Available online at www.sciencedirect.com
SCIENCE DIRECT®
ELSEVIER
Earth and Planetary Science Letters 220 (2004) 423–434
EPSL
www.elsevier.com/locate/epsl

A long connection (750–380 Ma) between South China and Australia: paleomagnetic constraints

Zhenyu Yang [a,*], Zhiming Sun [b], Tienshui Yang [b], Junling Pei [b]

[a] *Department of Earth Sciences, Nanjing University, Nanjing, PR China*
[b] *Laboratory of Paleomagnetism, Institute of Geomechanics, CAGS, Beijing, PR China*

Received 27 October 2003; received in revised form 6 January 2004; accepted 8 January 2004

Abstract

A new paleomagnetic study has been carried out on sediments of middle Cambrian age in the North Sichuan Basin (Yangtze Block). Detailed stepwise thermal demagnetizations allowed us to isolate three components. Site-mean direction derived from higher temperature components is D/I = 146.9°/–17.1° (α_{95} = 8.3°) yielding a pole position at 51.3°S, 166.0°E. The fold and reversal tests suggest that remanence was acquired during early stage of sedimentation. Combined with the high-qualities early Sinian (748 Ma) and middle Silurian poles obtained recently from the Yangtze block, the deriving polar track demonstrates a similar loop to that of Australia. After rotating these poles from South China to fit that of Australia, the South China Block is placed against northwestern Australia. This reconstruction favors the correlations of the Jiangnan Grenville-age orogenic belt with the Rudall belt of western Australia, and subsequently the late Proterozoic Jiangnan and Officer/Adelaide rift systems. The paleobiogeographic evidence also indicates that this configuration might maintain by the middle Devonian.
© 2004 Elsevier B.V. All rights reserved.

Keywords: South China Block; Australia; Paleomagnetism; Rodinia; Gondwana

1. Introduction

There exists a general consensus that the South China Block (SCB) was formed through the amalgamation of a collage between the Yangtze and Cathaysia blocks during the Grenvillian orogeny [1–3] (Fig. 1A), although there is significant debate regarding its paleoposition in Rodinia and Gondwana [4–9]. Based on tectono–stratigraphic correlations of the Australia, Cathaysia and Laurentia blocks, Li et al. [4] proposed that the SCB lay between Australia–East Antarctica and Laurentia in the Rodinian reconstruction. However, Zhou et al. [9] argued that the Yangtze block might have been an isolated continent, although it was presumably located near the Rodinian supercontinent. Recently, granites associated with the dykes were dated at 826 ± 10 and 819 ± 9 Ma [10] in northern Guangxi, southern margin of the Yangtze Block, Southeast China, for which a co-magmatic and plume-related genesis was proposed [11] regarding to the break-up of the Rodinia Supercontinent. The SCB assumably broke

* Corresponding author. Tel.: +86-10-68422365; Fax: +86-10-68422326.
E-mail address: yangzy@public3.bta.net.cn (Z. Yang).

0012-821X/04/$ – see front matter © 2004 Elsevier B.V. All rights reserved.
doi:10.1016/S0012-821X(04)00053-6

away from Eastern Australia around 750 Ma [4,12].

On the other hand, we note that the close biogeographic affinities between South China and Australia during early to mid-Paleozoic time have long been recognized [13]. Thus, did the SCB rift from the eastern part of Australia during the late Proterozoic, and drift to the western part of Australia during the early Paleozoic [7]? It is obvious that this kind of reconstructions of South China during the late Proterozoic and early Paleozoic are hampered by a paucity of high-quality paleomagnetic data. Only two key paleopoles of the late Proterozoic and middle Silurian were obtained recently [8,14].

In this paper we present new middle Cambrian paleomagnetic results from the Guangyuan area of the Yangtze Block, which may bridge the significant data gap of the late Proterozoic and mid-Paleozoic apparent polar wander path for South China, and permit a rigorous test of the proposed configuration of South China in Rodinia and Gondwana.

2. Paleomagnetic sampling and results

We sampled the middle Cambrian along a road in the eastern part of Guangyuan city (32.4°N, 106.3°E) in the northern Yangtze Block (Fig. 1B). The middle Cambrian Douposi formation mainly consists of red mudstone and gray sandy mudstone in its lower part, gray dolomitic limestone and red to gray sandy mudstone in its middle part and gray dolomite and dolomitic limestone interbedded with siltstone and shale in its upper part. A rich trilobite assemblage, including e.g. *Paragraulos kunmingensis*, *Chittidilla* aff. *Plana* and *Kunmingaspis yunnanonsis*, indicative of middle Cambrian age, was reported from the middle part of the formation [15]. The Douposi formation is underlain by the well-dated early Cambrian Kongmingdong formation that contains a rich *Palaeolenus lantenoisi*, *Paokannia chinensis*, *Redlichia meitanensis* assemblage, and is unconformably overlain by the early Ordovician Banhe and Zhaojiaba formations. The latter contains trilobites (e.g. *Tungtzuella* sp., *Isotelus* sp.) and graptolites (e.g. *Didgmograptus bifidus*, *D.* cf. *deflexus* [15]). The unconformities between the early Ordovician and middle Cambrian, next to the lower Cretaceous and upper Jurassic give a multiphase age of folding.

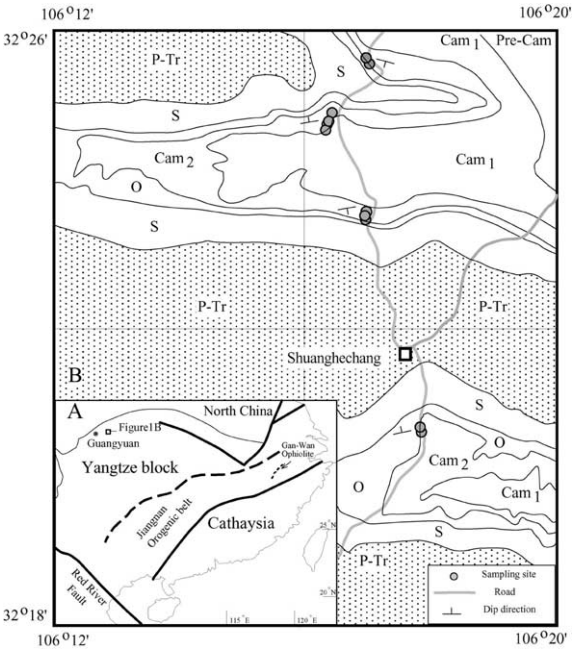


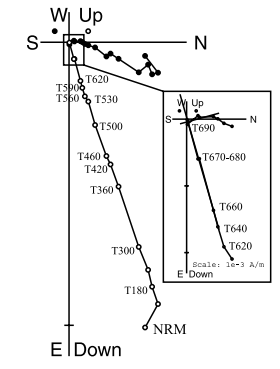
Fig. 1. (A) Tectonic framework of South China, and (B) geological sketch map of the sampling areas in the northeastern part of Guangyuan city (32.4°N, 106.3°E) in northern Yangtze Block. Locations of our sites (circles) are shown in the area. Abbreviations: Pre-Cam, Precambrian; Cam1, Early Cambrian; Cam2, Middle Cambrian; O, Ordovician; S, Silurian; P–Tr, Permo-Triassic.

