally recognized as Albian–Cenomanian. Site 6 may be younger and very recent.

4.1 TECTONIC CORRECTIONS

Tectonic corrections applied to sites 1, 2, 4, 5, 8 and 12 (Table 2) increase k from 6.6 to 77.8, indicating a positive fold test significant at a 99 per cent level even for the stringent McElhinny test (McElhinny 1964; McFadden & Jones 1981). This test indicates that the magnetization pre-dates the late Cretaceous folding phase. Nevertheless, it has been noted

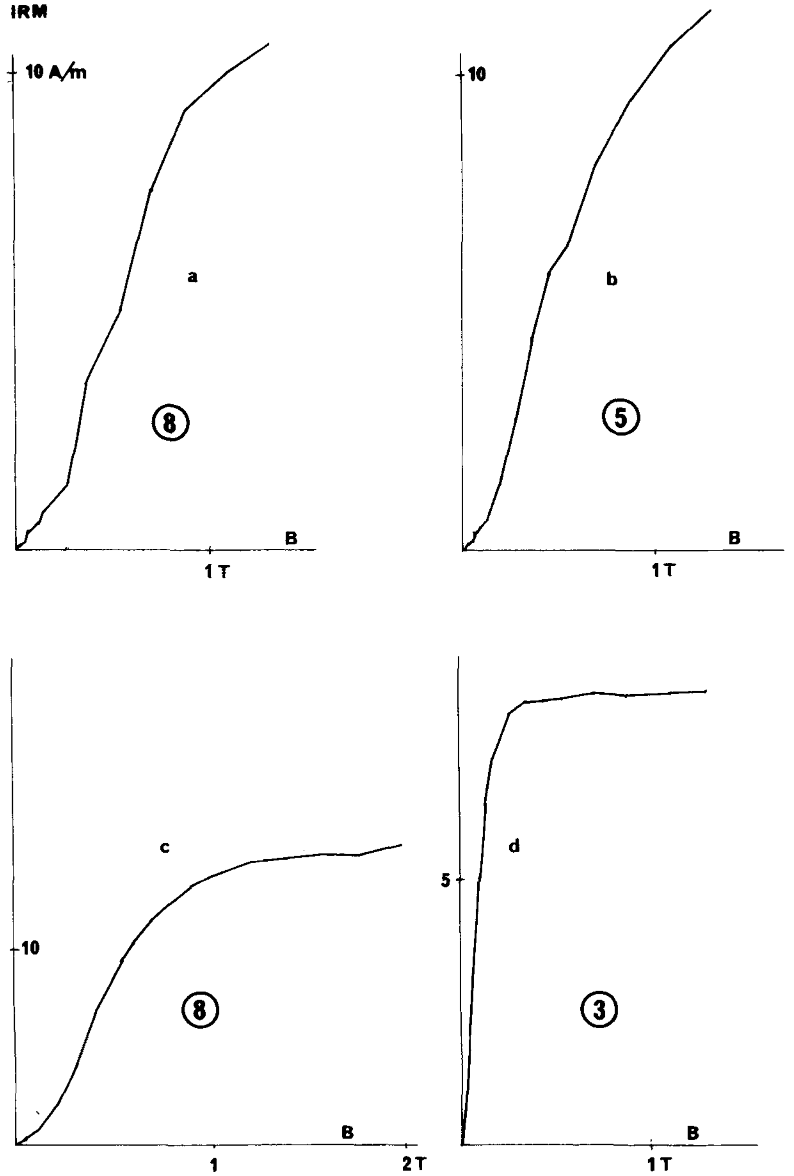

Figure 7. IRM acquisition curves for different specimens. Numbers refer to site and subsite.

that before tectonic corrections the Virtual Geomagnetic Poles (VGP) of sites 1, 2, 4, 5, 8 and 12 lie in the vicinity of the Apparent Polar Wander path of India (Pozzi *et al.* 1982; Klootwijk 1979), but for very different periods spreading from 65 Ma to the present. This favours the hypothesis of remagnetization after folding but with a Lhasa block attached to India and is not compatible with a positive fold test. This hypothesis can be safely ruled out. Fig. 8 shows that after tectonic corrections the directions of magnetization seem to overpass their mean. This can be easily explained if all or some of the sites have acquired their magnetization just at the beginning of the folding, that is to say not after the late Cretaceous.

