Earth-Science Reviews 117 (2013) 40–79

Contents lists available at SciVerse ScienceDirect

Earth-Science Reviews

journal homepage: www.elsevier.com/locate/earscirev

The dynamic evolution of the Palaeozoic geography of eastern Asia

L. Robin M. Cocks [a], Trond H. Torsvik [b,c,d,e,*]

[a] Department of Earth Sciences, The Natural History Museum, Cromwell Road, London SW7 5BD, UK
[b] Center for Physics of Geological Processes (PGP), University of Oslo, N-0316 Oslo, Norway
[c] Center for Advanced Study, Norwegian Academy of Science and Letters, N-0271 Oslo, Norway
[d] Geodynamics, Geological Survey of Norway, Leiv Eirikssons vei 39, N-7491Trondheim, Norway
[e] School of Geosciences, University of the Witwatersrand, WITS 2050 Johannesburg, South Africa

ARTICLE INFO

Article history:
Received 24 March 2012
Accepted 14 December 2012
Available online 22 December 2012

Keywords:
Palaeozoic
Palaeogeography
China
Malaysia
Sibumasu
Siberia

ABSTRACT

New palaeogeographical reconstructions are presented for eleven time intervals through the Palaeozoic of the eastern Asia region from the Middle Cambrian at 510 Ma to the end of the Permian at 250 Ma. They centre on the continental blocks of North China, South China, and Annamia (Indochina) and their relationships with northeastern Gondwana (which was united to form part of Pangea from the Late Carboniferous onwards). Also shown is the continent of Tarim during the Lower Palaeozoic, as well as the Hutag Uul–Songliao and Khanka–Jiamasu–Bureya terranes, both of which straddle the Russian, Mongolian and Chinese borders today, from Silurian times onwards. We conclude that Annamia and South China were united as a single continent throughout the Lower Palaeozoic and Early Devonian and were translocated by major strike-slip faulting along the northeastern Gondwana margin during that period from off Afghanistan to outboard of the Sibumasu and Australian sectors of the superterrane. They left the Gondwana marginal area together during the Lower Devonian opening of the Palaeotethys Ocean, but very shortly afterwards they themselves divided into the two separate continental blocks that we recognise today, not to reunite until the Triassic. The various Cambrian to Permian rocks found in Japan largely represent active volcanic arcs which originally lay to the southeast of South China, although the Carboniferous was more quiescent there. The Neotethys Ocean opened during the Permian, dividing Sibumasu and the Tibetan terranes from Gondwana, and the Palaeotethys Ocean started to close progressively in the Upper Palaeozoic as most of the East Asian continents and smaller terranes moved towards Siberia. The positions of the various continents and terranes have been deduced from a mixture of palaeomagnetic and faunal data, the positions of Large Igneous Provinces and kimberlites, and the need to provide kinematic continuity between maps of successive ages. However, many uncertainties remain.

Contents

---

* Corresponding author at: Center for Physics of Geological Processes (PGP), University of Oslo, N-0316 Oslo, Norway.
E-mail address: t.h.torsvik@geo.uio.no (T.H. Torsvik).

0012-8252/$ – see front matter © 2012 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.earscirev.2012.12.001

1. Introduction

Eastern Asia is made up of a complex mosaic, most of which were distinct entities of variable ages in the Palaeozoic. To the north of those shown in Fig. 1, at the western rim of the Pacific Ocean southwards from the Bering Straits, there are the Chukhot and adjacent terranes, which were peri-Laurentian and parts of the Chukhot-Arctic Alaska Continent (Cocks and Torsvik, 2011) and the eastern end of peri-Siberia, including the Verkhoyansk–Kolimian Fold Belt (Cocks and Torsvik, 2007). On Fig. 1, to the south of Siberia and peri-Siberia (coloured orange), there is the eastern sector of the Central Asian Orogenic Belt (Junggar, Tarim, Kunlun, Qaidam–Qilian, Ala Shan, Gurvansayhan, Nuhetdavaa, Hutag Uul–Songliao, Sulinheer, Khanka–Jiamusu Bureya, and the Japanese terranes), as well as North China, South China, and Annamia (Indochina). To the south of them lies the northeastern sector of the Gondwana superterrane (which included Sibumasu and East Malaya until the Permian).

That vast area is made up of a large number of geological units which have often been defined and named differently by different authors. Since the advent of the understanding of plate tectonics, many workers have tried to place those units in relation to each other before the Mesozoic; for example, Zonenshain et al. (1990) and Sengor and Natalin (1996) both published pioneer syntheses of Asian tectonics and palaeogeography. The CAOB stretches across Asia from the Urals to the Sea of Okhotsk in the Russian Far East. The belt was first recognised by Suess (1901), and runs between the stable cratons of Gondwana, Baltica and Siberia. All authors agree that Tarim, North China, South China and Annamia represented substantial Palaeozoic continental areas independent of Gondwana, Baltica and Siberia within the eastern Asia region. However, recognition of Sibumasu, East Malaya and the Tibetan terranes as separate entities has varied between authors, but we consider those units to have been integral parts of the margin of core Gondwana (Torsvik and Cocks, 2009, 2011) until the Permian opening of the Neotethys Ocean. In addition, there were also many other smaller geological entities, most of which appear to have originated as oceanic island arcs at various times stretching from the Neoproterozoic to the Permian.

The purpose of this paper is to review the identities and relative positions of the various major regions now in eastern Asia as they developed during the Palaeozoic. Firstly, the continents and terrane units are briefly characterised, and that is followed by a historical summary of each Palaeozoic period together with new palaeogeographical maps.

In Sections 2 to 4 the many units are reviewed in turn, although a few, such as the Gurvansayhan (Section 3.6) and Nuhetdavaa (Section 4.5) terranes of Mongolia are allocated rather arbitrarily within the sections. The easternmost unit, the Nadanhada–Sikhote–Alin Terrane, which borders the Japan Sea (NSA on Fig. 1), consists entirely of Upper Jurassic and later accretionary rocks with substantial Cretaceous granites and thus is not mentioned further here (apart from the Permian brachiopods which are found in blocks within those Jurassic prisms: Section 13). The terminology used varies widely in the literature, but we here use 'terrane' for the smaller units, 'microcontinent' for amalgamated smaller units, 'continent' for the larger units, 'superterrane' for Gondwana and Laurussia, and 'supercontinent' only for Pangea and Rodinia.