Twenty-two sites from the lower/middle part of the Douposi formation were collected from both flanks of the folds using a portable drill (Fig. 1B), and oriented with a magnetic compass. The samples were cut into 2.3-cm-long specimens with a diamond saw.

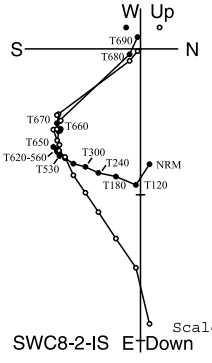
All samples were thermally demagnetized in 17–

→

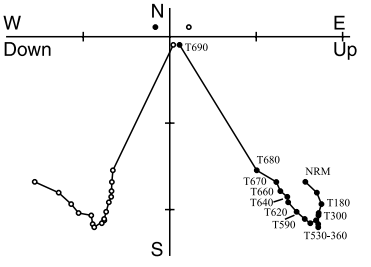
Fig. 2. Selected Zijderveld diagrams of thermal demagnetizations of NRM showing three NRM components in the samples. Solid (open) symbols refer to the projection on the horizontal (vertical) plane according to in situ coordinates. Key: T200 = 200°C.



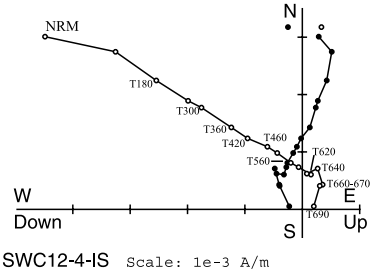
SWC4-4-IS Scale: 1e-2 A/m



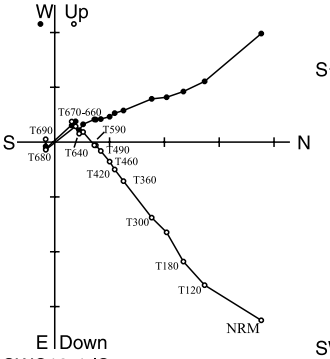
SWC8-2-IS Scale: 1e-3 A/m



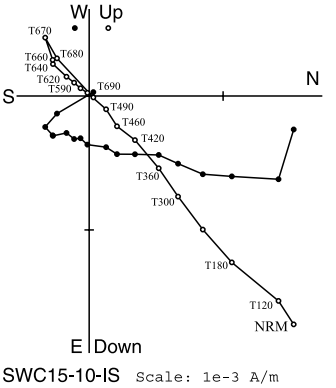
SWC9-6-IS Scale: 1e-3 A/m



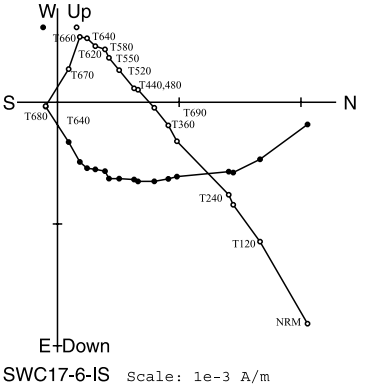
SWC12-4-IS Scale: 1e-3 A/m



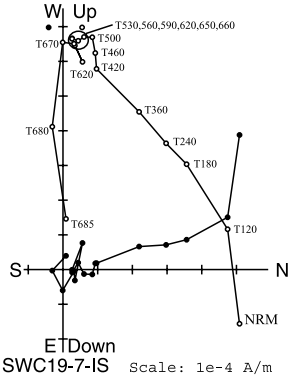
SWC13-4-IS Scale: 1e-3 A/m



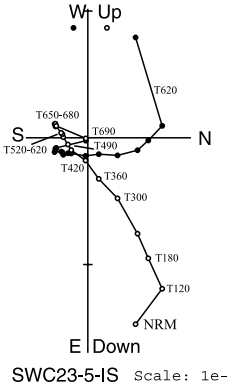
SWC15-10-IS Scale: 1e-3 A/m



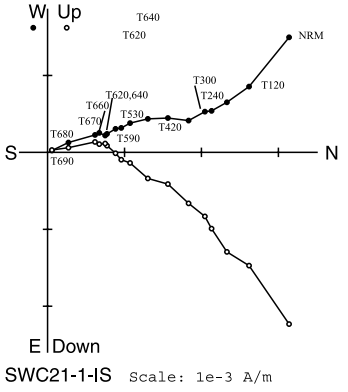
SWC17-6-IS Scale: 1e-3 A/m



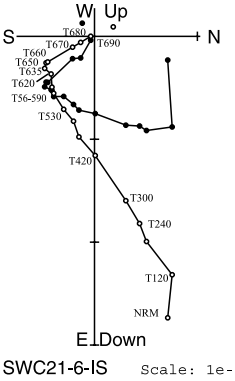
SWC19-7-IS Scale: 1e-4 A/m



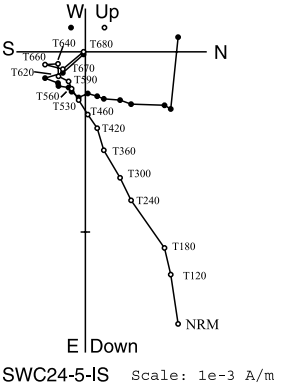
SWC23-5-IS Scale: 1e-3 A/m



SWC21-1-IS Scale: 1e-3 A/m



SWC21-6-IS Scale: 1e-3 A/m



SWC24-5-IS Scale: 1e-3 A/m

18 steps in an ASC-TD48 oven with an internal residual field lower than 10 nT. All measurements of natural remanent magnetization (NRM) were made on a 2G-755 magnetometer inside a set of large Helmholtz coils that reduced the ambient geomagnetic field to around 300 nT in the Paleomagnetic Laboratory of the Institute of Geomechanics in Beijing. Results were analyzed using principal component analysis [16] and Fisher statistics [17] or the McFadden and McElhinny method [18].

Three NRM components are recognized in the samples. A component A, for which in situ directions are close to the PEF, is separated below 240°C (Fig. 2). The mean direction (Dec = 357°, Inc = 52.1°, $\alpha 95 = 2.0°$, $N = 162$ samples) is close to the present dipole field which is Inc = 51.8°, and is probably a viscous remanent magnetization (Fig. 3A). A different component B is determined between 240°C and 620–640°C. Moreover, a component C of either reversed or normal polarity is revealed up to 690°C from these red bed samples. The presence of high-coercivity hematite is evidenced by the IRM acquisitions, thermal demagnetization and thermo-remanent analysis (Fig. 4). Component C decaying linearly to the origin could be determined from half of samples (Fig. 2). However, remanent directions after 650°C become erratic in the other half of samples, which prevents the determination of the final directions (Fig. 5). In this case, some samples displaying well-defined great circle paths at temperatures lower than 650°C are shown on the stereographic plot (Fig. 5). The site-mean direction is then computed using the intersection of sector-constrained great circles combined with directly observed directions by using the statistical method developed by McFadden and McElhinny [18]. The directions of component C with a northwest declination (downward inclination) and a nearly antipodal southeast declination (upward) after tilt correction are revealed from 15 out of 22 sampling sites. Seven sites with erratic demagnetization directions or completely Mesozoic overprint were rejected from further analysis.

