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Estimation of shortening between the Siberian and Indian Plates since the Early Cretaceous

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Abstract

A comparative study of the amount of latitudinal shift of the Siberian Plate, the Lhasa Block, the Himalayan Block and the Indian Plate using palaeomagnetic data shows that the Himalayan Block belongs to the Indian Plate. The Neo-Tethys Ocean, which separated the Himalayan and Lhasa Blocks, opened to its greatest width of 31.9° in latitude in the Early Cretaceous. The extent of shortening of the latitudinal distance between the Siberian and Indian Plates amounts to 58.2° since the Early Cretaceous. It was found that after the determination of the greatest width of Neo-Tethys Ocean, the latitudinal shortening of the crust between the Indian and Siberian Plates reached 26.3°, or about 2760 km. On the basis of the palaeomagnetic data obtained from the Qaidam Block, the latitudinal shortening between the Himalayan and Qaidam Blocks reached 50.2° since the Early Cretaceous. It was concluded that over the past 50 Ma, since the Early Cretaceous, the latitudinal shift of the southern blocks or plates was larger than that of the northern ones, and that shortening between the Qaidam and Himalayan blocks was greater than the shortening between the Qaidam Block and the Siberian Plate. This differential latitudinal movement is the main cause of convergence, resulting in the compression and uplift of the Qinghai–Tibetan Plateau.

Keywords: Latitudinal shift; The Himalayan Block; Compression

1. Introduction

Crustal shortening, due to collision between Indian and Eurasian plates, is regarded as the main factor causing the uplift and thickening of the Qinghai–Tibetan Plateau. Previously, most estimates of shortening, following the collision between the Indian and Asian plates, have been calculated on the basis of the amount of shortening between the Himalayan Block and India, and between the Himalayan and Lhasa blocks (Achache et al., 1983; Zhou et al., 1984; Patriat et al., 1984; Besse et al., 1984; Klootwijk et al., 1985; Dong et al., 1998; Li et al., 1994; Patzelt et al., 1996). If only the shortening between the Himalayas and India, and between the Himalayan and the Lhasa blocks is taken into account, the amount of shortening is insufficient to provide a mechanism for the uplift of the Qinghai–Tibetan Plateau.

The method of comparison used to estimate the amount of shortening is to compare the apparent polar wandering paths (APWP) of the respective blocks. Because of the effects of local rotations and deformations, different palaeomagnetic pole positions may be obtained from the strata of the same age but from different locations, within the same block. In this study, in order to avoid the influence of local rotations and deformations, a method of comparison of the extent of latitudinal shift is adopted. All the currently published palaeomagnetic data has been collected and used in this study.

2. Contrast in latitudinal shift between the Himalayan and Lhasa blocks

More than 55 Meso-Cenozoic palaeomagnetic measurements have been collected from the literature (Achache et al., 1983; Zhou et al., 1984; Besse et al., 1984; Zhu, 1985; Otofuji et al., 1989; Liu et al., 1990; Lin and Watts, 1988; Li et al., 1994; Patzelt et al., 1996; Dong et al., 1998). Palaeomagnetic data from the Qaidam and Himalayan blocks are listed in Tables 1 and 2; palaeomagnetic data from Lhasa Block are listed in Table 3; data on the Indian and Siberian plates from Van der Voo (1993) are not listed in the tables. Curves representing the extent of latitudinal shift for each block are shown in Fig. 1.

The ocean basin between the Himalayan and Lhasa blocks gradually began to open, after the middle Triassic

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Table 1
Cenozoic palaeomagnetic data from the Himalayan and Qaidam terranes (Note: δ_p is a difference between site palaeolatitude and palaeolatitude, D_s, I_s is the declination and inclination after tectonic correction; K is the precision parameter; α_{95} is the confidence angle; Refs. = references; Pal. = palaeolatitude.)