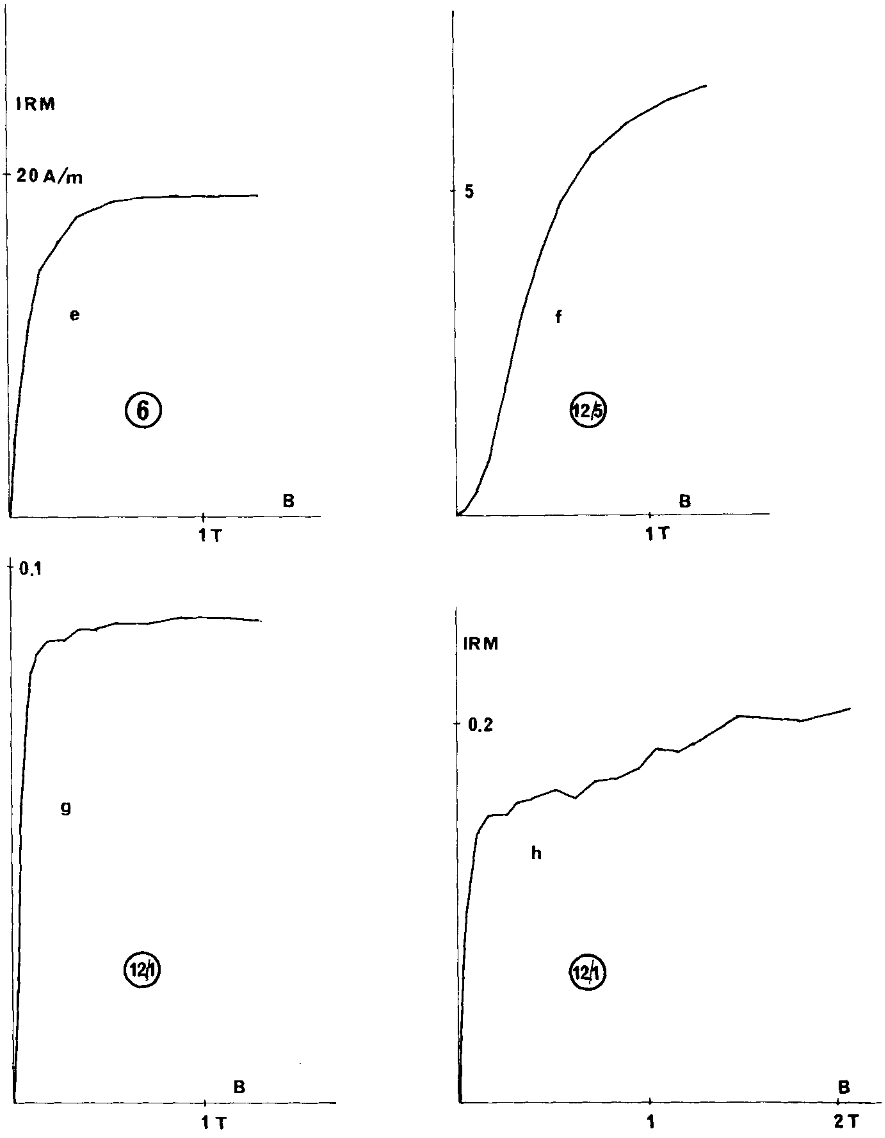

Figure 7 – *continued*

The mean direction is a good approximation of the direction of the field in Middle–late Cretaceous times but our opinion is that the uncertainty is larger than that merely determined by Fisher statistics. In fact, the sites having strong secondary components also give the higher palaeolatitude. The true palaeolatitude may be closer to 15°N than to 20°N.

Sites 3 and 7, respectively of ignimbrite from the Lingzizong formation and sediments from upper Takena include normal and reversed polarity and have thus been formed after the Campanian. They have lower inclinations than other sites and north–south declinations. Combining these two sites gives a palaeolatitude of about 10°N.

Site 6, which is more recent, gives a present-day palaeolatitude, but with a declination of 25° west.

