

# The Early Paleozoic paleogeography of the North China block and the other major blocks of China

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**Abstract** With the summarization of the Early Paleozoic paleomagnetic data recently obtained from the three major blocks of China, the Early Paleozoic (i.e. Cambrian and Ordovician) paleogeographic positions of the North China, South China and Tarim blocks were discussed in detail. The North China, South China and Tarim blocks were inferred to be located adjacent to East Gondwana in low latitudes of the Southern Hemisphere during the Early Cambrian. During the Early-Middle Ordovician, the South China and Tarim blocks were also located in low latitudes of the Southern Hemisphere with some affinities of the Gondwanaland, whereas the North China block may have episodically separated from the Gondwanaland, and might be sited close to the North America and Siberia. The reestablished paleogeographic configurations are in agreement with the studies on the biogeography, paleoclimate and sedimental facies of the North China and South China blocks.

**Keywords:** North China block, South China block, Early Paleozoic, paleogeographic reconstruction.

With the comparison of tectonostratigraphic and paleomagnetic data between the three major crustal blocks of China, namely North China, South China, and Tarim, and Laurentia including North America and Greenland, Siberia and Australia, Li and his colleagues recently discussed in detail the paleogeographic positions of the three major blocks of China in the Neoproterozoic Rodinia supercontinent (1050–720 Ma)<sup>[1–3]</sup>. By the Early Cambrian, South China, North China, and Siberia may have separated together from the Laurentia, and sited close to East Gondwana, with breakup of Rodinia supercontinent and formation of the integral Gondwana<sup>[4]</sup>.

The close lithostratigraphic and paleobiogeographic affinities between the East and Southeast Asian major continental blocks and East Gondwana during much of the Paleozoic have been recognized since at least the early 1970s<sup>[5, 6]</sup>, however, when and how they connected is an open question. This problem is of course desirable to more and more precisely paleomagnetic data. Recently, the Early Paleozoic (i.e. Cambrian and Ordovician) paleomagnetic study has made great progress on North China and the other major blocks of China<sup>[7–11]</sup>. This progress would provide constraints on the tectonic history of the blocks themselves and afford a clue to the paleogeographic reconstruction between East Asia and the adjacent regions of the world<sup>[12, 13]</sup>.

Together with the progress on the studies of biogeography, paleoclimate and sedimental facies from China, the Early Paleozoic tectonic history and paleogeographic reconstruction of the three major blocks of China will be discussed in detail in this paper, based upon the summarization of the paleomagnetic data recently obtained from them.

## 1 Paleomagnetic data

(i) North China block (NCB). Zhao and his colleagues<sup>[7]</sup> reported Early Paleozoic paleomagnetic results from the Early Cambrian to Middle Ordovician shales, limestones and dolomites from three widely distributed localities in Beijing, Hebei and Shandong provinces. The characteristic high temperature remanent magnetization passes the fold, baked contact and reversal tests. Regardless of the uncertain polarity assigned to the corresponding paleomagnetic poles, the Cambrian paleomagnetic pole of Zhao et al.<sup>[7]</sup> (table 1) is reliable. However, the reported Early-Middle Ordovician pole (table 1) is just a preliminary one because of a small number of samples.

Huang et al.<sup>[8]</sup> collected 917 oriented drill-core samples that covered over 124 sites from 22 units spanning the Early Cambrian to Middle Ordovician formations of three regions, namely Helanshan of Ningxia, Tongchuan-Hancheng of Shaanxi, and Yuncheng-Luliang of Shanxi along the margin of the

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Table 1 The paleomagnetic data obtained from North China and the other two major blocks of China