Site		Age	D_s	I_s	K	α_{95}	Pal.	δ_p	Refs.
(°N)	(°E)								
Himalaya									
28.5	86.3	Q_1	5.0	48.5	10.0	9.9	29.5	− 1.0	Zhu (1985)
28.5	86.3	N_2	− 5.0	49.0	10.0	17.0	29.9	− 1.4	Zhu (1985)
27.6	89.1	N_2	7.0	41.0	8.0	9.0	23.5	4.1	Zhu (1985)
28.3		58–62 Ma	182.7	− 11.6			5.8	22.5	Li et al. (1994)
28.8	87.0	E_1	317.0	9.1	17.0	17.0	4.6	24.2	Zhou et al. (1984)
28.8	89.3	57 ± 1 Ma	335.0	− 6.0		11.0	− 2.5	31.3	Besse et al. (1984)
28.3	88.5	64–66 Ma	177.1	− 12.9	180.1	9.2	6.5	21.8	Patzelt et al. (1996)
28.3	88.5	63–65 Ma	3.2	18.6			9.6	18.7	Patzelt et al. (1996)
28.3	88.5	55–63 Ma	176.2	− 7.9	28.7	7.5	4.0	24.3	Patzelt et al. (1996)
29.4	87.5	K_2–E_1	− 66.9	− 2.6	27.9	3.6	1.3	28.1	Otofuji et al. (1989)
Qaidam									
38.0	94.2	N					33.4	4.6	Wu et al. (1997)
38.4	90.9	N_2^2	20.6	53.5	10.1	11.8	34.0	4.4	Yang et al. (1992)
37.5	90.9	N_2^1	338.8	55.3	20.7	7.7	35.8	1.7	Yang et al. (1992)
37.4	95.8	N_2	225.9	− 48.5	9.3	15.8	29.5	7.9	Zheng et al. (1991)
36.0	94.0	N_2	0.0	50.8	23.5	8.4	31.5	4.5	Zheng et al. (1991)
38.0	94.2	E					30.3	7.7	Wu et al. (1997)

(Fig. 1). By the Early Cretaceous (at ~120 Ma), this oceanic basin had opened to its greatest width, about 31.9° of latitude.

3. Contrast in latitudinal shift between Indian and Siberian plates

The Himalayan Block and the Indian Plate have the same rate of latitudinal shift and the same trend since the beginning of the Mesozoic (Fig. 1), thereby showing that the Himalayan Block is part of the Indian Plate.

Siberia has been stable for about 120 Ma, since the Early Cretaceous. By comparing the extent of latitudinal shift between the Siberian and Indian plates, it can be seen that the total amount of shortening from the Early Cretaceous to the present day reached ~58.2° in latitudinal distance. After deducting the greatest width of the Neo-Tethys Ocean between the Himalayan and Lhasa blocks (31.9°), it was found that the crustal shortening between Siberia and India reached 26.3° in latitude, or a total of about 2760 km.

Table 2
Mesozoic palaeomagnetic data from the Himalayan terrain and Qaidam block. See Table 1 for explanation and abbreviations

Site		Age	D_s	I_s	K	α_{95}	Pal.	δ_p	Refs.
(°N)	(°E)								
Himalaya									
29.0		K_2	309.0	− 8.0	12.0	15.0	− 4.0	33.0	Liu et al. (1990)
28.0		K_2	7.2	− 16.7	73.0	6.5	− 8.6	36.6	Besse et al. (1984)
28.0	89.2	K_2	72.4	− 17.6	28.6	13.1	− 9.1	37.1	Dong et al. (1998)
28.3	88.5	65–71 Ma	4.0	− 11.2	22.8	8.5	− 5.7	34.0	Patzelt et al. (1996)
28.3	88.5	98–107 Ma	351.0	− 39.3			− 22.3	50.6	Patzelt et al. (1996)
28.9	89.6	K_1	344.4	− 48.2	31.0	7.6	− 29.2	58.1	Dong et al. (1998)
28.6	87.2	K	331.0	− 37.0	13.0	16.5	− 20.7	49.3	Zhu (1985)
28.9	89.8	J_3	292.0	− 40.0	22.0	11.0	− 22.8	51.7	Zhu (1985)
29.0	89.0	J_3–K_1	290.0	− 39.9	54.0	12.6	− 22.7	51.7	Liu et al. (1990)
29.0	86.0	J_2	288.1	− 41.6	15.0	11.3	− 23.9	52.9	Liu et al. (1990)
28.5	86.1	T_{1-2}	318.0	− 41.8	22.0	6.3	− 24.1	52.6	Zhu (1985)
Qaidam									
37.0	94.2	K					31.0	7.0	Wu et al. (1997)
38.0	94.2	J					29.8	8.2	Wu et al. (1997)
38.0	94.2	T					22.2	15.8	Wu et al. (1997)