Table 2. Lhasa block characteristic mean directions (29.9°N, 91.0°E).

Site	*N*	D_m	I_m	D'_m	I'_m	k	α_{95}
1	8	335	2	324	37	68	7
2	7	341	9	333	43	16	16
4	9	350	42	333	28	90	5
5	10	352	33	328	47	36	8
8	11	0	52	338	29	51	6
12	12	344	-33	341	42	48	6
Mean 6 sites		346	18	/	/	6.6	28
		/	/	333	38	78	8
Corresponding paleomagnetic pole :				64°N	348°E		
7*	11	10	25	3	24	69	6
3**	12	358	36	358	11	107	4
Mean 2 sites		4	31	0	18	/	/
Corresponding paleomagnetic pole :				69°N	270°E		
6	16	37	72	335	50	269	2
9	4	too scattered					
V.G.P. :				68°N	10°E		
Previous results from Linzhou, Takena Redbeds (Middle-Late Cretaceous)							
Zhu Xiang Yuan et al. (1977)							
	12	/	/	335	16	66	5
Zhu Zhi Wen et al. (1981)							
	42	/	/	338	40	20	7
Late Jurassic Lhasa limestones							
Zhu Zhi Wen et al. (1981)							
	21	/	/	175	2	5	17

*Both reverse and normal samples.
**Normal samples.

4.2 INTERPRETATION

Geological evidence (Sengör 1981; Tapponier *et al.* 1982; Bally *et al.* 1980) shows that the Lhasa block had Gondwanian affinities till the Trias and separated from it during the late Triassic or Jurassic. North of Lhasa, several suture zones have been identified or predicted, for instance, the Banggong Hu-Dongqïao zone and the Kunlun Altyn Tagh zone. The suturing of these zones may be Jurassic or at most early Cretaceous. The position of the Lhasa block was then not too far from its present position (this also allows us to reject the hpothesis of a remagnetization together with India).

The palaeomagnetic evolution of the Lhasa block is shown in Fig. 9 and Table 3. European (Irving 1977), Indian (Klootwijk & Radhakrishnamurty 1981) and Tibetan data are reduced to Lhasa (29° 40′ N, 91° 09′ E) and the corresponding declinations and palaeolatitudes are shown.

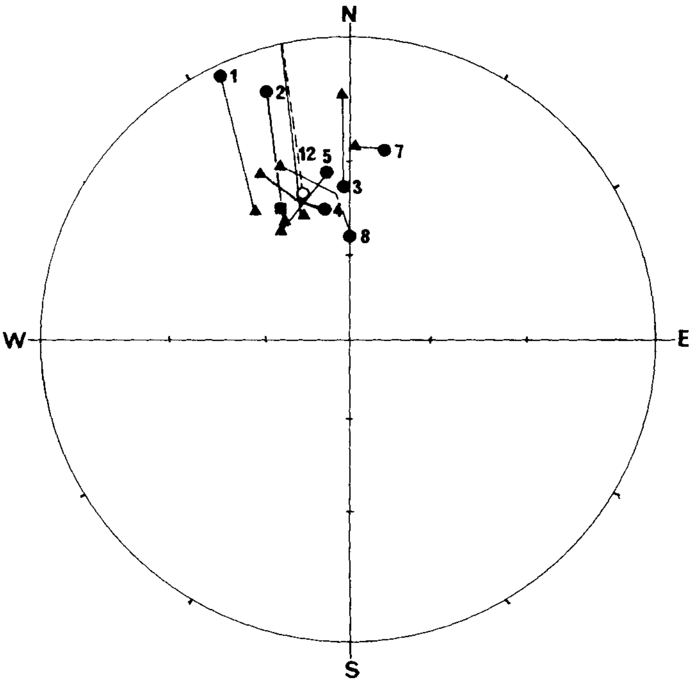

Figure 8. Stereogram showing the effect of tectonic corrections for sites 1, 2, 4, 5, 8, 12 and 3 and 7. Circles: directions before tectonic corrections, triangles: directions after tectonic corrections, square: mean direction of sites 1, 2, 4, 5, 8 and 12 after tectonic correction.