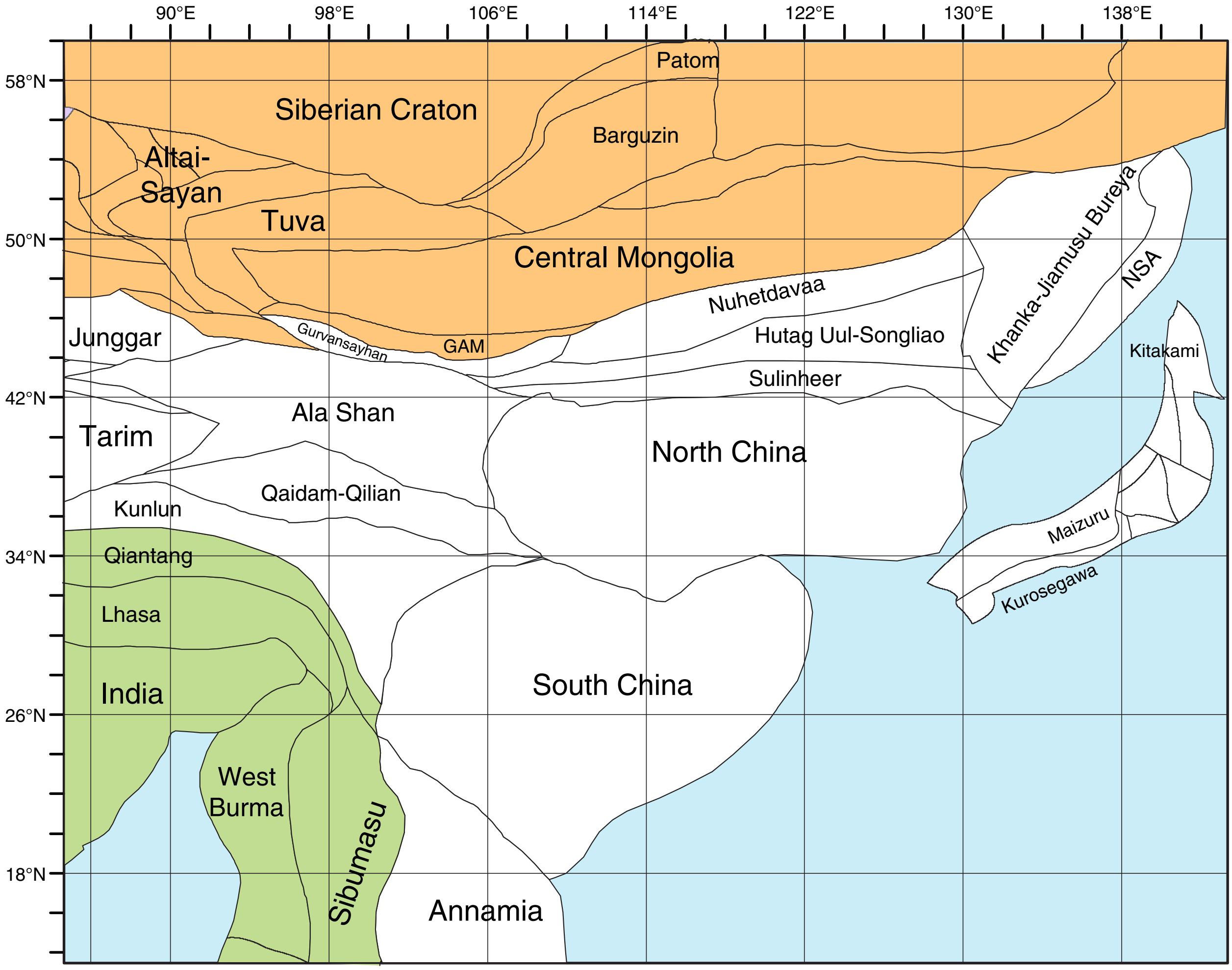

Fig. 1. A modern map of Central and Eastern Asia showing the boundaries of the Palaeozoic terranes. Orange shade, Siberia (including peri-Siberia: for more details of the terranes shown see Cocks and Torsvik, 2007); green, Gondwana (Torsvik and Cocks, 2009); blue is ocean. GAM, Gobi Altai and Mandalovoo terranes in Mongolia; NSA, Nadanhada–Sikhote–Alin Terrane. The small triangular areas between Junggar and Tarim are the eastern ends of the Atasu–Zhamshi and South Tien Shan terranes.

2. East Asian units

2.1. Annamia

The continent of Annamia (otherwise termed Indosinia) occupied most of today's Indochina Peninsula, as well as parts of adjacent China and Thailand. The Kontum Craton of Vietnam is a Palaeoproterozoic basement, with some parts dated at 2.3 Ga (Hutchison, 1996), which underwent an Early Cambrian thermal event at about 530 Ma (Sengor and Natalin, 1996). Within that craton are many varied Palaeozoic rocks, including a Late Ordovician granodiorite and Silurian to Early Devonian (428–407 Ma) charnockite, granite and gneiss (Carter et al., 2001; de Jong et al., 2006), and there is a substantial unconformity seen over much of the craton consisting of overlying continental red beds which are all intruded by Late Triassic to Cretaceous granites (Lepvrier et al., 2004). Previously, Annamia's margins were poorly constrained; however, its boundaries are now much better known since the works of Sone and Metcalfe (summarised in, 2008) and Cai and Zhang (2009). The various papers within Ridd et al. (2011) have greatly illuminated the Thai sector of the terrane, which centres on the Loei area of northeast Thailand. Sone and Metcalfe (2008) described Carboniferous and Permian deposits in the region of oceanic origin, including carbonates originally deposited on sea mounts which later accreted to Annamia's margins; and they identified within peri-Annamia the Simao Subterrane and the Chanthaburi, Lincang and Sukhotai terranes (the latter three were Permian volcanic island arcs which accreted to Annamia during the Middle Permian): all are shown combined as the Sukhotai island arc on our reconstructions. Sone and Metcalfe (2008) also described the Sra Kaeo Suture Zone at Annamia's southwestern margin, within which are the remains of a Permian back-arc basin, and in addition recognised the Inthanon Suture Zone (where the Palaeotethys Ocean closed in the Middle to Late Triassic and Annamia and Sibumasu merged) as situated at the western margin of their Sukothai Terrane within Thailand. That work superseded Metcalfe (2006), who had then regarded Simao as a separate terrane derived from South China by back-arc spreading in the Early Carboniferous, and which did not accrete to Annamia until the Middle Triassic along the Nan–Uttardit Suture. Metcalfe also regarded the Annamia–South China accretion along the Song Ma Suture as of Late Carboniferous to Early Devonian age, rather than Triassic. Cai and Zhang (2009) concluded that the Simao area of Laos and southern China was connected to South China rather than Annamia; however, we follow the contrasting view of Sone and Metcalfe (2008), who placed it as a subterrane of Annamia.