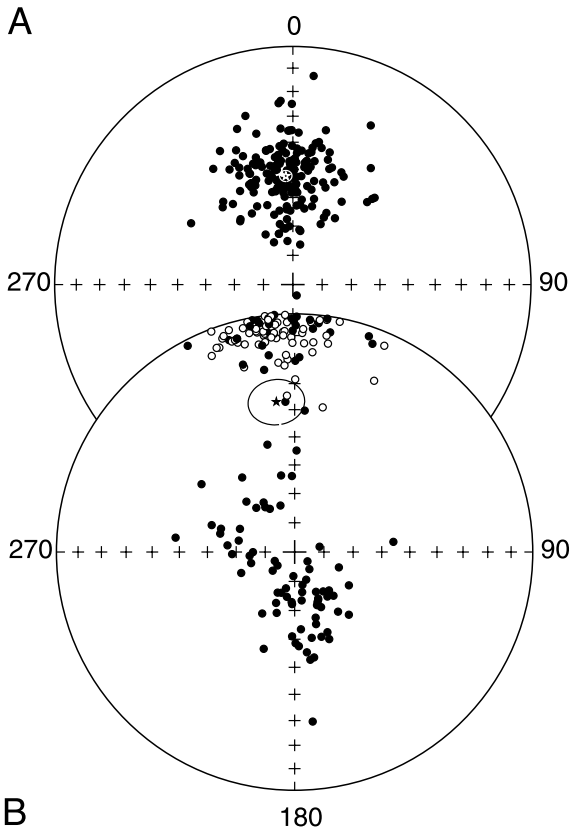


Fig. 3. Equal-area stereographic projection of lower temperature component A in (A) geographic, and (B) stratigraphic coordinates, respectively. Lower (upper) hemisphere directions are marked with closed (open) symbols.

The tilt corrections disperse the grouping of site-mean directions for component B (Fig. 6A). The ratio of precision parameters before correction and after progressive corrections ($kg/ks = 98/3.9$) shows a negative fold test. Site-mean direction before tilt correction appears to be statistically indistinguishable from late Cretaceous directions reported from the Yangtze Block [19], which implies that this direction would be a Cretaceous remagnetization and correspond to the late phases of the Yanshanian orogeny in the Sichuan Basin [19].

Finally, the tilt correction greatly improves the clustering of site-mean directions for component C (Fig. 6B). The average site-mean direction is $D = 140.4°$, $I = -30.3°$, $\alpha_{95} = 23.5°$ before, and $D = 146.9°$, $I = -17.1°$ and $\alpha_{95} = 8.3°$ (ks/kg = 22/3.6) after tilt correction (Table 1). The fold test is positive at the 99% probability level according to the fold tests of McElhinny [20] and McFadden

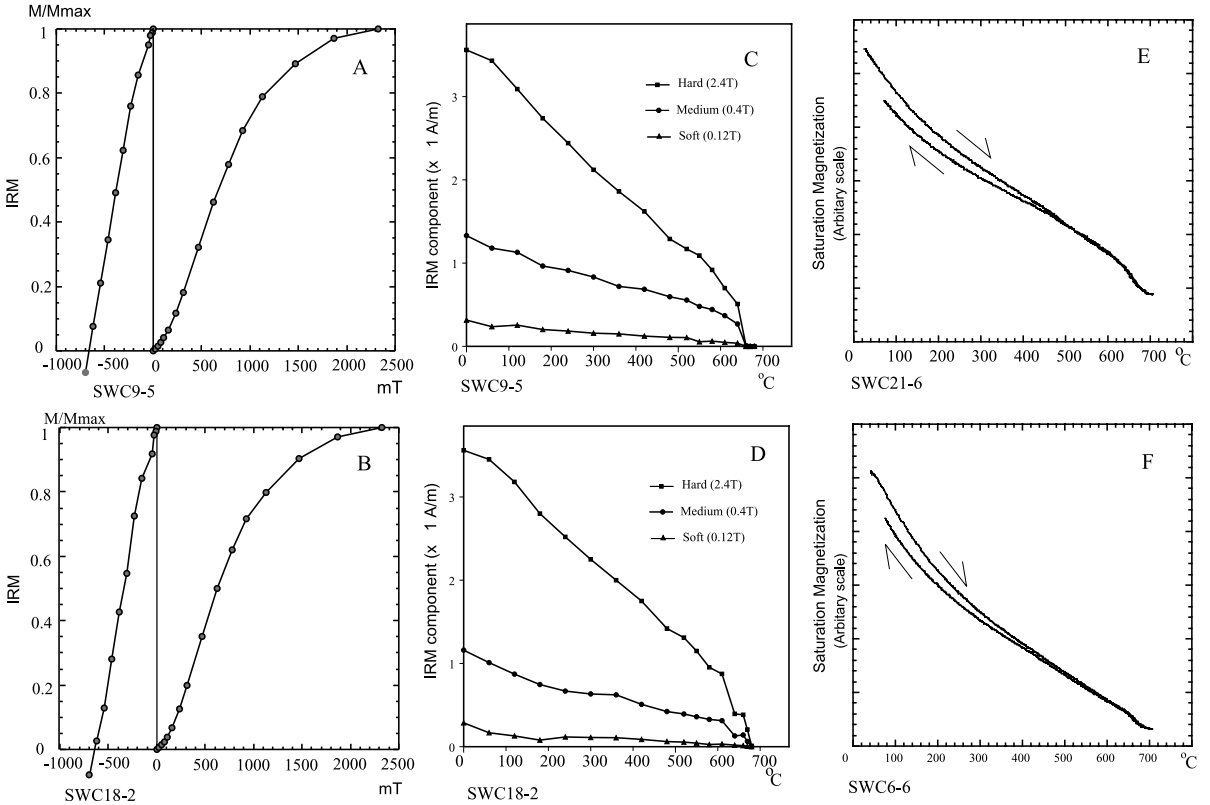


Fig. 4. (A,B) Normalized isothermal remanent magnetization acquisition curves of red mudstone samples and opposite field demagnetization. (C,D) Three-component IRM thermal demagnetization showing unblocking temperatures around 680°C. Open circles indicate soft component, 0.12-T field; triangles indicate medium component, 0.4-T field, and squares indicate hard component, 2.5-T field. (E,F) Thermomagnetic curves of bulk specimens of the red bed samples showing the Curie points of hematite around 680°C.