Table 3
Meso-Cenozoic palaeomagnetic data from the Lhasa Block

Site		Age	D_s	I_s	K	α_{95}	Pal.	δ_p	Refs.
(°N)	(°E)								
29.9	91.7	E	17.9	34.2	14.2	7.1	18.7	11.2	Dong et al. (1998)
29.9	91.3	K_2–E_1	338.0	40.0	20.0	7.0	22.8	7.1	Zhu (1985)
29.9	91.3	K_2	349.5	35.6	46.5	6.7	19.7	10.2	Zhou et al. (1984)
29.9	91.3	K_2	347.8	35.4	6.9	21.0	19.5	10.4	Zhou et al. (1984)
31.0	91.5	K_2	345.7	37.2	135.8	3.7	20.8	10.2	Zhou et al. (1984)
32.0	92.0	K_2	340.3	33.1	49.8	10.6	18.0	14.0	Zhou et al. (1984)
31.7	90.9	90 Ma	342.9	30.8	37.3	15.2	16.6	15.1	Lin and Watts (1990)
31.5	92.0	96 Ma	357.8	34.8	74.3	6.0	19.2	12.3	Lin and Watts (1990)
31.5	92.1	K_2	263.0	13.0	41.0	2.9	6.6	24.9	Dong et al. (1998)
29.9	91.2	K_2	331.6	22.7	12.5	5.9	11.8	18.1	Dong et al. (1998)
29.3	88.9	K_2	348.1	8.3	6.3	12.2	4.2	25.1	Dong et al. (1998)
32.0	90.8	K_1	251.8	16.9	9.0	13.6	8.6	23.4	Dong et al. (1998)
29.9	91.2	K_1	350.9	19.6	47.9	7.5	10.9	19.0	Lin and Watts (1990)
29.7	91.1	J_3	175.0	2.0	5.0	6.6	− 1.0	30.7	Zhu (1985)
31.2	91.8	J_3	348.3	− 13.8	20.2	7.7	− 7.0	38.2	Dong et al. (1998)
29.7	91.5	J_{2-3}	346.5	− 13.8	17.5	10.1	− 7.0	36.7	Dong et al. (1998)
29.7	91.4	T_3	66.4	− 37.8	32.5	6.0	− 21.3	51.0	Dong et al. (1998)
30.0	90.8	T_3	346.0	− 47.0	5.0	25.0	− 28.2	58.2	Zhu (1985)
29.6	90.0	T_2	333.0	− 48.7	6.0	15.4	− 29.6	59.2	Zhu (1985)

4. Contrast in latitudinal shift between the Himalayan and Qaidam blocks

Meso-Cenozoic palaeomagnetic data from the Qaidam Block was obtained from Zheng et al. (1991); Yang et al. (1992); and Wu et al. (1997). Data from rocks of the same age have been averaged.

When the extent of latitudinal shift of the Qaidam Block was compared with that of the Himalayan Block, it was found that the greatest latitudinal distance between the two blocks was observed during the Early Cretaceous (~120 Ma) (Fig. 3). Then, the Himalayan Block began to shift rapidly northwards, its rate of movement being faster than that of the Qaidam Block (Fig. 2). During the period from the Early Cretaceous to the present, latitudinal shortening between the Himalayan and Qaidam blocks reached about 50.2°.

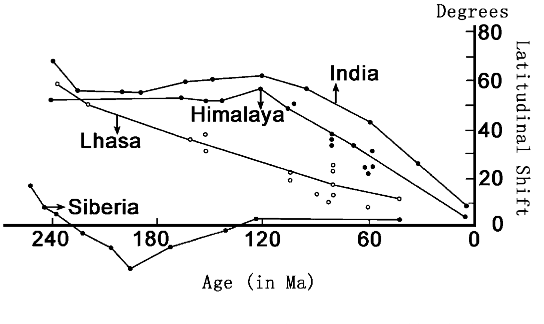

Fig. 1. Curves comparing the extent of latitudinal shift of Siberia, Lhasa, Himalaya and India.

5. Discussion

Because some parameters, such as α_{95} (or A_{95}), are not given for all the published palaeomagnetic data, the accuracy of the curves, especially for the values of crustal shortening cannot be determined. The reference point for the palaeomagnetic data from the Indian Plate is 25°N, 80°E, in the central area of Himalayan Block (Fig. 3). Because of rotational underthrusting, the latitudinal shift of the Indian Plate and the Himalayan Block is different for the eastern and western parts. The calculated value for crustal shortening is, therefore, only an average value, which does not represent the shortening value of either the eastern or western parts. Although this is not an ideal situation,

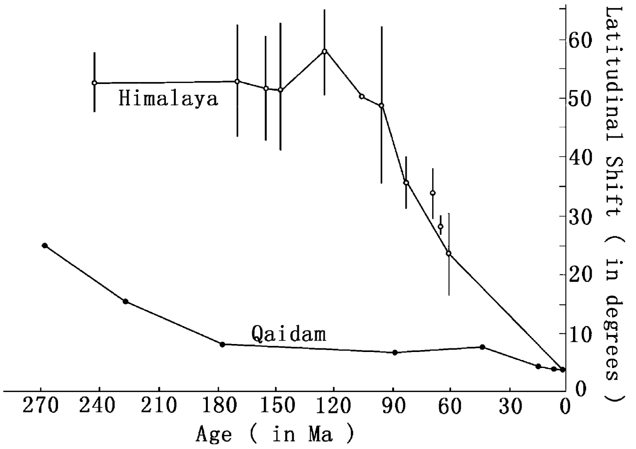

Fig. 2. Curves comparing the extent of latitudinal shift of the Qaidam and Himalayan blocks.