Relatively few Palaeozoic faunas from the former French Indochina have been described in recent years, and most of those described during that colonial period are in sore need of revision. However, Late Silurian brachiopods and other shelly faunas are known from the Vietnamese sector (Rong et al., 1995; Tong-Dzuy et al., 2001), and in the latter paper there is also a brief overview of central and northern Vietnam. In places the latest Silurian *Retziella* Fauna of Rong et al. (1995) is overlain unconformably by rocks of Late Devonian (Famennian) age, and elsewhere non-marine Early Devonian strata lie unconformably on Ordovician beds, and the overall affinities of the Silurian and Devonian faunas lie with South China. However, fortunately Annamia also includes parts of political southeastern China, the Northern Qiangtang-Simao region of Zhou et al. (2007). Thus Zhou et al.'s (1998a, 2001b) description of Early Ordovician trilobites, including the provincially distinctive *Neseuretus*, and Fang and Cope's (2004) work on bivalves from the same locality in Yunnan Province, part of Palaeozoic Annamia, are useful modern studies, and both faunas indicate that Annamia was then near Gondwana. The Thai sector of Annamia, was comprehensively reviewed in the various papers within Ridd et al. (2011) as follows. Lower Palaeozoic rocks are largely absent, apart from some Mid to Late Silurian shelly faunas in the Loei area which are not terrane diagnostic. Those are followed by Devonian corals and other shelly fossils of South Chinese affinity which developed on platform carbonates, but deeper-shelf sediments are nearby, and contemporary rocks in Laos probably represent an accretionary complex. Following Late Devonian rhyolites (374 Ma) and basalts (361 Ma), volcanism continued on into the Early Carboniferous, and there is a widespread unconformity below Upper Carboniferous rocks which are of terrestrial origin, including coals and associated Cathaysian Province floras. There are Middle Carboniferous (320 Ma) granites. Throughout the Late Carboniferous and Permian, the substantial Khao and Pha Nok Khao shallow-water carbonate platforms near Loei were separated by the Nam Duk Basin, which is filled by deeper-water sediments, including turbidites. Metcalfe and Sone (2008) reported a biogeographically significant conodont fauna, including *Sweetognathus* and *Pseudosweetognathus* from Lower Permian (Kungurian, about 275 Ma) rocks within the Annamian sector of Thailand. The Late Permian floras, for example those described by Asama et al. (1968), again place Annamia within the Cathaysian Province, and they are plotted on Fig. 24. The positions of Annamia at successive times are further discussed in Section 15.

2.2. South China

The boundaries of the old and substantial South China continent within modern China and northeastern Vietnam are largely agreed, and it contains many well-studied rocks of Palaeozoic age, many of which have yielded provincially diagnostic fossils. It appears to have been unified as a continental craton during the Proterozoic at about 1 Ga. Zhang (in Zhang et al., 2003) showed it divided into three sedimentary provinces during the Cambrian, from northwest to southeast the Yangtze Platform, the Jiangnan Belt and the Southeast China Fold Belt, subdivisions also recognised in the biostratigraphy of the Ordovician by Xu et al. (in Zhang et al., 2003) and Zhou et al. (2007). Cambrian rocks extend over much of the Precambrian South China Craton and are largely shallow-water, including Late Cambrian gypsum and doleritic deposits in places. Chen et al. (2010) provided continuous facies maps at successive Ordovician time intervals for South China, and Rong et al. (2003) for the Silurian, both of which we have used here. In general the deposition of deeper-water turbidites was situated in the southeastern section of the area throughout the Palaeozoic. Although we assume South China to have been a single continental crustal unit throughout the Phanerozoic, the Cathaysia sector, which includes Hainan Island, is today displaced southward along the southwest northeast trending Hepu–Hetai strike-slip fault of Mesozoic age (Cai and Zhang, 2009). It was offshore of that same Cathaysian southeastern margin that the island arcs and accretionary prisms now located in Japan were originally deposited, following the change from a passive to an active margin there during Cambrian times at about 520 Ma (Isozaki et al., 2010).

Above an Archaean (2.8 Ga) and Proterozoic basement, there are Early Cambrian volcanics, whose bentonites have been dated at 539 and 526 Ma (Compston et al., 2008). Rong et al. (2003) and Zhou et al. (2007) used 'Cathaysia' as a term for the land mass which existed for much of the Lower Palaeozoic there, in spite of the same name also being used for the Late Palaeozoic floral province in South China and surrounding areas. South China includes the international Cambrian stratotype localities for the Guzhangian Stage, and the Furongian Series and concomitant Pabian Stage, both in Hunan Province; and the Ordovician stratotypes for the Dapingian (Hubei Province), Darriwilian (Zhejiang Province), and Hirnantian (Hubei Province) stages, all summarised in Cocks et al. (2010). The South China continent was intruded by the substantial Emeishan Large Igneous Province outpourings in the Late Permian, from which Torsvik et al. (2008) obtained an objective position for the palaeolongitude.