[21]. The antipodal directions of component C also pass the reversal test of McFadden and McElhinny [22] at the 95% probability level (C class). Thus, component C most likely represents the original remanent direction.

3. Discussion

A high-quality late Proterozoic (748 ± 12 Ma, basal Sinian Liantuo formation) pole was obtained from the Three Gorge areas of Yangtze block by Evans et al. [8]. In comparing the new lower Sinian pole with the coeval Australian MDS pole, Evans et al. [8] tried to test the different reconstruction models of South China relative to Australia. These results negate the reconstruction postulated in the 'missing link' hypothesis of Li et al. [4], except that South China was separated from Australia by 750 Ma or with different orientation. On a series of paleogeographic maps recently proposed by Li and Powell [7] for the Australia and South China, South China was designed by an intriguing moving path located in the east margin (1000–600 Ma) to the north (505 Ma), and then to the western part (480–450 Ma, and 320 Ma) of Australia. As pointed out by Evans et al. [8], the SCB lacks high-quality paleomagnetic poles from the interval 700–500 Ma. Thus, these reconstructions are not rigorous at present. Four preliminary paleopoles of the early Cambrian and Pre-Cambrian/Cambrian boundary were reported from the SCB [23–26]. However, as shown in Fig. 7, these poles were close either to

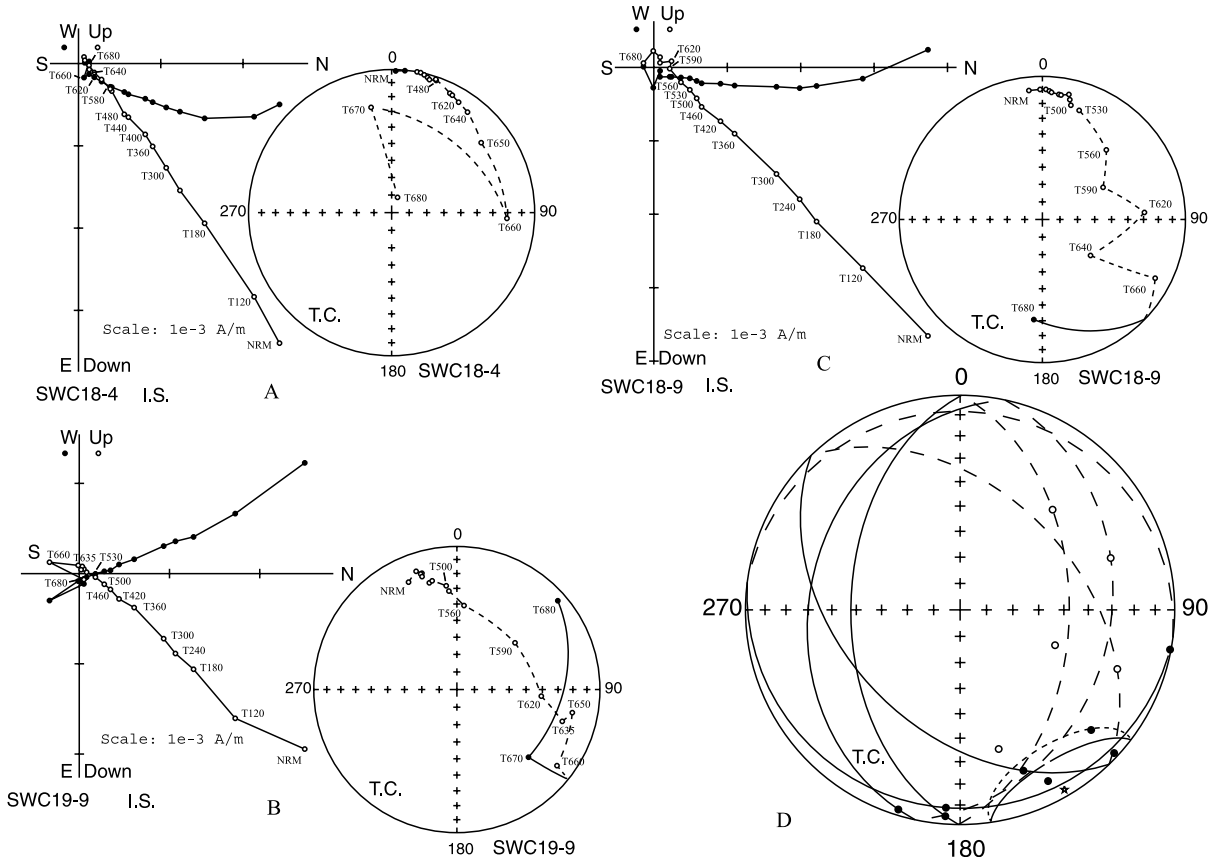


Fig. 5. (A–C) Orthogonal vector projection of NRM thermal demagnetization showing erratic directional changes after heating to 600–650°C according to in situ (I.S.) coordinates, and stereographic projections of the change in NRM directions along remagnetization great circles after tilt corrections (T.C.). (D) The site-mean direction (star) for the site SWC18–19 calculated from the intersection of the great circles with limiting sector constraints and directly observed components.

the Silurian or late Mesozoic poles of the SCB, which may indicate the later overprint of the rocks [27].

Positive reversal and fold tests for the high-temperature component C of the Douposi formation allow us to define a reliable middle Cambrian north pole at 51.3°S, 166.0°E with dp = 4.4° and dm = 8.6°. We note that the post-folding remagnetization pole calculated from the secondary component B is coherent with the late Cretaceous pole of South China, and that the early Triassic pole reported from same sampling area matches well with that of the Yangtze Block [19,28]. These results suggest that the middle Cambrian pole originates from sediment sequences situated in an autochthonous region of the SCB. The sampling area of the SCB was located in a Southern Hemisphere palaeolatitude (~9°) during the middle Cambrian.

A preliminary early Ordovician pole was obtained in only 37 samples (5 sites) from Eastern Yunnan of the SCB [29], which places the SCB in an intermediate paleolatitude compared with Baltica. However, as pointed out by Nie [30], this higher southern paleolatitude is incompatible with the geological information. The dominance of successive thick platform carbonates, reefs deposition and the lack of evaporates in the early Paleozoic suggest that South China might still been in a dry zone of even tropical latitudes (5–20°). The Ordovician pole is therefore not considered in present study.