| Age  | Sampling site                   |                | <i>N</i> ( <i>n</i> ) | Paleomagnetic Pole |                | <i>A</i> <sub>95</sub> (°) | Paleolatitude/(°) | Test    | Ref. |
|--|---------------------------------|----------------|-----------------------|--------------------|----------------|----------------------------|-------------------|---------|------|
|  | <i>F</i> /(°E)                  | <i>I</i> /(°N) |                       | <i>F</i> /(°E)     | <i>I</i> /(°N) |                            |                   |         |      |
| North China block (NCB), reference site: Shaanxi, 35°N, 110°E        |                                 |                |                       |                    |                |                            |                   |         |      |
| O <sub>2</sub>   | Ningxia, Shaanxi, Shanxi        |                | 9(56)                 | 327.7              | 31.5           | 7.0                        | -14.7±7.0         | F, R    | [8]  |
| O <sub>2</sub>   | Henan (113.2, 35.3)             |                | 6                     | 310.4              | 27.9           | 9.2                        | -24.2±9.2         | C       | [9]  |
| O <sub>2</sub>   | Liaoning (121.7, 39.4)          |                | 1(5)                  | 332.5              | 43.2           | (10.6)                     | -2.7±10.6         | R       | [15] |
| O <sub>1-2</sub>   | Ningxia (105.5, 37.2)           |                | 13(74)                | 326.5              | 31.8           | 9.5                        | -14.9±9.5         | F, R    | [16] |
| O <sub>1-2</sub>   | Shandong and Hebei              |                | 4(15)                 | 305.4              | 29.2           | 26.0                       | -24.2±26.0        | F, R, B | [7]  |
| O <sub>1</sub>   | Shaanxi (110.5, 35.6)           |                | 9(41)                 | 324.3              | 37.4           | 8.5                        | -10.9±8.5         | F, R    | [8]  |
| Є <sub>3</sub>   | Ningxia and Shaanxi             |                | 11(66)                | 329.6              | 31.7           | 5.4                        | -13.6±5.4         | F       | [8]  |
| Є <sub>2</sub>   | Ningxia, Shaanxi & Shanxi       |                | 17(86)                | 326.7              | 37.0           | 5.5                        | -10.3±5.5         | F       | [8]  |
| Є <sub>1</sub>   | Ningxia and Shanxi              |                | 8(32)                 | 341.9              | 18.5           | 6.5                        | -17.3±6.5         | F       | [8]  |
| Є <sub>1</sub>   | Shandong, Liaoning, Korea       |                | 7(58)                 | 298.6              | 15.0           | 9.9                        | -39.3±9.9         | R       | [15] |
| Є <sub>1</sub>   | Shaanxi (110.2, 35.5)           |                | (20)                  | 217.2              | 15.3           | 17.5                       | -4.7±17.5         |         | [17] |
| Є <sup>a)</sup>  | Liaoning                        |                | 5(40)                 | 334.5              | 26.8           | 8.9                        | -15.2±8.9         | C       | [18] |
| Є  | Shandong and Hebei              |                | 14(83)                | 329.9              | 23.5           | 10.4                       | -20.3±10.4        | F, R, B | [7]  |
| South China block (SCB), reference site: Sichuan, 32°N, 106°E        |                                 |                |                       |                    |                |                            |                   |         |      |
| O <sub>1-2</sub> <sup>b)</sup>                                       | Hubei (110.4, 31.2)             |                | 5(33)                 | 157.6              | -36.0          | 17.8                       | 6.6±17.8          |         | [11] |
| O <sub>1</sub>   | Yunnan (102.6, 25.6)            |                | 5(26)                 | 235.7              | -38.9          | 16.9                       | -49.0±16.9        | F       | [19] |
| Є <sub>1</sub>   | Zhejiang, Hubei & Yunnan        |                | 8                     | 195.0              | 3.4            | 8.8                        | 2.6±8.8           | R, C    | [15] |
| Є <sub>2</sub>   | Yunnan (102.3, 24.4)            |                |                       | 270.7              | 68.6           | 6.6                        | 11.2±6.6          |         | [20] |
| Є <sub>2</sub>   | Wangcang, Sichuan (106.2, 32.1) |                | 9(74)                 | 185.1              | -39.5          | 7.8                        | -12.3±7.8         | F       | [10] |
| Tarim block (TRM), reference site: Kuruketag of Xinjiang, 40°N, 98°E |                                 |                |                       |                    |                |                            |                   |         |      |
| O <sub>1</sub>   | Kuruketag                       |                | 3                     | 180.6              | -20.4          | 8.5/15.0 <sup>c)</sup>     | -7.6±?            |         | [21] |

F, Fold test; R, reversal test; B, baked test; C, consistency test; *N*(*n*), the number of sites (samples); *A*<sub>95</sub>, angular radius of cone within 95% confidence. a) After the recalculation by Zhao et al.<sup>[7]</sup>; b) After the recalculation of this study; c) small and big axis of the ellipse within 95% confidence (*dp/dm*).

Ordos Basin. The lithology of sampled rocks is dominated by limestone, dolomite, dolomitic limestone, and marlaceous limestone. After detailed rock magnetic experiments<sup>[14]</sup> and careful demagnetization, characteristic remanent magnetizations for five periods between the Cambrian and Ordovician are isolated from 281 samples. Reliability of the five corresponding paleomagnetic poles (table 1) is ascertained through the positive fold test in the five directions and the positive reversal test on the two Ordovician directions.