There are a great many monographs and other papers on the Palaeozoic floras and faunas of the continent: some of those which are relevant to deciphering the palaeogeography in the Ordovician and Silurian were reviewed by Fortey and Cocks (2003), although there are many fewer from Vietnam than from modern China. The provincial signals are mixed. A large number of abundant Early Ordovician trilobites, such as the distinctive asaphids *Birmanites* and *Tangyaia*, were endemic to South China. However, there are many others which are also found in nearby Gondwana, although not beyond, such as the dikelocephalinids *Asaphopsis* and *Hungioides*. In a series of papers (e.g., 2004), Turvey and Zhou have documented shallow to deeper-water trilobite distribution patterns which reflect the Early Ordovician (Floian to Darriwilian) transgression across South China, including the *Neseuretus* Association in the shallower shelf and the Nileid–Asaphid, Trinucleid, and *Taihungshania* associations outboard of it, and the *Pseudopetigurus* Association under even deeper water. Fortey (1997), when describing the Middle Ordovician (Sandbian) Pagoda Limestone fauna from China, discovered that it was essentially identical, even at the species level, to a fauna of the same age in southern Thailand, which was a part of Sibumasu and at that time also part of core Gondwana; although, since those trilobites inhabited the deeper part of the shelf, high endemism would not be expected. Comparably Xu and Liu (1984) described a rich Early Ordovician brachiopod fauna of 55 genera with many endemic, including *Metorthis*, the only representative of its family. Another diverse brachiopod fauna representing several communities deposited on the shallow to the mid-shelf, from the Late Ordovician of Jiangxi and Zhejiang provinces, showed that, although a quarter of the genera were apparently endemic, there were also many in common between South China and the Chu–Ili Terrane of Kazakhstan (Zhan and Cocks, 1998).

To the north of South China lies the Qinling orogenic belt, which is considered further below under North China. The boundary between South China and Annamia is formed by the Ailaoshan and Song Ma Suture zones, as shown by Metcalfe (2006). Although Metcalfe thought that the accretion had occurred in the Latest Devonian or Earliest Carboniferous, Cai and Zhang (2009) have demonstrated conclusively that today's southwestern margin of South China was passive from the Devonian to the Early Triassic, and they agreed with other authors that accretion with Annamia was at a much later date, during the Middle to Late Triassic, which we follow here. In addition, Findlay (1998) demonstrated that the Song Ma Suture itself is post-Cretaceous, and there is contained within it the remnants of a Cambrian to Ordovician island arc which accreted to the South China continent in an active margin setting before the Devonian. However, since the original positions of that arc are unknown, it is not depicted separately here.

The questions of where South China lay in the Palaeozoic and the relationships to it of Annamia and North China are discussed in Section 15 below.