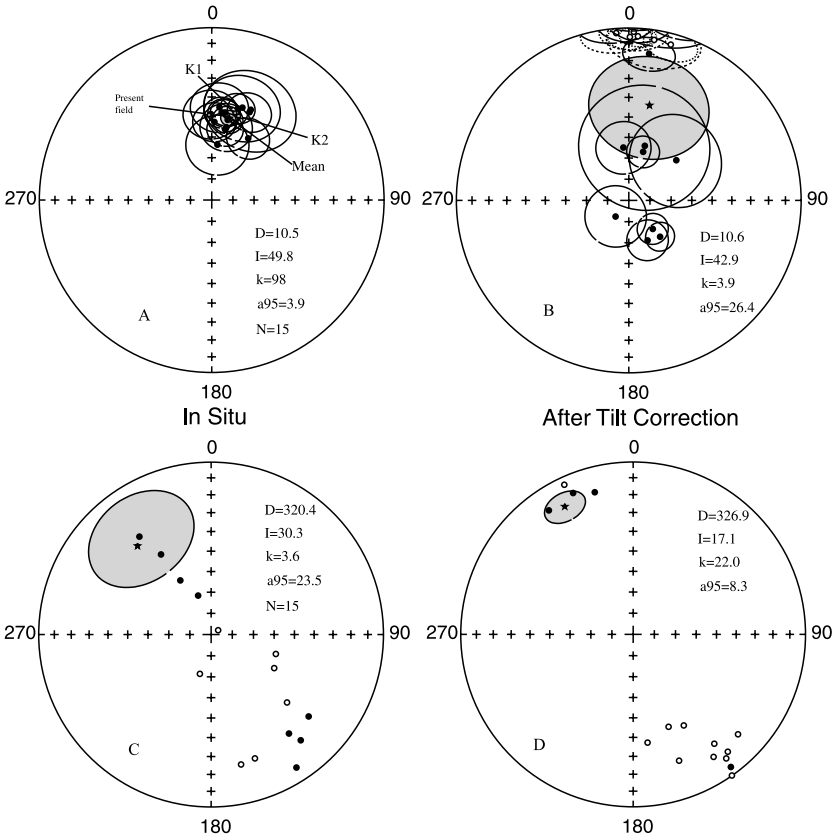


Fig. 6. (A,B) Equal-area stereographic projections of site-mean directions of component B before and after tilt corrections. Present field of sampling area is indicated as a diamond, and deduced Cretaceous magnetization directions are plotted in solid squares. (C,D) Site-mean directions of component C. Lower (upper) hemisphere directions are marked with closed (open) symbols.

Huang et al. [14] and Opdyke et al. [27] reported two middle Silurian poles from the Sichuan and Guizhou provinces of the Yangtze block. A pre-folding nature and widespread sampling area suggest a key pole nature for the Yangtze Block. These three poles, 748 ± 12 Ma of the Liantuo formation, middle Cambrian and Silurian, may form a reliable track for the Yangtze Block, and can be used for comparison with the coeval apparent polar wander path from Australia.

The paleomagnetic data from Australia were recently summarized by McEhlinny et al. [31]. Critical assessment of Paleozoic paleomagnetic results from Australia shows a coherent pattern compared to that of Gondwana. For the convenience of comparison, the Australian APWP in the Northwest Africa coordinate is rotated back to itself coordinate around an Euler pole at 28.1°S, 293.2°E with angle of −52.1° [31]. The extension of the Australian APWP may join to the key poles of 755 ± 3 Ma derived from the Mundine Well dyke swarm (MDS) of the Pilbara Craton, Western Australia [32], and the Elatina and Yaltipena formations (600 Ma) of the central Flinders Range of South Australia [33].

A comparison of paleolatitudes at reference points in both South China and Australia is shown in Fig. 8 according to the poles around 750 Ma and the lower Paleozoic poles of both blocks. Both blocks occupied the equatorial tropical latitudes. Thus, a synchronous change of paleolatitudes implies that a close correlation may have existed between these two blocks, in addition

Table 1
Characteristic directions of the middle Cambrian from the Guangyuan area (106.3°E, 32.4°N), South China

Site	Dip direction		N	Dg	Ig	Ds	Is	k	α_{95}
SWC1	252	49	3	327.0	60.4	333.6	11.9	27.7	28.0
SWC2	261	52	4	324.6	44.4	331.9	−5.0	141.4	9.0
SWC4	255	55	2	338.2	70.6	341.5	15.7		
SWC6–7	232	54	10	192.5	−70.7	156.6	−23.1	7.4	20.6
SWC8	82	57	3	138.4	27.8	140.0	−22.1	57.8	16.4
SWC9	82	57	6	126.6	27.0	130.2	−17.1	11.0	23.3
SWC12–13	84	55	5	316.8	−33.8	322.4	14.1	20.5	19.6
SWC15–16	263	56	6	128.4	−40.6	140.2	5.0	7.3	27.5
SWC17	259	59	6	103.3	−57.8	137.7	−13.6	12.4	20.1
SWC18–19	258	55	9	114.6	−55.9	139.7	−11.0	6.9	21.5
SWC20	265	55	4	55.0	−86.1	169.0	−36.8	49.1	15.4
SWC21	76	27	4	143.9	9.2	143.3	−16.1	23.1	19.5
SWC22	110	21	5	157.1	−24.8	147.5	−39.4	55.1	11.8
SWC23	105	22	6	163.6	−23.7	155.6	−42.1	16.1	18.3
SWC24	105	35	4	136.3	20.7	141.6	−0.1	26.5	24.7
Mean			15	140.4	−30.3	146.9	−17.1	22.0	8.3

Fold test is positive according to McElhinny method [20]: ks/kg = 22/3.6 = 6.08 > F(2*(n2−1), 2*(n1−1)) = 1.88; McFadden method [21]: critic Xi at 95% = 4.51, Xi1 IS = 5.634, Xi1 TS = 5.11.
Reveral test is positive: angle between the mean directions $r = 3.87° < r_{\text{critic}} = 18.4°$, classification C.

to a close biological connection during the early Paleozoic [13].

In a series of reconstructions of South China and Australia during late Proterozoic and early Paleozoic, the paleopoles from these two continents should overlap. To satisfy the available paleomagnetic data, the APW path and block are rotated so that the middle Cambrian and middle Silurian poles for South China are coincident with coeval poles of Australia (Fig. 9). We rotate South China into the Australian co-ordinate using an Euler pole at 16.0°S, 325°E (with an angle of −67.3°). We note, on the other hand, that the Liantuo pole (748 ± 12 Ma) of Evans et al. [8] is not consistent with the MDS pole (755 ± 3 Ma) of Australia, even if they are located in the same small circle swathe centered in the Three Gorge sampling areas of South China. The discrepancy between the Australian MDS pole and that of Liantuo of Yangtze Block may reflect either age differences, or local rotations occurring in either sampling area. As noted by Evans et al. [8], local rotation may have occurred during the gentle folding in between the Three Gorges region and Yunnan province of Southwest China. In addition, Shen et al. [34] studied the lower Triassic Daye limestone at Zigui area in the Three Gorges region (30.1°N, 110.79°E). High temperature components separated from five sampling sites showed that clockwise rotation of 14.3° ± 9° occurred in the regions relative to the Sichuan Basin of the Yangtze Block. A correction of local rotation (20°) of the Sinian Liantuo pole may make an overlap to the MDS pole of Australia (Fig. 9).

