Palaeomagnetic constraints on the collision and rotation of North and South China

Xixi Zhao & Robert S. Coe

Earth Sciences Board, University of California, Santa Cruz, California 95064, USA

The eastern half of China is dominated by the North China Block (NCB) and South China Block (SCB), separated by a complex fold system that trends roughly east-west. Interpretation of the geology of this fold belt has led to a variety of estimates of the age of amalgamation of these two blocks\(^1\)-\(^7\). Palaeomagnetic results are few and have also been subject to conflicting interpretations\(^8\)-\(^11\). Here we present our own palaeomagnetic results for late Permian rocks for both the SCB and NCB and summarize other relevant palaeomagnetic data. By reinterpreting the polarity given in some previous studies we are able to synthesize the results for the widespread Emeishan basalt of the SCB and to suggest a new model for the collision and relative rotation of the two blocks.

Most palaeomagnetic data of Permian age for the SCB are derived from the Emeishan Basalt Formation, which is widespread throughout southwest China. In 1980 one of us (X.Z.) sampled 32 lava flows spanning 212 m of section at the type locality (29.6° N, 103.4° E) on the east limb of the Nubeishan anticline near Emei Mountain, Sichuan Province. Table 1 shows the results of this study\(^12\). Both alternating-field and thermal stepwise demagnetization experiments were conducted on these basalt. In general, both types of treatment were equally successful, and a stable component of magnetization was isolated that decayed univectorially towards zero. The directions of this stable component are clustered about a mean with northeasterly declination and shallow upward inclination. Here we interpret these data as primary directions acquired in a field of normal polarity.

The results of four other studies\(^12\)-\(^14\) of the Emeishan basalts in the same area have revealed very similar north-east and upward palaeomagnetic directions (Fig. 1). The data for one of these studies\(^2\) pass the fold test, which means that the magnetization precedes the folding, a necessary (but not sufficient) requirement for the directions to be primary. In all four studies the polarity assigned is opposite to our interpretation; that is, reversed. The reason for the reversed polarity choice is that the age of the Emeishan basalt was thought to lie within the late Palaeozoic Kiaman Reversed Interval\(^15\). Assignment of reversed polarity to these palaeomagnetic directions with north-east declinations, however, implies that the area has undergone an azimuthal rotation since Permian time of about 160°. McElhinny et al.\(^2\) originally interpreted this as a rotation of the entire SCB. Chan et al.\(^10\), however, pointed out that the area sampled might have undergone a local rotation because it lies within the Lungmenshan thrust zone.

Recent studies of the Emeishan basalts in other regions reveal that some flows have directions with southwesterly declinations and shallow downward inclinations. Lin et al.\(^4\) reported such a direction from a single lava flow in Guizhou Province. They interpreted this magnetization as reversed, attributing the apparently conflicting earlier results\(^6\) from the Emei Mountain region to secondary remagnetization or local rotation. Later studies\(^6\)-\(^8\) of the Emeishan Basalt from southern Sichuan and Yunnan Provinces report directions for sequences of flows with both northeasterly and southwesterly declinations. Particularly diagnostic is the latter, in which the upper flows have northeasterly and upward directions and the lower flow has a southwesterly and downward direction. The underlying, Lower Permian bauxite beds also have southwesterly declinations. The simplest interpretation is that the Emeishan Basalt Formation does not lie exclusively within the Kiaman Reversed Interval, and that the results record both normal (northeasterly declination) and reversed (southwesterly declination) polarity of the ancient field. In this way we accept the results of all studies and eliminate the need for exceptionally large azimuthal rotations. This interpretation is also one of three possible explanations of Emeishan data offered by Huang et al.\(^16\).

Recently published radiometric dates from the Emeishan Basalt support this hypothesis. Yuan et al.\(^18\) find an age range of 230–280 Myr for the basalt, with a tendency toward older ages to the south. They cite a mean age of 236 Myr for flows from Sichuan Province, which corresponds to the upper limit of the Kiaman Reversed Interval\(^19\)-\(^20\). If these ages are accurate, it is not surprising that both normal and reversed polarity are found and that, in particular, the polarity recorded by the flows

![Fig. 1](image)

**Fig. 1** Site mean directions of Permian rocks from the SCB and NCB (equal-area projection with circles and crosses representing upper and lower hemisphere, respectively, and with reversed directions inverted to normal). On the SCB all sites are Emeishan Basalt: (1) ref. 12 (Table 1); (2) ref. 9; (3) ref. 14; (4) ref. 13; (5) ref. 16; (6) ref. 17; (7) ref. 11; (8) ref. 10. On the NCB, sites are in redbeds, sandstone, and siltstone: (9) Jingle redbeds (Table 1); (10) Kouquan sandstone and siltstone (Table 1); (11) Linchong sandstone (Table 1); (12) ref. 11; (13) W. Z. Lin, J. Shao and Z. Zhao, unpublished data; (14) ref. 9; (15) ref. 13.