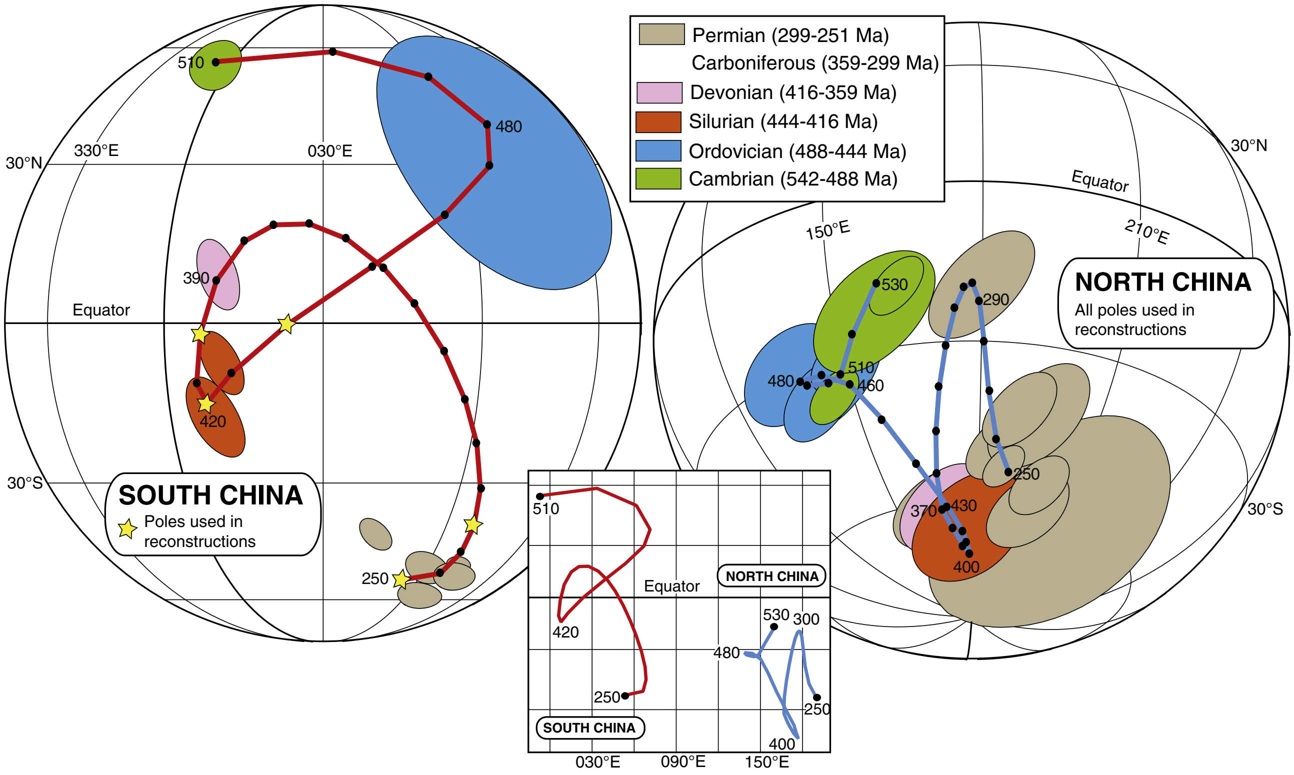

Fig. 2. Apparent Polar Wander (APW) paths for North and South China (orthogonal projection). Input poles are shown as 95% confidence ovals and coloured according to geological age (note that there are no Carboniferous poles). South China input poles include Cambrian and Ordovician poles reported in Yang et al. (2004) and Fang and Van der Voo (1990). Silurian and Devonian poles from Opdyke et al. (1987), Huang et al. (2000) and Fang et al. (1989). There are numerous Late Palaeozoic–Early Mesozoic poles, e.g. Huang and Opdyke (1998). North China input poles include Cambrian and Ordovician poles from Zhao et al. (1992) and Huang et al. (1999). Silurian and Devonian poles are those reported in Huang et al. (2000). Early Permian pole from Embleton et al. (1996). Also numerous Late Palaeozoic–Early Mesozoic poles from North China, e.g. Huang et al. (2005). The APW paths (Table 1) are spherical spline paths with moderate smoothing (smoothing factor = 300; see Torsvik et al., 1996 for procedure). Detrital sedimentary input poles are corrected for potential inclination error (flattening factor *f* of 0.6). Inset diagram compares South and North China APW paths.

2.3. North China

North China is often termed Sinokorea, since the continent includes most of the Korean Peninsula as well as much of northern and eastern China. Zhou et al. (2007) divided North China into four areas, Yellow River, Ordos, Dunhuang–Alexa and Qaidam–Qilian. Ordos forms the western margin of the Lower Palaeozoic Yellow River Platform, and we group those Archaean cratons as a united North China continent here. Ordos is bordered to its west by the Helanshan and Liupansan Faults which separate it from the Dunhuang–Alex (or Alax) block of Ala Shan to the northwest and the Qaidam–Qilian block to the southwest (Zhou et al., 2007). Qaidam–Qilian is regarded here as a separate tectonic unit (Section 3.3), although it joined North China during the Devonian. Dunhuang–Alexa (or the Alax or Alxa Block of some authors) has relatively few Lower Palaeozoic rocks, and there is controversy about whether or not it was part of the Ala Shan composite terrane on the one hand, as stated by Xiao et al. (2009a) and Zhang et al. (2011b) who we follow here (Section 3.5); or whether it was an integral sector of the North China continent during the Palaeozoic, as shown by e.g., Metcalfe (2006), and also suggested by Wilhem et al. (2012). The geology of North China and its adjacent terranes has been well summarised in the book edited by Zhou and Dean (1996). There is a substantial Archaean basement. Following the deposition of widespread Cambrian shallower-water deposits, including evaporites in the centre of the craton, substantial Ordovician rocks were also laid down. Zhou et al. (1989) have mapped the elongate facies belts present in North China from the Arenig to the Ashgill, and the Ordovician seas were generally deeper in the west than on the main Yellow River and Korean platform in the east. The continent must have originally extended further eastwards for a substantial distance during the Palaeozoic by comparison with the present day, as may be deduced from the truncation of the Ordovician facies belts by the Mesozoic Tancheng–Lusan Fault system (Chen et al., in Zhang et al., 2003), and that eastward extension is shown diagramatically on our reconstructions. The shelf seas over the great majority of the North China area were extensive and shallow, since there are substantial Early Ordovician (Floian to Darriwilian) evaporites in the centre of the craton, as well as several land areas in the north of the continent (Chen et al., in Zhang et al., 2003).

There is also a substantial unconformity between the Upper Ordovician and the Middle to Upper Carboniferous across nearly the whole continent, with 315 Ma (Carboniferous: Bashkirian) bauxites at the base of the unconformity in Shanxi Province (Wang et al., 2010). Those missing rocks make the Silurian to Middle Carboniferous history of the area enigmatic, and since there are no palaeomagnetic data: we simply show the main bulk of North China as land throughout that time, apart from in the marginal Sulinheer and Qaidam–Qilian areas and the Laoling Arc part of the Wundurmiao Collage.

Not all authors have reached the same conclusions on the affinities of the various terrane biotas. For example, Jeong and Lee (2000) reviewed the Late Cambrian conodonts at the species level in the Korean sector of North China. They concluded firstly that Korea formed an integral part of North China; and secondly that there were great similarities between the conodont faunas between the whole of the North China continent and South China during the Cambrian but they demonstrated that the succeeding Ordovician faunas of the two terranes were strikingly different and represented two separate faunal provinces. In contrast, although Choi et al. (2003) also found that the trilobites within the Upper Cambrian rocks in both North and South China were very similar to each

Table 1
Apparent polar wander paths for South and North China. Spherical spline paths with moderate smoothing factor (300), and all clastic sedimentary rocks have been corrected for inclination shallowing using a flattening factor of 0.6 as recommended by Torsvik et al. (2012). See text and Fig. 2 caption for additional information.

Age (Ma)	South China		North China	
	Pole latitude	Pole longitude	Pole latitude	Pole longitude
250	−53.5	54.7	−54.0	189.4
260	−51.6	66.3	−47.9	184.6
270	−45.8	68.5	−39.1	181.9
280	−39.4	67.8	−30.0	180.5
290	−31.2	65.3	−22.9	179.5
300	−22.1	61.4	−19.5	178.1
310	−13.8	57.3	−20.3	176.5
320	−4.8	52.3	−24.1	174.7
330	3.6	46.7	−30.7	172.5
340	10.0	41.2	−38.1	170.5
350	15.5	34.3	−46.3	168.6
360	18.3	27.4	−54.3	167.1
370	18.1	20.6	−61.8	166.8
380	15.0	15.2	−65.9	169.7
390	7.7	10.2	−69.9	173.7
400	−1.8	7.3	−72.0	177.1
410	−10.8	6.1	−69.4	175.3
420	−14.4	7.9	−66.7	173.9
430	−9.0	13.0	−60.9	168.8
440	−0.2	23.5	−51.9	161.6
450	10.5	39.1	−42.6	155.5
460	19.9	53.8	−35.2	150.1
470	29.7	67.0	−32.1	144.2
480	38.6	71.4	−31.7	138.6
490	50.7	61.6	−33.0	140.0
500	58.7	33.5	−33.9	145.3
510	55.3	353.8	−33.0	148.6
520			−26.5	153.2
530			−18.1	159.5

other, they demonstrated that those similarities also continued into the Lower Ordovician, which is the opposite conclusion from that drawn from the conodonts found by Jeong and Lee (2000) in the same rocks.