Yang et al.<sup>[9]</sup> isolated a high temperature remanent magnetization from six sites of Middle Ordovician limestone in Jiaozuo of Henan Province (table 1). The single reversed polarity of this component is coincident with a 25–30 Ma period reversed superchron during the Arenig and Llanvirn stages, which has recently been confirmed by the magnetostratigraphic studies in Siberia<sup>[22, 23]</sup>. Together with coeval results from the margin of the Ordos Basin, Shandong and Hebei<sup>[7, 8]</sup>, this direction passes regional consistency test.

Huang et al.<sup>[16]</sup> reported paleomagnetic results for Early-Middle Ordovician Miboshan and Tianjinshan formations of the eastern part of the Hexi Corridor, northwest China. The characteristic high temperature component was isolated from 74 out of 114 samples after detailed studies on the rock magnetism and demagnetization behavior. This component exhibited dual polarity and passed the fold and reversal tests at the 95% confidence level. The corresponding paleopole is in agreement with the coeval poles from the margin of the Ordos Basin, Jiaozuo of Henan, Shandong and Hebei<sup>[7–9]</sup>,

indicating that the Alashan and Hexi Corridor terrane was not subject to relative movement with respect to the stable North China block (NCB) since that period. The Alashan and Hexi Corridor terrane would be the western extension of the NCB since at least the Early-Middle Ordovician. The post-Ordovician paleomagnetic results from the Alashan and Hexi Corridor terrane may therefore be used to discuss the tectonics of integral NCB.

Three other Early Paleozoic paleomagnetic poles were reported for the NCB by Gao et al.<sup>[18]</sup>, Lin et al.<sup>[15]</sup>, and Wu<sup>[17]</sup> in the 1980s (table 1). Among these paleomagnetic poles, the one of Gao et al. shows good consistency with the other coeval ones for the NCB (fig. 1), after the reanalysis and recalculating by Zhao et al.<sup>[7]</sup>. The pole of Wu<sup>[17]</sup> from Early Cambrian red marl rocks of Shaanxi Province seems to be calculated from two significantly different magnetizations, in which the SE component was possibly acquired close to the Late Permian, because its corresponding paleomagnetic pole is located close to the Late Permian one of the NCB. The Cambrian pole of Lin et al.<sup>[15]</sup> was obtained from limited samples and no field test is used to constrain the magnetization age, however, this pole lies at a similar position with the one obtained in the boundary of Cambrian/Ordovician from Tangshan of Hebei Province<sup>[24]</sup>. This may imply that the Cambrian pole of Lin et al.<sup>[15]</sup> is a mean result spanning a large interval. On the other hand, a Middle Ordovician pole from five limestone samples of Majiagou Formation of Liaoning Province<sup>[15]</sup> clusters close to the Permian one for the NCB. This Ordovician pole might be subjected to contamination by Late Paleozoic overprint and rejected by original authors<sup>[25]</sup>.

To sum up, most Early Paleozoic paleomagnetic results for the NCB are reliable and show good consistency, except for a few poles reported in the 1980s, which suffered from limited samples,