In our paleomagnetic fit, the SCB was placed against northwestern Australia. The connection of the SCB with Australia leads to a continuation of the diachronic orogenic belts between the Jiangnan Grenville-age belt and the Rudall belt (or Miles Orogen) in West Australia, suggesting the link between these two blocks might have initiated prior to 1 Ga. Wang and Li [36] also demonstrate that the basin history in South China prior to ca. 600 Ma can be well correlated with that in the Adelaide and Officer rift systems in southeastern and central Australia. The depositional sequences and volcanic successions associated with multistage rift phases in the Jiangnan belt and following platform-facies carbonate deposits, e.g. cap carbonates, suggest that South China could have been adjacent to Australia in the supercontinent Rodinia. However, the proposed position of South China relative to Australia and the time of separation between them must be reconciled.

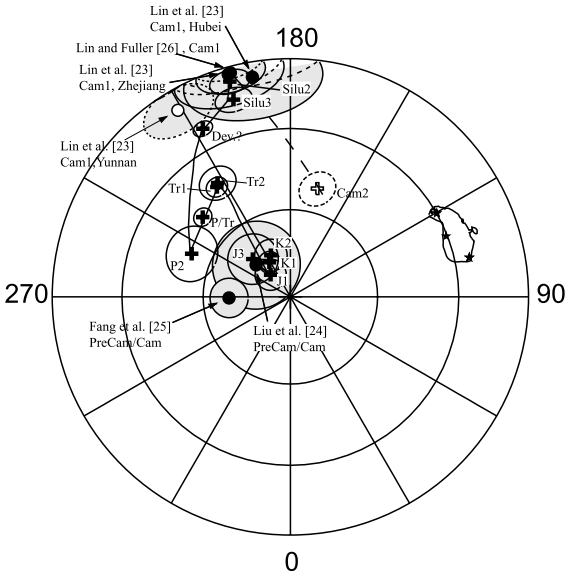


Fig. 7. Stereographic north polar projection of the available early Cambrian and Precambrian/Cambrian boundary poles with circles of 95% confidence and their sampled locations from South China [23–26]. Paleozoic and Mesozoic poles of the SCB are also presented for further comparison [14,19]. North (South) Hemisphere poles are marked with closed (open) symbols. Abbreviations: PreCam/Cam, PreCambrian/Cambrian boundary; Cam1, early Cambrian; Cam2, middle Cambrian; Silu2, middle Silurian; Dev, Devonian; P2, Late Permian; P/T, Permo–Triassic boundary; T1, Early Triassic; T2, Middle Triassic; J1, early Jurassic; J3, late Jurassic; K1, early Cretaceous; K2, late Cretaceous.

Recent geochronological dating of the Doushantuo formation does not support the argument for separation between South China and Australia during the Sturtian/Nantuo glaciation [37]. The Doushantuo formation was dated around 600 Ma using the Hf–Lu and Pb–Pb methods. It overlies conformably the so-called Nantuo glacial formation. Two glacial formations (the Nantuo and Gucheng formations) are identified in the Yangjiaping section of Hunan province in the Yangtze Block. The upper part of the Dieshuihe formation that underlies conformably the lower glacial deposit (Gucheng formation) was dated at 758 ± 23 Ma by the SHRIMP U–Pb method on zircon [38]. Thus, the Nantuo and Gucheng formations may be correlated with the Marinoan and Sturtian glaciations of Australia, respectively.

The coherent Silurian poles between South China and Australia in our reconstruction that the SCB sited against Northwest Australia also imply that two blocks maintained their relative positions during the early Paleozoic period. This configuration is consistent with the faunal distribution and early Paleozoic biogeographic evidence [13], next to the affinity of middle Devonian fresh-water fish found in West Yunnan of South China and the Canning Basin of Australia [39]. The latter suggests that South China probably broke away from Australia after the middle Devonian. Fang et al. [40] presented preliminary Devonian results in 33 samples (7 sites) from the southwestern part of South China, which gives a consistent paleolatitude for the SCB compared with Australia in the reconstruction (Fig. 8). However, as noted by Yang and Besse [41], the sampling areas bounded between the Red River Fault and Xiaojiang Fault have suffered from significant clockwise rotation. We therefore exclude the Devonian pole from eastern Yunnan to be representative of the SCB.

Our reconstruction favors a long-lived connection between the Australian and South China

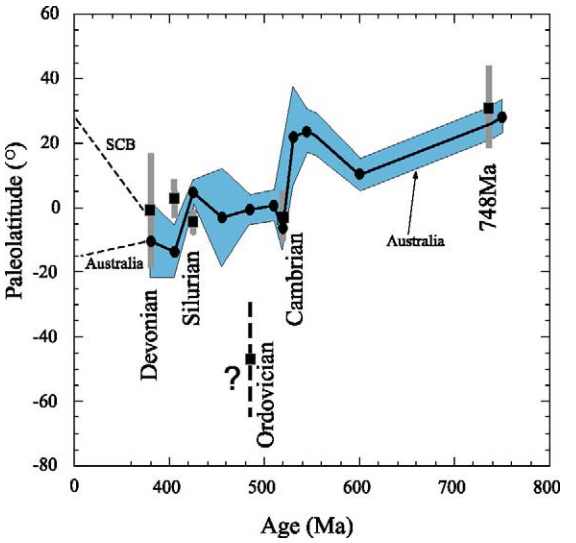


Fig. 8. Plot of paleolatitudes recalculated from 750 Ma and early Paleozoic poles of Australia and South China for the reference points at 23°N, 103°E (South China) and −15°N, 120°E (Australia) vs. time. Vertical bars are latitudinal limits for the reference points.