The eastern (Korean) part of the North China palaeocontinent is termed the Nangnim (or Nangrim)-Pyeonngam (or Kyanggi) Massif, and in the Pyeonngam Basin of North Korea there is an Archaean to Neoproterozoic basement overlain by shallow marine sediments of Late Early Cambrian to Middle Ordovician age, the Joseon (or Chosen) Supergroup (Jeong and Lee, 2000). Choi et al. (2003) described the Cambrian and Ordovician trilobites there and their correlation with other parts of China and Australia. The Upper Cambrian and Ordovician Joseon Supergroup in the Taebaek area of east central Korea is unconformably overlain by the Late Carboniferous (Moscovian) to Permian Pyeongan Supergroup (Otoh et al., 1999). The latter consists largely of shallow-water marine carbonates with corals and brachiopods, with coal-bearing rocks being deposited adjacent to the land to its north (Lee et al., 2010). Further south there is the Yeongnam Massif and adjacent Ogcheon (or Okcheon) Belt and Gyeongsang Basin of South Korea which have yielded Lower Ordovician trilobites and conodonts of North China affinity (Kim and Choi, 2000). To the south of the Pyeonngam Basin lies the Gyeonggi Massif. Although many authors, reviewed by Metcalfe (2006), have thought that the Gyeonggi Massif should be included within South China, there appears to be no direct Palaeozoic evidence to support that affiliation, since that massif consists only of Precambrian basement unconformably overlain by Triassic and later rocks (Otoh et al., 1999). Thus the massif is parsimoniously retained within North China here.

There was a continental margin arc on the north margin of the North China Craton which was probably active from the Early Devonian (400 Ma) to the Middle Permian (275 Ma). By the end of the Carboniferous, Andean-type granites were being intruded, lavas ranging from basalt to rhyolite extruded, and tuffs deposited, and all that continued up to the end of the Permian, as reviewed by Cope et al. (2005).

The Solonker (or Suolon or Solon-Linxi or Junggar-Helen) Suture forms the northern boundary of the old North China continent, and was formed when the Hutag Uul–Songliao Terrane was accreted to North China, marking the final closure of the Palaeo-Asian Ocean there (Cope et al., 2005). Published opinions differ on the age of that suture; Windley et al. (2007) dated it as Middle or Late Carboniferous, whilst de Jong et al. (2006) and Cope et al. (2005) thought it was of end-Permian age. However, Shen Shuzhong (personal communication, 2012) considers that the closure was oblique, starting at the western end in the Late Carboniferous and not complete in the east until the Middle Permian, and thus we show the opposite sides as having joined each other between our 310 and 280 Ma maps. The lateral extent of the Solonker Suture also varies between publications; for example, de Jong et al. (2006, Fig. 1) show it as extending from southwest Kazakhstan to the Sea of Japan, whilst most authors, for example Sengor and Natalin (1996), do not show it further west than China. Xiao et al. (2010b) considered that the Beishan Collage consisted of three Early to Middle Palaeozoic island arcs which merged during the Late Carboniferous to Permian as a western extension of the Solonker Suture zone: a collage that eventually extended westwards as far as Tarim. However, North China did not accrete to South China along the Qinling–Dabie Suture until Latest Triassic or Jurassic times (Metcalfe, 2006; Liu et al., 2009; Dong et al., 2011).

In Inner Mongolia, China, Jian et al. (2008, 2010) recognised 'paired orogens' on the opposite sides of the Solonker Suture Zone. The southern part of the orogen extends westwards into Mongolia, where Badarch et al. (2002) termed it the Sulinheer Terrane, which we use as the name for the whole complex, which we figure as an integral sector of North China from the Silurian onwards. The principal rocks there are metamorphosed Silurian to Devonian metamorphics, including ophiolites, which are intruded by gabbro and granodiorites, which are all overlain by Carboniferous and Permian clastics and limestones whose Permian invertebrate faunas were described by Pavlova et al. (1991). Further Permian and Triassic (271–208 Ma) metamorphism also occurred there. The Ordovician–Silurian Ondor Sum subduction–accretion complex, within which was also included the Ulan Arc and the 490–470 Ma Tulinkai Ophiolite, and which lies adjacent to the Bainaimiao Arc, was described by de Jong et al. (2006) as an eastwards extension of the Sulinheer Terrane within China. Parfenov et al. (2009) also recognised the Bainaimiao Arc (which they termed the Wundurmiao Collage), which consists of a subduction zone terrane of Mesoproterozoic to Middle Ordovician age, and also the Laoling Island Arc Terrane of Late Ordovician to Silurian age. The Bainaimiao Arc is largely Ordovician, and includes a 466 Ma Late Ordovician granodiorite and a granite of Early Silurian (430 Ma) age, above which are shallow-water marine deposits with Upper Silurian corals. Jian et al. (2008, 2010) and Wilhem et al. (2012) concluded that the whole area was a typical arc–trench complex, consisting of Ordovician (497–444 Ma) ophiolites and other volcanics, followed by Latest Ordovician and Early Silurian (448–438 Ma) plutonism and subsequent Latest Silurian (419–415 Ma) collision with the passive northern margin of the North China continent. The area includes the M1 to M3 units of the Manchurides as defined by Sengor and Natalin (1996) and forms an integral part of North China in our Late Silurian (420 Ma) and subsequent maps.