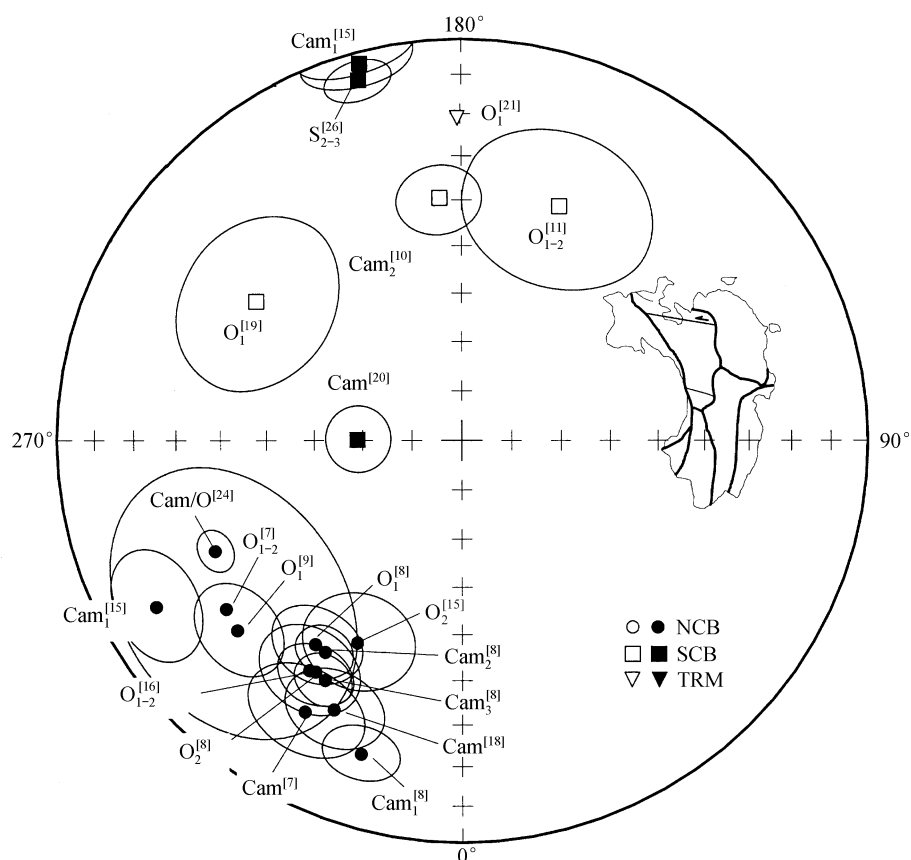


Fig. 1. Equal-area projection of the Paleozoic paleomagnetic paleo-north poles from the North China, South China and Tarim blocks. Solid/open symbols represent paleopole positions plotted onto the Northern and Southern hemispheres.

contamination by overprint, and lack of available field test to ascertain the magnetization age.

(ii) South China block (SCB) and Tarim. Bai et al.<sup>[10]</sup> collected 140 orientated drill-core samples that covered over 12 sites from the Middle Cambrian Douposi Formation of Wangcang section, Sichuan Province. The lithology is dominated by purplish sandstone and red mudstone. Detailed rock magnetic study and careful demagnetization exhibited that the high temperature remanent magnetization isolated from 74 red mudstone samples from nine sites resides in hematite, and passes the traditional McElhinny's fold test at the 95% confidence limit. This implies that this characteristic remanent magnetization is of pre-Cretaceous folding time. Together the corresponding paleomagnetic pole of this observation (table 1) is distinctly different from the post-Silurian paleomagnetic poles for the South China block (SCB), this characteristic direction is probably primary and the corresponding paleomagnetic pole is reliable.

Paleomagnetic study on the Ordovician limestone rocks from the Xingshan-Zigui section of Hubei Province exhibited two high temperature remanent magnetizations, which is usually unblocked around 570°C<sup>[11]</sup>: directions of the Early and Middle Ordovician samples cluster around southerly direction with downward inclination and its antipode, whereas directions of the Late Ordovician samples tend toward the southeast with downward inclination or southwest with upward inclination. Fisher statistic recalculation on the 33 Early and Middle Ordovician samples covered over five sites yields a mean direction of  $D/I=142.5^\circ/18.3^\circ$  with  $a_{95}=18.5^\circ$  after tilt correction. The corresponding paleomagnetic pole of this direction is located at 157.6° E, 36.0° S with  $A_{95}=17.8^\circ$  (table 1). Nevertheless, directions of the 44 Late Ordovician samples covered over three sites might suffer from a local rotation of about 40°, which was caused by an overthrust fault in sampling section. This Late Ordovician result is therefore rejected.

At the beginning of the 1990s, Fang et al.<sup>[19]</sup> studied the Early Ordovician sandstone and mudstone from the Hongshiya Formation of Yunnan Province, and isolated a high temperature remanent magnetization from 26 samples covered over five sites. The characteristic high temperature component is usually unblocked by about 680°C and is of single reversed polarity, which is in agreement with a reversed superchron during the Arenig to Llanvirn stages. This Ordovician long interval of reversed polarity was confirmed by a lot of paleomagnetic and magnetostratigraphic results in the NCB and Siberia<sup>[8, 22-24]</sup>. On the other hand, this component passes fold test at 95% confidence limit indicative of a pre-Tertiary folding nature. The corresponding paleomagnetic pole is markedly different from those of post-Silurian for the SCB. This Ordovician pole is probably reliable but with a large of uncertainties.