Table 1 Summary of palaeomagnetic results on rocks from the SCB and the NCB

<table>
<thead>
<tr>
<th>Rock type and locality</th>
<th>Site lat.</th>
<th>Site long.</th>
<th>N</th>
<th>Dec.</th>
<th>Inc.</th>
<th>a(_{95})</th>
<th>k</th>
<th>Pole lat.</th>
<th>Pole long.</th>
<th>A(_{95})</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>South China Block</strong></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Emeishan Basalt, Emei, Sichuan (ref. 12)</td>
<td>29.6°</td>
<td>103.4°</td>
<td>32†</td>
<td>20.7°</td>
<td>-12.6°</td>
<td>4.0°</td>
<td>38.6</td>
<td>49.0°</td>
<td>251.0°</td>
<td>2.1°</td>
</tr>
</tbody>
</table>

**North China Block**

| Redbeds, Jingle, Shaxi | 38.6° | 112.1° | 11 | 316.1° | 31.5° | 10.0°* | 45.6 | 46.2° | 5.2° | 10.1°* |
| Sandstone and siltstone, Kouquan, Shaxi | 40.1° | 113.2° | 13 | 347.9° | 35.5° | 15.1°* | 20.6 | 67.1° | 523.6° | 14.0°* |
| Sandstone, Linchong, Hebei | 37.5° | 114.4° | 17 | 324.7° | 34.4° | 11.3°* | 36.4 | 54.3° | 4.1° | 8.7°* |

N, number of samples used; Dec., declination; Inc., inclination; a\(_{95}\), semiaxis of the cone of 95% confidence; k, precision parameter for directions; A\(_{95}\), circle of 95% confidence limit of pole.

*Confidence limits obtained by ordinary Fisher statistics from 50% of the samples that exhibited stable polarity.
at the type locality near Emei Mountain is normal.

Figure 1 shows results for the various studies of the Emeishan Basalt. In general these directions agree very well with each other and, as discussed above, some of them pass fold and reversal tests. For these reasons, and because of the wide distribution of sampling sites (see Fig. 3a), we believe that these are primary directions suitable for calculating a late-Permian pole position for the SCB. We have done this in three different ways: (1) averaging by regions \( N = 5 \), (2) averaging by studies (all studies, \( N = 8 \)), and (3) averaging by selected studies (omitting only small numbers of samples \( N = 6 \)). All three methods yield similar results, but we prefer the third because the mean directions used to obtain the poles are more nearly comparable in terms of numbers of samples and flows.

Next, we sampled sedimentary sections of the Shihezi Formation at three widely separated areas in Shanxi and Hebei provinces in the NCB. In Shanxi province more than 800 m of Permian sandstone and siltstone are exposed in the Kouquan area \( 40.1^\circ N, 113.2^\circ E \) of the Datong Basin. In the Jingle area \( 38.6^\circ N, 112.1^\circ E \) the same formation is well exposed on both limbs of a syncline. In the Lincheng area \( 37.5^\circ N, 114.4^\circ E \) of Hebei province, fresh exposures of a sandstone unit crop out along the banks of the Shaba ravine. At all three localities the coal-bearing Shihezi Formation, which is early Permian in age, can be easily recognized at the base of the sections. The strata we sampled are palaeontologically dated as late Permian \( 21 \), and are mainly yellowish except at Jingle, where red beds are common. Rocks from all three areas exhibited similar magnetic behaviour in the laboratory. Progressive thermal demagnetization of the samples from each locality revealed, in \( \sim 50\% \) of the cases, a characteristic component of magnetization with southeasterly or northwesterly declinations and shallow upward or downward inclinations. We also found evidence for this component in the demagnetization planes of the remaining samples. Reanalysis of our data using the joint demagnetization line and plane method of Kirschvink\( 22 \) yielded a direction that is not distinguishable at 95\% confidence from the characteristic component.

Table 1 gives the palaeomagnetic results of this analysis. A detailed account of these studies will be published elsewhere. The site mean directions pass the fold test at \( >95\% \) confidence. Thus the remanent magnetization at these localities was acquired before folding, which occurred in the middle Jurassic\( 23 \).

Moreover, the normal and reversed directions that we find are closely antiparallel. The successful fold and reversal tests, and the fact that this characteristic component is carried by both magnetite and haematite, strongly suggest that the magnetization is primary.

Four other Permian palaeomagnetic results are available for the NCB (refs 9, 11, 13 and W. Z. Lin, J. Shao and Z. Zhao, unpublished data). These are all derived from a redbed sequence of late Permian age near Taiyuan, Shanxi Province. They agree roughly well among themselves and with our results from

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Fig. 2 Permian pole positions. NCB: 51.4° N, 359.8° E, \( A_p = 9.3 \); SCB: 49.8° N, 240.5° E, \( A_p = 8.4 \); Siberia (SIB): 45.0° N, 141.0° E, \( A_p = 8.1 \).