Between North and South China lies the Qinling (or Qin Lin or Qinling–Dabei–Sulu) orogenic belt, which, although wide, is not large enough to show as a separate unit on our reconstructions. However, the rocks within the belt are varied and include the substantial Songshugou ultramafic massif, which has been dated to 510 Ma (Middle Cambrian) by Liu et al. (2009). In their reviews, de Jong et al. (2006) and Dong et al. (2011) described arcs there which were volcanically active in the Cambrian and Ordovician, and which accreted to the margin of North China before the intrusion of latest Silurian to Early Devonian (422–283 Ma) post collisional granites. Hacker et al. (2004) and Xiang et al. (2012) have documented the detailed history of the suture zone, describing how the Erlangping Arc (termed North Qinling by Xiang et al., 2012) was emplaced on to a Qinling microcontinent (termed South Qinling by Xiang et al., 2012) in the Late Ordovician before both units were subducted under the North China plate. The North Qinling area was subsequently intruded by an Andean-style batholith from 440 Ma. After that, the southwestern margin of North China remained largely passive for the rest of the Palaeozoic, although metamorphism continued in the zone between North and South Qinling until the Early Devonian at about 400 Ma. Middle Carboniferous sediments were deposited along that North China margin, and Hacker et al. (2004) described a Late Devonian to Carboniferous accretionary wedge there, indicating some subduction activity nearby.

2.4. Japanese terranes

Although Japan is a much smaller country than many in Asia, it has several terranes with Palaeozoic rocks. Undoubted Lower Palaeozoic rocks occur only in the Kitakami (or South Kitakami), Hida and Maizuru terranes, all on Honshu Island, central Japan, and also in the Kurosegawa Terrane on Kyushu Island in southwest Japan, but other terranes include Upper Palaeozoic rocks. Ehiro and Kanisawa (1999) reviewed many publications about Kitakami, and concluded that there is a metamorphosed Cambrian to Middle Ordovician basement which probably represents an accretionary prism and a volcanic island arc including ophiolites and trondjhemites dated at 466 Ma overlain by Late Ordovician sediments (Isozaki, 2011). These were intruded by Late Ordovician (457–440 Ma) granites and unconformably overlain by Middle Silurian and later rocks with corals of Australian and South China affinity, although the associated brachiopods include no terrane-diagnostic forms. There are Lower Devonian calc-alkaline volcanics and Late Devonian (Famennian) brachiopods and plants, unconformably overlain by Lower Carboniferous rocks including Tournaisian shales with ammonoids and Visean limestones with brachiopods. After the Ordovician to Devonian arc activity, the Carboniferous was relatively quiescent until fresh arc activity resumed in the Permian (Tazawa, 2005). The Permian plants are of the Cathaysian Floral Province, and the Middle Permian brachiopods are similar to North China. Deposition extended upwards to the end of the Permian, the Changhsingian, where the deeper-water strata have yielded diagnostic ammonoids, including *Cyclolobus*, as well as a few brachiopods, foraminiferans and conodonts (Tazawa, 2001; Shi, 2006). The Hida (or Hida Gaien) Terrane contains Cambrian ophiolites (de Jong et al., 2006), Early to Middle Ordovician sedimentary rocks, some dated at 472 Ma (Isozaki, 2011), and Carboniferous bryozoans and foraminifera, and its rich Permian brachiopod and fusulinid faunas are similar to the Kitakami Terrane as well as those of Khanka–Jiamusu–Bureya (Shi, 2006). The Maizuru Terrane is largely an Upper Palaeozoic arc system, but includes within it shales which have yielded Middle Ordovician conodonts and Late Silurian trilobites and radiolarians (Tsukada and Koike, 1997), but those do not show diagnostic biogeographical affinities.

Japanese terranes with Upper Palaeozoic rocks, briefly reviewed by de Jong et al. (2006), are the Kurosegawa Terrane and parts of the Paleo-Ryoke Terrane, although the last is small and heavily metamorphosed. The Kurosegawa Terrane of southwest Japan, reviewed by Metcalfe (2006) and Shi (2006), has been severely modified by subsequent accretionary tectonics, but it consists of Lower Palaeozoic metamorphic rocks above which lie Silurian to Devonian volcanoclastic sediments including carbonate blocks containing Devonian faunas. There are also Permian blocks with volcanics and shallow-marine invertebrate faunas, all of which probably represent a Permian island arc.

Tazawa (2001) reviewed the Middle Permian brachiopod faunas of nine Japanese terranes, and concluded that, since the Maizuru Terrane of central Japan contains only Boreal Province elements such as the productides *Anemonaria*, *Yakovlevia* and *Kochiproductus*, that terrane had been substantially displaced southwards during Early Cretaceous tectonic activity. In contrast, the other Japanese terranes (including South Kitakami, Akiyoshi and Mino) have yielded either Tethyan Province or a mixture of Boreal and Tethyan faunas of Permian age. Shi (2006) concluded that the Permian rocks of the Akiyoshi Terrane (of which he considered the Maizuru Terrane a part) were probably originally formed from an amalgamation of ancient oceanic sea mounts. Because the tectonics affecting Japan have been so great since the Palaeozoic, it is not possible to define the Japanese terranes individually on our palaeogeographical reconstructions; however, Shi (2006, Fig. 5) placed the Akiyoshi and Maizuru terranes offboard from South China, and the others further to the north, off North China, in the Middle Permian. In contrast, we accept the conclusions published by various authors, originally by Otoh et al. (1999) and reviewed by Isozaki et al. (2010), that the Palaeozoic rocks found today in Japan were deposited as accretionary prisms and island arcs off the Cathaysian margin of South China, and so we show them diagrammatically there in an active arc setting. Although there might have been more than one arc, we depict them here as a single arc (with associated islands) which was active throughout the Palaeozoic, apart from much of the Carboniferous, when the arc appears to have been quiescent.

2.5. Hutag Uul–Songliao Terrane

The substantial triangular area straddling the northeastern Chinese, southeastern Russian and Mongolian borders has no agreed composite geographical name but it is made up of several tectonic units, which we recognise as the Hutag Uul–Songliao Terrane, and the Khanka–Jiamusu–Bureya microcontinent. Unfortunately the area is much tectonised in places, and most of the Palaeozoic and earlier rocks are obscured by Mesozoic volcanics and Mesozoic to Cenozoic sediments (Zonenshain et al., 1990; Wilde et al., 2010). The north of this region is bounded by peri-Siberia (Cocks and Torsvik, 2007), represented there by the Xiguitu–Tayuan Suture Zone. To the south of the units is the northern boundary of the North China Continent, the Solonker Suture Zone.