Additionally, Lin et al.<sup>[15]</sup> reported an Early Cambrian paleomagnetic pole from three widely separated sections in Zhejiang, Hubei and Yunnan provinces in the middle of the 1980s. This paleomagnetic pole passes regional consistency and reversal tests at the 95% confidence limit, indicating that it may exclude local rotation and represent the record of the Cambrian. Nevertheless, this preliminary paleomagnetic pole almost shares the same location with the Middle-Late Silurian pole of Opdyke et al.<sup>[26]</sup> obtained from the Xiushan of Sichuan Province (fig. 1). This implies that the Cambrian paleomagnetic pole of Lin et al.<sup>[15]</sup> is probably contaminated by the Silurian overprint.

Similarly, Cambrian paleomagnetic pole reported by Liang et al.<sup>[20]</sup> lies close to the Permian pole for the SCB<sup>[11]</sup>, suggesting that the Late Paleozoic to Early Mesozoic overprint may not have been completely removed from the characteristic remanent magnetization.

As shown in fig. 1, two Ordovician paleomagnetic poles for the SCB, which were reported by Fang et al.<sup>[19]</sup> and Wu et al.<sup>[11]</sup> respectively, exhibit distinct difference in position. Of course, the two Ordovician poles were both from limited samples, and both have a large of uncertainties (table 1). Because no much detail was presented about the origin of the characteristic remanent magnetization for the paleomagnetic pole of Wu et al., we reject it in this study. The pole of Fang et al.<sup>[19]</sup> passes a Tertiary fold test, and it may therefore be a reliable Ordovician paleomagnetic pole for the SCB at present.

The Early Paleozoic paleomagnetic study on the Tarim block did not make great progress in the past decade, and the published paleomagnetic data are not enough to discuss the Early Paleozoic paleogeography and tectonic history in detail for the Tarim. Up to now, only an Early Ordovician paleomagnetic pole was reported from the carbonate rocks of the Baiyungan Formation of Yaerdanshan,

Kuruketag of Xinjiang Uygur Autonomous Region<sup>[21]</sup>. The high temperature remanent magnetization resided in magnetite show a good consistency over three sampling sites, indicating that it might be a primary component.

Another Early Paleozoic paleomagnetic study was performed by Zhao et al. (personal communication, 1999), who collected some Late Cambrian and Middle Ordovician limestone samples from the Kuruketag Mountain of the Tarim Basin. After removal of a low-temperature component that resembles both Tertiary and present field directions and fails a fold test, a well-grouped characteristic high temperature component remains in Late Cambrian and Middle Ordovician limestones that is of dual polarity. This component passes a middle Silurian fold test at more than 99% confidence level. The corresponding paleomagnetic poles place Tarim at the Southern Hemisphere of 27.8° S and 36.5° S in Late Cambrian and Middle Ordovician time respectively.

## 2 Rapid apparent polar wander for the Early Paleozoic

A lot of paleomagnetic data confirmed that most major blocks of the world experienced a rapid continental motion during the Early Cambrian, which was characterized by a rapid apparent polar wander (APW) at different extent<sup>[8, 24, 27–29]</sup>. Of course, the upper-mantle convection was not sufficient to drive large plates at velocities in excess of 25 cm/a<sup>[30]</sup>. After the examination of selected paleomagnetic data available from Laurentia, Gondwana, Siberia and Baltica for the interval from latest Vendian through Ordovician time, Kirschvink et al.<sup>[28]</sup> proposed that an approximately 90° of rapid APW could be observed during the period from Early Cambrian to early-Middle Cambrian (523–508 Ma) in most major blocks of the world. Kirschvink et al.<sup>[28]</sup> further proposed that this rapid APW was resulted from a inertial interchange true polar wander (IITPW), which is a special case of true polar wander (TPW) wherein the Earth's intermediate inertial axis and maximum inertial axis interchange. Admittedly, the IITPW requires that each APW path of all the plates and blocks of the world should allow for approximately 90° of motion in a relatively short amount of geological time (ca. 15–20 Ma), except the motion of the continent was purely antithetical to the direction of TPW<sup>[27]</sup>.