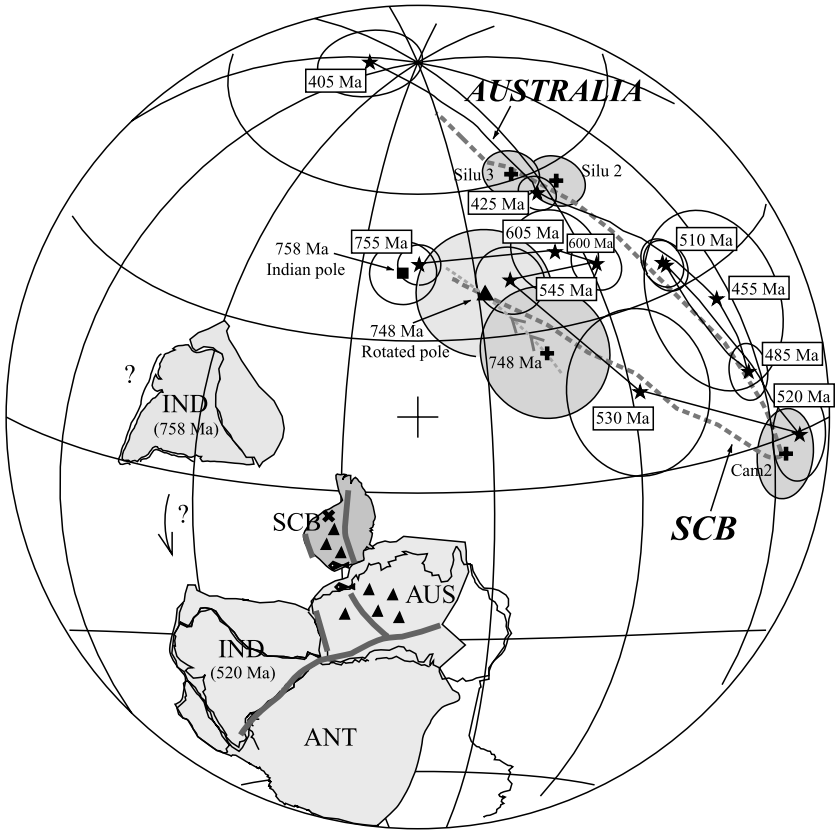


Fig. 9. Paleomagnetically based palaeogeographic reconstruction of South China and Australia/East Gondwana for the late Proterozoic and early Paleozoic in Australian coordinate. This reconstruction is made by rotating the middle Cambrian and middle Silurian poles (crosses with 95% confidence levels) of South China, which coincide with those of Australia/Gondwana, 67.3°CCW around an Euler pole at 325°E and 16°S. Australian APWP (stars) in Australian coordinate is after McElhinny et al. [31], Sohl et al. [33] and Wingate and Giddings [32]. Note that the late Proterozoic (748 Ma) Liantuo pole of South China (triangle) is coherent with the coeval pole of Australia after correcting a local clockwise rotation of 20° in the sampling area (cross symbol in South China). Abbreviations: ANT, Antartica; AUS, Australia; IND, India. This reconstruction shows the Jiangnan orogenic belt between the Yangtze and Cathaysia blocks may be the northern continuation of the Grenville-age Rudall belt in West Australia. Bold lines indicate Grenvill-age orogenic belts. Filled triangles are glacial deposits. India was rotated to Australia in present coordinate about the Euler pole at 12.7°N, 190°E, CW rotation 65° for the fit of East Gondwana, and a possible position at 755 Ma after superposing the MDS pole from Australia and the Malani igneous suite (MIS) pole of India [35]. Abbreviations: Cam2, middle Cambrian; Silu2, middle Silurian; Silu3, late Silurian.

blocks that disregards the occurrence of a breakup event in Rodinia around 750–820 Ma [12]. At the same time, this reconstruction critically avoids the complex large movements of the SCB relative to Australia during the latest Proterozoic and early Paleozoic [7]. The proposed reconstruction and post-middle Devonian breakup between these two blocks, although preliminary, will be tested by additional high-quality lower Paleozoic paleopoles and geological evidence.

4. Conclusions

This study provides a reliable middle Cambrian pole obtained from the northwestern part of the Sichuan Basin in the Yangtze Block. The high-quality pole is insured by both reversal and fold tests, and a location situated in an autochthonous region of the Yangtze Block. Combined with the available high-quality late Proterozoic (748 ± 12 Ma) [8] and Silurian poles [14] reported from

the Yangtze Block, these poles compose of three guide posts for the late Proterozoic and early Paleozoic APWP of South China.

By comparing the APWP from the SCB and that of Australia, we suggest that the SCB was connected with the northwestern margin of the Australian Block during latest Proterozoic and early Paleozoic times, and probably started to break away from Australia in the middle Devonian. The reconstruction proposed is contrary to the 'missing link' model where the SCB was placed between Australia and Laurentia in the late Proterozoic, and drifted away around 750 Ma, followed by large relative movements during the early Paleozoic [4].

Acknowledgements

This study was funded by the Chinese National Natural Science Foundation (49925410) and partly by a grant 40132010. We thank Drs. J. Besse, L.S. Shu and Yue Zhao for sparkling discussions. Paleomagnetic data were analyzed using R. Enkin's and J.P. Cogné's computer program packets. We are grateful to S.A. Pisarevsky and X. Zhao for constructive reviews. This is a contribution to IGCP 491: Middle Paleozoic Vertebrate Biogeography, Paleogeography and Climate.*[VC]*

References

[1] J.F. Chen, K.A. Foland, F.M. Xing, X. Xu, T.X. Zhou, Magmatism along the southeastern margin of the analysis by means of both the SHRIMP and Yangtze block: Precambrian collision of the Yangtze and conventional methods suggest that these granite Cathaysia blocks of China, Geology 19 (1991) 815–818.

[2] L. Shu, J. Charvet, Kinematics and geochronology of the Proterozoic Dongxiang–Shexian ductile shear zone: with HP metamorphism and ophiolitic mélange (Jiangnan Region, South China), Tectonophysics 276 (1996) 291–302.

[3] Z.X. Li, X.H. Li, H. Zhou, P.D. Kinny, Grenvillian continental collision in South China: New SHRIMP U–Pb zircon results and implications for the configuration of Rodinia, Geology 30 (2002) 163–166.

[4] Z.X. Li, L.H. Zhang, C.M.A. Powell, South China in Rodinia: Part of the missing link between Australia–East Antarctica and Laurentia?, Geology 23 (1995) 407–410.

[5] X.X. Zhao, R.S. Coe, S.A. Gilder, G.M. Frost, Palaeomagnetic constraints on the palaeogeography of China: Implications for Gondwanaland, in: Z.X. Li, I. Metcalfe, C.McA. Powell (Eds.), Breakup of Rodinia and Gondwanaland and Assembly of Asia, Aust. J. Earth Sci. 43 (1996) 643–672.

[6] Q. Zhang, J.D.A. Piper, Paleomagnetic study of Neoproterozoic glacial rocks of the Yangzi block: Paleolatitude and configuration of South China in the late Proterozoic Supercontinent, Precamb. Res. 85 (1997) 173–199.

[7] Z.X. Li, C.McA. Powell, An outline of the palaeogeographic evolution of the Australasian region since the beginning of the Neoproterozoic, Earth-Sci. Rev. 53 (2001) 237–277.

[8] D.A.D. Evans, Z.X. Li, J.L. Kirchvink, M.T.D. Wingate, A high-quality mid-Neoproterozoic paleomagnetic pole from South China, with implications for ice ages and the breakup configuration of Rodinia, Precamb. Res. 100 (2000) 313–334.

[9] M.F. Zhou, D.P. Yan, A.K. Kennedy, Y. Li, J. Ding, SHRIMP U–Pb zircon geochronological and geochemical evidence for Neoproterozoic arc-magmatism along the western margin of the Yangtze Block, South China, Earth Planet. Sci. Lett. 196 (2002) 51–67.