Fig. 3 a. Present location of the North and South China blocks. Thin-line boundaries are shorelines (not block boundaries) and the broken line is the Tancheng-Lujiang fault. The sampling sites from the NCB and SCB are also indicated with squares representing Triassic sites, and circles and crosses representing Permian sites.

b. Schematic reconstruction of the NCB and SCB in Permo-Triassic time. The NCB is arbitrarily kept in its present orientation relative to north. The boundaries are simplified in the collision zone, and the Tancheng-Lujiang Fault is omitted.
The Permian palaeomagnetic directions for the SCB and NCB shown in Fig. 1 are completely different from each other. The corresponding mean palaeomagnetic poles computed from these directions (Fig. 2) are distinct at >99% confidence. Because the data for both the SCB and NCB pole positions pass fold and reversal tests and are mutually consistent, we believe they represent primary remanence with little or no contamination by unreminded secondary components. Thus we must look for tectonic causes to explain the discrepancy. Moreover, these directions are representative of large areas on the SCB and NCB (Fig. 3a), so that local rotation of small blocks is not a likely explanation.

The palaeolatitudes implied by the data from the SCB and NCB are similar, but the mean direction of palaeo-north for the SCB is rotated clockwise more than 60° with respect to that for the NCB. Thus the NCB and SCB could not have been in their present configuration in late Permian time. A model involving relative rotation of the SCB and NCB is suggested by the geometrical relationships evident in Fig. 2. The great circle equidistant between the SCB and NCB poles intersects the boundary between these two blocks near its eastern end. A finite rotation of 67° about this point of intersection brings the SCB and NCB poles into coincidence. As Fig. 3 shows, this is what might be expected if collision occurred initially at this point in easternmost China and progressed westward as the SCB rotated clockwise relative to the NCB. The distribution of Triassic flysch deposits suggests that this model merits serious consideration. These are well developed along the northwestern margin of the SCB, whereas on the northeastern margin there are only littoral and subaerial deposits of that age.

Of course, a different finite rotation about any other point on the bisecting great circle (Fig. 2), or any number of more complex combinations of rotations, can bring the palaeomagnetic poles for the SCB and NCB into coincidence. An interesting case is rotation about a point chosen so that the relative displacement between the SCB and NCB along their boundary is approximately strike-slip. The amount of displacement needed to accomplish the azimuthal rotation required by the palaeomagnetic data, however, is very large: more than 5,000 km. We know of no geological evidence for such displacement.

Early Triassic data for the NCB and SCB are similar to those for the late Permian. Two studies11,12 near Taiyuan in Shanxi Province yield directions that agree well with those from the late Permian rocks from the same area. A third result12,22 from the Benxi area, far to the east in Liaoning Province, does not agree with the other two for the NCB, even after correction of a mistake in the calculation of the mean direction and pole. The inclination is concordant with the other two, but the declination is rotated about 40° anticlockwise, in agreement with the sense of rotation that would be expected from the nearby Tancheng-Lujiang Fault. The possibility of such local rotations near this major fault zone has been suggested by others25,26. For this reason, and because no evidence was presented demonstrating that the magnetization is primary, we exclude this result from further consideration. On the SCB, one middle Triassic and three early Triassic results10,11,27 agree well with each other and are similar to the late Permian results. Because of their wide distribution (Fig. 3a), they further support the contention that the palaeomagnetic directions are representative of the whole SCB.

Thus the early Triassic data may be explained in the same way as those of the late Permian. If we average the two sets of data to obtain Permo-Triassic poles for the SCB and NCB, the model illustrated in Fig. 3 applies with only minor modification. The main change is that the point of initial collision about which the blocks rotate is shifted several hundred kilometres westward along the SCB–NCB boundary.

The question of where the SCB and NCB collided and became completely sutured still cannot be answered precisely. Well-documented studies show that the SCB and NCB palaeomagnetic poles are statistically indistinguishable in late Cretaceous time28. Therefore, collision and suturing was complete before then. Middle and late Jurassic pole positions11,23 have been published that are similar for both blocks, but no documentation was offered to demonstrate that these rocks escaped Cretaceous overprinting that is so pervasive in eastern China. We know of no data for the late Triassic and early Jurassic. Geological evidence is even less definitive, with estimates ranging from Devonian to Jurassic.17,18 We favour the hypothesis that North and South China initially collided in the early Triassic and finished most of their relative rotation during the Jurassic.

A final question concerns the time of amalgamation of China and Siberia. Some geological29 and palaeomagnetic30 articles have suggested that the NCB accreted to Siberia before the late Permian. The late Permian (Fig. 2) and early Triassic palaeomagnetic data contradict these interpretations. As pointed out first by McElhinny et al.5 in 1981 and most recently by Opdyke et al.22 in 1986, these data imply that both the SCB and the NCB lay far to the south compared with their present positions relative to Siberia. Where and when the relative displacement between China and Siberia was accommodated remains an important problem in the tectonics of Asia.

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