The little amount of the Early Paleozoic paleomagnetic data for the SCB and Tarim is obviously not enough to test the IITPW hypothesis, however, detailed Early Paleozoic paleomagnetic study on the NCB exhibited an APW of only about 20° during the period from Early Cambrian to Middle Cambrian<sup>[8]</sup>. A recent paleomagnetic pole, at 294.6° E, 32.9° N with  $A_{95}=4.0^\circ$ , from the boundary of Cambrian/Ordovician of Tangshan section<sup>[21]</sup> may allow a much larger APW for the NCB during the period from Early Cambrian to Middle Ordovician time. However, because of the non-synchronous APW, this pole cannot be used to test the IITPW hypothesis. A recent review of paleomagnetic data for Laurentia, Baltica, Siberia and Gondwana<sup>[27]</sup> indicates that none of APW paths approaches the necessary length of IITPW hypothesis, and the APW paths of Laurentia and Gondwana just allow an APW of  $31 \pm 13^\circ$  and  $58 \pm 11^\circ$  during the period of  $(565 \pm 10) - (508 \pm 5)$  Ma and  $(535 \pm 3) - (505 \pm 5)$  Ma, respectively. All of these may imply that the IITPW is not supported by the available data. Alternatively, the observed rapid APW on most major blocks of the world during the Early Cambrian may represent an enhanced plate motion driven by lower-mantle thermal anomalies and possibly TPW caused by the plate reorganization after the breakup of the Neoproterozoic Rodinia supercontinent<sup>[27]</sup>.

## 3 Tectonic history and paleogeographic reconstruction

The revised Paleozoic APW path for the NCB<sup>[8, 31]</sup> exhibited an obvious APW during the period from Early Cambrian to Middle Cambrian, which reflects the NCB was subjected to a significant counterclockwise rotation but accompanied by insignificant latitudinal displacement during that period<sup>[8]</sup>. Huang et al.<sup>[32]</sup> recently isolated a high temperature remanent magnetization from a total of 239 Silurian and Devonian orientated drill-core samples covered over 23 sites, which were collected from three widely distributed sections in Zhongwei County, the eastern part of Hexi Corridor. This high temperature component resides both in hematite and magnetite, and passes the fold and reversal tests. By comparing the corresponding Silurian paleomagnetic pole with that of the Ordovician, a 32° clockwise polar wandering implies that the NCB experienced a rapid northward latitudinal displacement and passed the paleo-equator during that period. For the long period from Cambrian to

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Silurian, it is therefore reasonable to infer that the tectonic history of the NCB was dominated by latitudinal displacement accompanied by little rotation, based upon the comparison of changes in paleolatitude and paleoinclination on the reference site of Jiayuguan (98.0° E, 40.0° N)<sup>[12]</sup>.

Both the paleomagnetic and paleoclimatic data indicate that the NCB was located around 17° S of the Southern Hemisphere during the Early Cambrian (reference site: Hancheng of Shaanxi Province, 110° E, 35° N)<sup>[8,13,33]</sup>. The paleobiogeographic study on the Cambrian trilobites suggests that the NCB belongs to the Asia-Australian biogeographic realm<sup>[34]</sup>. In the basis of the above knowledge, the NCB could be inferred to site adjacent to eastern Antarctic-Australia integral continent of Gondwana during the Early Cambrian (figs. 2 and 3), with the APW path of the NCB clockwise rotated of 133.5° according to an Euler rotation pole at 4.9° N, 70.2° E. This paleogeographic configuration takes the Early Paleozoic connections between the NCB and East Gondwana is similar to that of Piper and Zhang<sup>[38]</sup> deduced from a Neoproterozoic paleomagnetic study of glacial rocks for the NCB. Moreover, collision of the NCB and Antarctic as the terminating event of the Early Paleozoic Ross orogeny of East Gondwana is indicated by comparable Rb-Sr isochrons and Sm-Nd ages for slates and phyllites in the North Qilian terrane and central Transantarctic Mountains<sup>[39]</sup>.

The NCB was still located at low latitudes of the Southern Hemisphere during the Ordovician, and had less change in paleolatitudes during the period from the Cambrian to Ordovician time. However, the paleogeographic study on trilobite assemblages suggests that the NCB belongs to same paleobiogeographic realm as Siberia but to different ones with the SCB and Australia during the Middle Ordovician<sup>[34]</sup>. This indicates that the NCB was not far away from Siberia beyond 1 000 km but located far away from the SCB and Australia beyond at least 1 000 km during that period<sup>[40]</sup>. Studies on the biogeography of conodont and sedimental facies of marine carbonate rocks further confirm that the NCB had a close affinity to Siberia rather than to the SCB and Australia during that period<sup>[41]</sup>. On the other hand, with the NCB sited close to eastern Antarctic-Australia integral continent (figs. 2 and 3), the APW path of the NCB would separate from that of Gondwana after the