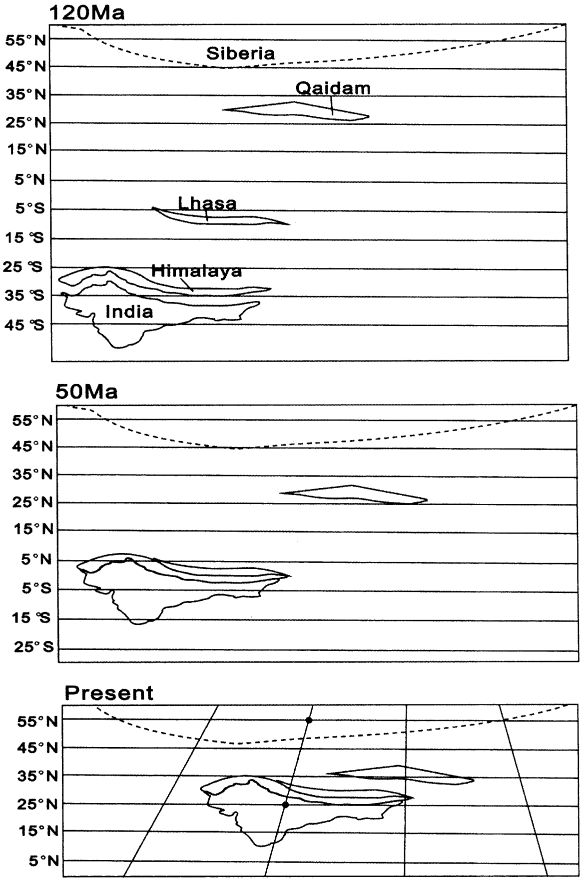

Fig. 3. Sketch maps showing the relative positions of the Siberian, Qaidam, Lhasa, Himalayan and Indian blocks at 120, 50 Ma and the present day. The black dots in the figure represent reference points. The longitudinal positions cannot be determined for 12 and 50 Ma.

because of the lack of sufficient palaeomagnetic data, nevertheless sufficient information is available to enhance our understanding of the tectonic evolution of Tibet.

On the basis of the comparisons given earlier, crustal shortening, represented by the latitudinal distance between the Himalayan and Qaidam blocks, reached 18.3° since the Early Cretaceous, after deducting the greatest width of the Neo-Tethys Ocean (31.9°).

The Himalayan Block is considered to have collided with the Lhasa Block at 50 Ma. By interpolating the extent of latitudinal shift between the Qaidam and Himalayan blocks since 50 Ma (Table 4), crustal shortening is found to have reached a latitudinal distance of 12.4. During the Early Cretaceous, from about 120–50 Ma, there was still about 5.9° shortening between the Himalayan and Qaidam blocks.

After deducting 18.3° of shortening between the Himalayan and Qaidam blocks from the 26.3° latitudinal distance between the Indian and Siberian plates, since the Early Cretaceous, there is still 8° of shortening between Indian and Siberian plates to be accounted for. The Siberian plate was stable since the Early Cretaceous. According to the extent of latitudinal shift of the Siberian plate (3.7°) and the Qaidam Block (7.2°), there was only 3.5° of latitudinal shortening between Qaidam and Siberia.

Table 4
Latitudinal shift amount of the Himalayan and Qaidam blocks after linear interpolation (Age unit is in Ma; δ_{p1}/δ_{p2} represents Himalaya/Qaidam latitudinal shift amount)

Age	δ_{p1}	δ_{p2}
10	4.6	3.0
20	8.5	3.8
30	12.3	5.4
40	16.1	7.0
50	20.0	7.6
60	23.8	7.5
70	34.3	7.4
80	35.0	7.3
90	41.9	7.2
100	48.9	7.1
110	51.9	7.1
120	57.4	7.2
130	55.9	7.4
140	53.3	7.6
150	51.7	7.8
160	52.3	7.9
170	52.9	8.1
180	52.8	8.7
190	52.8	10.2
200	52.8	11.7
210	52.7	13.3
220	52.7	14.8
230	52.6	16.6
240	52.6	18.9
250	52.5	21.2
260	52.5	23.6
270	52.4	25.3

It is possible that a further 4.5° shortening took place between the Indian Plate and the Himalayan Block since the Early Cretaceous, which can be accounted for by southward thrusting along the main boundary thrust (MBT) and the main central thrust (MCT).

Figs. 1–3 show that the extent of latitudinal shift for each block becomes larger and larger southwards, from the Siberian to the Indian plates. This illustrates the collision developed from north to south. Since the Early Cretaceous, or since 50 Ma, the latitudinal shift of the southern blocks or plates was found to be larger than that of the northern ones, and the shortening between the Qaidam and Himalayan blocks was greater than that between the Qaidam Block and the Siberian Plate. This must be one of the main causes of convergence and compression of materials, which caused the uplift of the Qinghai–Tibetan Plateau.

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