[10] X.H. Li, U–Pb zircon ages of granites from the southern margin of the Yangtze block: Timing of the Neoproterozoic Jinning Orogeny in SE China and implications for Rodinia assembly, Precamb. Res. 97 (1999) 43–57.

[11] X.H. Li, Z.X. Li, H. Zhou, Y. Liu, P.D. Kinny, U–Pb zircon geochronology, geochemistry and Nd isotopic study of Neoproterozoic bimodal volcanic rocks in the Kangdian Rift of South China: Implications for the initial rifting of Rodinia, Precamb. Res. 113 (2002) 135–154.

[12] Z.X. Li, X.H. Li, P.D. Kinny, J. Wang, S. Zhang, H. Zhou, Geochronology of Neoproterozoic syn-rift magmatism in the Yangtze Craton, South China and correlations with other continents: Evidence for a mantle superplume that broke up Rodinia, Precamb. Res. 122 (2003) 85–109.

[13] C. Burrett, J. Long, B. Stait, Early–Middle Palaeozoic biogeography of Asian terranes derived from Gondwana, In: W.S. McKerrow, C.R. Scotese (Eds.), Palaeozoic Palaeogeography and Biogeography, Geol. Soc. Lond. Mem. 12 (1990) 163–174.

[14] K. Huang, N. Opdyke, R. Zhu, Further paleomagnetic results from the Silurian of the Yangtze Block and their implications, Earth Planet. Sci. Lett. 175 (2000) 191–202.

[15] Sichuan Bureau of Geology and Mineral Resources (SBGMS), Regional Geology of Sichuan Province, Geological Memoirs 23, Geological Publishing House, Beijing, 1991, 730 pp.

[16] J.L. Kirschvink, The least-squares line and plane and analysis of paleomagnetic data, Geophys. J. R. Astron. Soc. 62 (1980) 699–718.

[17] R.A. Fisher, Dispersion on a sphere, Proc. R. Soc. Lond. A 217 (1953) 295–305.

[18] P.L. McFadden, M.W. McElhinny, The combined analysis of remagnetization circle and direct observation in palaeomagnetism, Earth Planet. Sci. Lett. 87 (1988) 161–172.
[19] Z. Yang, J. Besse, New Mesozoic apparent polar wander path for South China: Tectonic consequences, J. Geophys. Res. B 106 (2001) 8493–8520.
[20] M.W. McElhinny, Statistics of the fold test in paleomagnetism, Geophys. J. R. Astron. Soc. 8 (1964) 338–340.
[21] P.L. McFadden, A new fold test for paleomagnetic studies, Geophys. J. Int. 103 (1990) 163–169.
[22] P.L. McFadden, M.W. McElhinny, Classification of the reversals test in palaeomagnetism, Geophys. J. Int. 103 (1990) 725–729.
[23] J.L. Lin, M. Fuller, W.Y. Zhang, Preliminary Phanerozoic polar wander paths for the North and South China blocks, Nature 313 (1985) 444–449.
[24] C. Liu, Q. Liang, Y. Li, Magnetostratigraphy of the Precambrian–Cambrian boundary section at Meishucun, Jinning, Yunnan, Sci. China 3 (1988) 314–320.
[25] W. Fang, R. VanderVoo, Q. Liang, Reconnaissance magnetostratigraphy of the Precambrian–Cambrian boundary section at Meishucun, southwest China, Cuad. Geol. Iber. 12 (1988/1989) 205–222.
[26] J.L. Lin, M. Fuller, Paleomagnetism, North China and South China collision, and the Tan-lu fault, Philos. Trans. R. Soc. Lond. A331 (1990) 589–598.
[27] N.D. Opdyke, K. Huang, G. Xu, W.Y. Zhang, D.V. Kent, Paleomagnetic results from the Silurian of the Yangtze paraplatform, Tectonophysics 139 (1987) 123–132.
[28] L. Bai, H.N. Wu, R.X. Zhu, Paleomagnetic result of the Early Triassic from the Wangcang area in North Sichuan, Sci. China D 27 (1997) 514–520.
[29] W. Fang, R. VanderVoo, Q. Liang, Ordovician paleomagnetism of eastern Yunnan, China, Geophys. Res. Lett. 17 (1990) 953–956.
[30] S.Y. Nie, Paleoclimate and paleomagnetic constraints on the Paleozoic reconstruction of South, North China and Tarim, Tectonophysics 196 (1991) 279–308.
[31] M.W. McElhinny, C.M. Powel, S.A. Pisarevsky, Paleozoic terranes of eastern Australia and the drift history of Gondwana, Tectonophysics 362 (2003) 41–65.
[32] M.T.D. Wingate, J.W. Giddings, Age and palaeomagnetism of the Mundine Well dyke swarm, Western Australia: Implications for an Australia–Laurentia connection at 755 Ma, Precamb. Res. 100 (2000) 335–357.
[33] L.E. Sohl, N. Christie-Blick, D.V. Kent, Paleomagnetic polarity reversals in Marinoan (ca. 600 Ma) glacial deposits of Australia implications for the duration of low-latitude glaciation in Neoproterozoic time, Geol. Soc. Am. Bull. 111 (1999) 1120–1139.
[34] Z. Shen, D. Fang, P. Wang, X. Tan, Z. Wang, Paleomagnetism of Early Triassic Daye formation and its tectonic implication, Chin. Sci. Bull. 44 (1999) 412–418.
[35] T. Torsvik, L.M. Carter, L.D. Ashwal, S.K. Bhushan, M.K. Pandit, B. Jamtveit, Rodinia refined or obscured: Paleomagnetism of the Malani igneous suite (NW India), Precamb. Res. 108 (2001) 319–333.
[36] J. Wang, Z. Li, History of Neoproterozoic rift basins in South China: Implications for Rodinia break-up, Precamb. Res. 122 (2003) 141–158.
[37] G.H. Barfod, F. Albarede, A.N. Knoll, S.H. Xiao, P. Telouk, R. Frei, J. Baker, New Lu–Hf and Pb–Pb age constraints on the earliest animal fossils, Earth Planet. Sci. Lett. 201 (2002) 203–212.
[38] C.Y. Yin, D. Liu, L. Gao, Z. Wang, Y. Xing, Lower boundary of Nanhua system and the age of Gucheng glacier: SHRIMP II dating evidences, Chin. Sci. Bull. 48 (2003) 1721–1725.
[39] J. Long, C. Burrett, Fish from the upper Devonian of the Shan–Thai terrane indicate proximity to east Gondwana and South China, Geology 17 (1989) 811–813.
[40] W. Fang, R. VanderVoo, Q. Liang, Devonian paleomagnetism of Yunnan province across the Shan Thai–South China suture, Tectonics 8 (1989) 939–952.
[41] Z. Yang, J. Besse, Paleomagnetic study on Permain and Mesozoic sedimentary rocks from North Thailand supports the extrusion model for Indochina, Earth Planet. Sci. Lett. 117 (1993) 525–552.