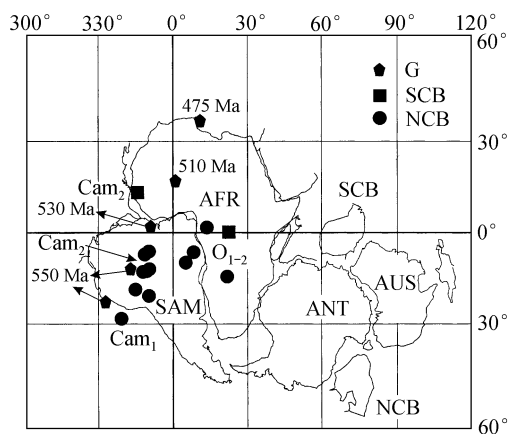


Fig. 2. Schematic Mercator projection showing paleogeographic reconstruction of North China, South China and Gondwana during Early Cambrian in African coordinates. Relative longitudes of the blocks are unconstrained. The Early Paleozoic paleomagnetic poles for the NCB and SCB are listed in table 1. The APW path for the Gondwana is drawn according to Van der Voo<sup>[35]</sup>, Grunow<sup>[36]</sup>, Meert et al.<sup>[37]</sup>. All the paleomagnetic poles are paleo-south poles. Euler rotation poles: NCB to Africa, 4.9° N, 70.2° E,  $D=-133.5^\circ$ ; SCB to Africa, 39.8° S, 134.7° E,  $D=51.6^\circ$ . AFR, Africa; ANT, Antarctic; AUS, Australia; G, Gondwana; NCB, North China block; SAM, South America; SCB, South China block.

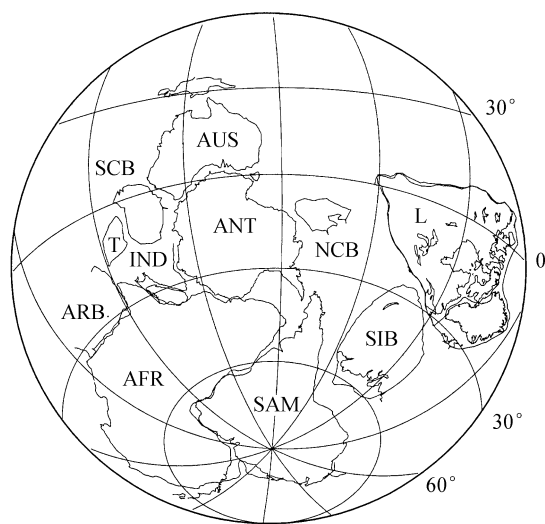


Fig. 3. Schematic equal-area projection showing paleogeographic reconstruction of the North China, South China and adjacent areas during Early Cambrian in geographic coordinates. ARB, Arabia; BAL, Baltica; IND, India; L, Laurentia; NAM, North America; SIB, Siberia. The other symbols are the same as in fig. 2.

Middle Cambrian (fig. 2). This indicates that the paleogeographic connection of the NCB with Antarctic-Australia integral continent of Gondwana shown in figs. 2 and 3 would just be available by the Middle Cambrian. After this time, the NCB may have separated from that integral continent<sup>[3, 8]</sup>, and may have sited close to southern Siberia and North America in the Middle Ordovician (fig. 4).

We note that the proposed Cambrian and Ordovician paleogeographic configurations for the NCB (figs. 3 and 4) are quite different from those established by Zhu and his colleagues (fig. 6(a), (b) of Zhu et al.<sup>[12]</sup>). Indeed, because of the assumed symmetry of the geomagnetic field, longitudinal motion is not quantifiable from paleomagnetic reconstructions alone. However, the newly proposed paleogeographic configurations for the NCB are based upon not only the paleomagnetic data, but also a lot

of constraints from the studies of paleontology and sedimental facies, such as the similarity of Cambrian trilobite assemblages between the NCB and Australia<sup>[34, 42]</sup>, differences in the Middle Ordovician biogeographic realms, the Ordovician similarities of conodont and sedimental facies of marine carbonate rocks between the NCB and Siberia<sup>[40]</sup>, and so on.