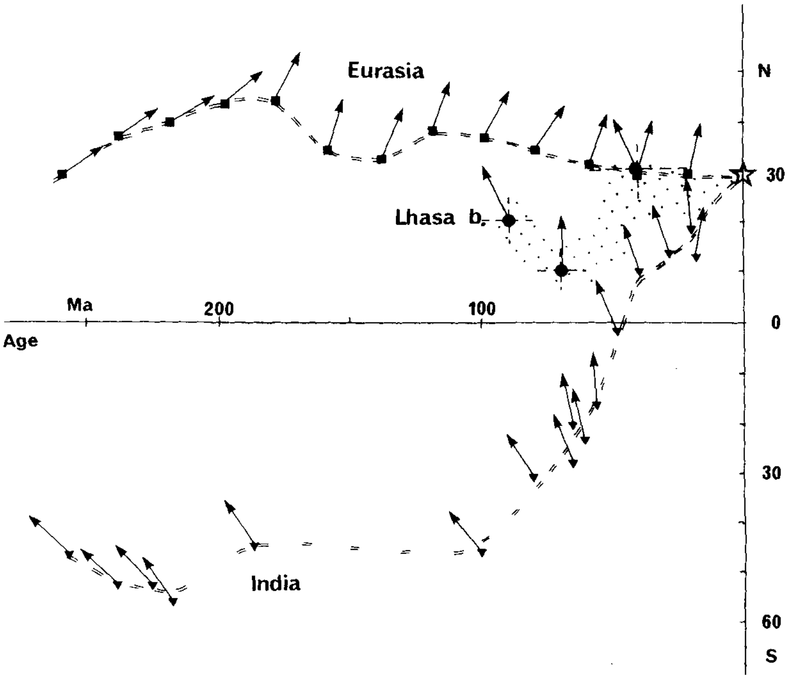

Figure 9. Palaeolatitude and orientation reduced to Lhasa for Eurasia (squares), India (triangles) and the Lhasa block (circles). The arrows give the palaeodeclination. The movement of the Lhasa block should be within the dotted zone.

Table 3. Palaeolatitude and orientation of Lhasa (South Tibet) as if it were linked to Asia or to India (Irving 1977; Klootwijk 1981).

Age	*Asia*		*India*		*South Tibet*		*Ref.*
	D	λ	*D*	λ	*D*	λ	
Premian	55	35N	295	45S			
Triassic	50	40N	300	53S			
Jurassic	16	33N			355	1S	(1)
Early Cretaceous	23	36N	320	45S			
Late Cretaceous	22	33N	340	30S	333	20N	(2)
					338	22N	(1)
Early Tertiary	17	30N	350	25S	0	10N	(2)
Later					335	31N	(2)

(1) Zhu Zhi Wen *et al.* (1981).
(2) This paper.

During the Middle Cretaceous the Lhasa block was around 20°N and the distance from Eurasia was about 1500–2000 km. The Lhasa block then moved about 10° South. It only returned northward later on. After that, an anticlockwise rotation, parallel to India, occurred.

A late Cretaceous southward movement is also visible on the Eurasia curve but it is less important. Shortening between Asia and the Lhasa block is probably not smaller than 2000 km. As several relative rotations have occurred, it is not simply a question of crustal thickening, though strike-slip movements must have been important. In fact, even if the Lhasa block is of Gondwanian origin, it need not necessarily have detached from India. It could equally have detached from eastern Africa. The eastward component of movement between Asia and the Lhasa block would then be much more important than the northward movement.

The geometrical relationship between the Lhasa block and Asia from the Cretaceous up to the present is still not well understood. It is clear from these results that further palaeomagnetic work is needed but also that absolute or palaeontological dating is necessary to fix more precisely the relative movements.

In the early Cretaceous India was still far in the southern hemisphere at about 30–40°S. It started its rapid northward drift only during the late Cretaceous. The 40–50°C convergence would probably have been absorbed between the Lhasa block and the southern foot of the Himalayas. Subduction along the Yarlung Zangbo suture zone probably played a prominent part in this process. The convergence of less amplitude (20°) between the Lhasa block and Asia would have been solely absorbed by crustal shortening.

Acknowledgments

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