The available Cambrian and Ordovician paleomagnetic data indicate the SCB and Tarim were located at middle to low latitudes of the Southern Hemisphere, and may have a significant southward displacement during that period. Comparison of the Middle Cambrian paleomagnetic pole of Bai et al.<sup>[10]</sup> with that of the Early Ordovician of Fang et al.<sup>[19]</sup>, a rapid southward displacement of  $36.7 \pm 14.9^\circ$  was indicated during that period. Similarly, the significant Early Paleozoic southward motion was also observed on the Tarim block: the Late Cambrian and Middle Ordovician paleomagnetic results from the Kuruketag Mountain suggest the Tarim block had a southward displacement of about  $10^\circ$  during that period (personal communication, Zhao, 1999). As pointed out by Zhu et al.<sup>[12]</sup>, the Early Paleozoic affinities between the South China and Tarim blocks and Australia have been confirmed by a lot of geological and paleontological studies. We note that the early Arenig chitinozoan of South China is characterized by the typical chitinozoan of high latitudinal Gondwana (*Eremochitina baculata*, *E. Brevis*, *Lagenochitina obeliger*, *Jenkinochitina vulgaris*)<sup>[42]</sup>, whereas appearance of conodont fauna represented by *Serratognathus* place the SCB in middle to low latitudinal warm areas. However, characters of chitinozoan indicate that South China belonged to the North Gondwana during the Early Paleozoic.

The SCB was inferred to site adjacent to western Antarctic-Australia integral continent of Gondwana during the Cambrian (fig. 3), with the SCB counterclockwise rotated of  $51.6^\circ$  according to an Euler rotation pole at  $39.8^\circ$  S,  $134.7^\circ$  E, which could take the Middle Cambrian pole for the SCB<sup>[10]</sup> correlate with that of Gondwana (fig. 2). The SCB was most probably located close to western Australia or was one part of Gondwanaland during the Cambrian<sup>[15]</sup>. Obviously, the SCB was unattached with the NCB during the Cambrian since these two blocks were located at different sides of Antarctic-Australia integral continent of Gondwana during that time (fig. 3). This configuration is in agreement with biogeography of Cambrian trilobite assemblages: South China, North China and Australia all belong to the Asia-Australia biogeographic realm but significant differences existed between South China and North China<sup>[34]</sup>. The Ordovician paleomagnetic pole for the SCB<sup>[19]</sup> does not correlate with the Early Paleozoic APW path of Gondwana, with the SCB counterclockwise rotated of

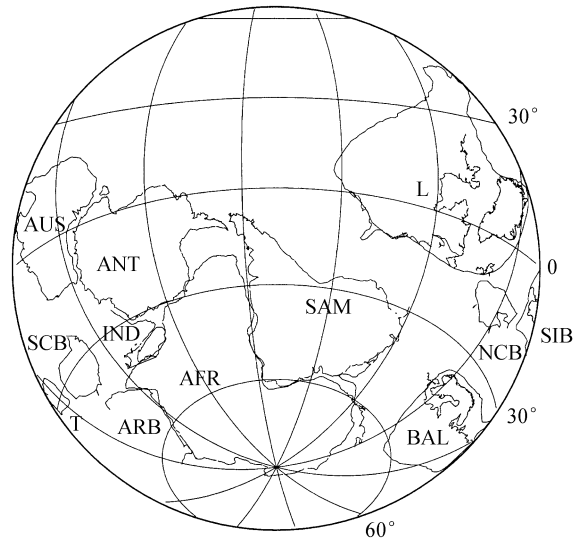


Fig. 4. Schematic equal-area projection showing paleogeographic reconstruction of North China, South China and adjacent areas during Middle Ordovician in geographic coordinates. The other symbols are the same as in fig. 3.

51.6° according to an Euler rotation pole at 39.8° S, 134.7° E (fig. 2). This may imply a relative displacement of the SCB with respect to Gondwana during the Early Paleozoic. As suggested by Li et al.<sup>[3]</sup> and Zhao et al.<sup>[44]</sup>, the three major blocks of China may locate close to East Gondwana during the long period from the Cambrian to Silurian, however, they were unlikely to have been attached to Gondwana during the entire Cambrian-Silurian interval. They may episodically drift off East Gondwana during that long period although they may not have drifted far from East Gondwana.

#### 4 Conclusions

The three major blocks of China, namely the North China, the South China and Tarim block, were located at middle to low latitudes of the Southern Hemisphere, and show some affinities with East Gondwana during the period from the Cambrian to Ordovician. However, the NCB may episodically separate from East Gondwana during that period, and may have sited close to Siberia and North America during the Middle Ordovician.

The NCB was unattached with the SCB during the Cambrian: the NCB was sited adjacent to eastern Antarctic-Australia integral continent of Gondwana, whereas the SCB as well as Tarim was located adjacent to western Antarctic-Australia integral continent of Gondwana.

During the period from the Cambrian to Ordovician, the tectonic motion of the NCB was dominated by counterclockwise rotation, whereas the tectonic motion of the SCB and Tarim was dominated by significant southward latitudinal displacement.

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