The Songliao (or Songhuajiang) Terrane is separated from the Greater Hinggan Massif to its north by the Hegenshan–Heihe Fault Zone, the northeastern extension of the Main Mongolian lineament of Badarch et al. (2002). In China, Wu et al. (2011) divided the area between a large triangular Songliao Terrane and a smaller Liaoyuan Terrane: the latter is subparallel to North China and incorporates the orogenic belt to the north of the Solanker Suture, but we have combined the two on our diagrams. Today's Songliao Massif has a large Mesozoic and later sedimentary basin with no Palaeozoic outcrops, but drill cores there have revealed weakly metamorphosed Palaeozoic sediments and granites, some including Palaeoproterozoic zircons. Chen et al. (2010) termed this Precambrian core the Songuajiang Oldland. Wu et al. (2011) identified and dated 282 granites from the combined terrane, of which the great majority are of Permian or later ages; however, there are also three Cambrian (508–492 Ma), three Ordovician (477 to 447 Ma) and seven Carboniferous (361–314 Ma) intrusions there. In the Da Hinggan Ling area there was an Early Devonian (Pragian) marine transgression which reached its widest extent during the Emsian; however, there was a subsequent regression, so that the area was land again by the end of the Devonian (Su, 1988).

In Inner Mongolia, China, the southern margin of the Hutag Uul–Songliao Terrane is bounded by the northern orogen of the Solonker Suture Zone (Jian et al., 2008, 2010), and consists of the Baohdao arc–accretion complex, which includes Late Cambrian to Ordovician (498–461 Ma) near-trench plutons and juvenile arc crust followed by Early Silurian (440–434 Ma) ridge subduction and subsequent microcontinent accretion. Jian et al. (2010) recognised the Baohdao unit as an eastern extension of the Hutag Uul Terrane as defined by Badarch et al. (2002; their Unit 42) in Mongolia. The latter terrane consists of Precambrian basement unconformably overlain by volcanics and carbonates of Devonian age which are in turn overlain by Upper Carboniferous volcanics. Thus we show Hutag Uul and Songliao combined as a single terrane from our Late Silurian (420 Ma) map onwards.

In Mongolia, Badarch et al. (2002) also defined the Enshoo Terrane (their Unit 41) which consists of metamorphosed Late Silurian and Devonian rocks which are overlain by a Late Devonian volcanic island arc and shelf limestones and by Upper Carboniferous to Permian carbonates, some of which have yielded colder-water foraminifera, including *Monodiexodina*. They are all intruded by Late Carboniferous granites and Permian andesites. Badarch et al. (2002) identified Enshoo as a western extension of the Hegenshan Zone of Inner Mongolia, China, although Wilhem et al. (2012) linked it with the adjacent Nuhetdavaa Terrane (Section 4.5). The Hegenshan Zone is an eastward-extending ophiolitic-arc-accretionary complex which appears to be of comparable ages to Enshoo, and we include them both within the Hutag Uul–Songliao Terrane.

2.6. Khanka–Jiamusu–Bureya microcontinent

To the east of the Songliao Terrane, and separated from it by the Mudanjiang Fault Zone, are the Bureya and Khanka areas. Between those two lies the Jiamusu [or Jiamusi] Massif, which Ren et al. (1999) grouped with Bureya. Zonenshain et al. (1990, p. 112) showed two substantial Precambrian blocks between the Kirin and Sikhote–Alin areas, the Bureya Massif and the Khankai (or Khanka or Xingkai of other authors) Massif. What Cocks and Torsvik (2007) also then termed the Khingan–Bureya Terrane was then schematically depicted just outside the Mongol–Okhotsk area of the Siberian part of Pangea in the latest Permian. The Khanka–Jiamusu–Bureya microcontinent includes units M4 (Jiamusi) and M5 (Lesser Hingan) within the 'Manchurides' of Sengor and Natalin (1996).

Zhou et al. (2010) demonstrated that the Khanka Massif and Jiamusu Massif, although considered as separate terranes by some authors, have the same Neoproterozoic zircon signatures as each other and thus have been united since then. The Jiamusu block consists of Neoproterozoic granulites intruded by Early Cambrian granitoids, all metamorphosed in the Late Cambrian (at about 500 Ma), some undeformed Permian granitoids, and the Heilongjiang Complex, which was thought to be of Palaeozoic age by various authors but is now known to be Triassic (Zhou et al., 2010). We assume here that the entire Khanka–Jiamusu–Bureya area formed a single microcontinent during most of the Palaeozoic, although de Jong et al. (2006) considered that Khanka alone was made up of four separate terranes in the Ordovician which amalgamated during the Silurian. The basement of the Khanka Massif may include some Proterozoic rocks, but is also largely composed of Lower Palaeozoic and later granitoids (Wilde et al., 2003), with subsequent Late Cambrian (approximately 500 Ma) high grade metamorphism. Wu et al. (2011) recorded 16 granites from the Jiamusu Massif within China, of which eleven were Cambrian and five Permian in age. There are marine Early Cambrian fossils with archaeocyathids (Astashkin et al., 1995). Zhou et al. (2007), who termed the whole area the Hinggan region, identified fossiliferous Ordovician rocks in only two places, Ergun Hinggan and Yichun; however, the region is only within the maps in this paper from the Late Silurian (420 Ma) onwards. In addition, Khanka, Jiamusu and Bureya all include similar Devonian and Lower Carboniferous continental rift-related volcanics and sedimentary rocks, some yielding brachiopods (Hamada, 1971), although there were no plutonic intrusions there in those times.

In the Russian sector to the north, there is a Palaeozoic and Mesozoic cover of clastic, carbonate and volcanic rocks overlying the Neoproterozoic, and it is intruded by a Middle Ordovician (Dapingian) syenite dated at 471 Ma (Zonenshain et al., 1990, p. 112). Shi (2006) reviewed the rich succession of Permian rocks in the South Primorye area near Vladivostock, Russia, which include Early Permian volcanics and interbedded floral assemblages overlain by intercalated terrestrial rocks interspersed with occasional marine horizons with Middle Permian (Kungurian) brachiopods. Those beds are in turn succeeded by marine rocks with more brachiopods and fusulinid foraminifera which continue on upwards into the Late Permian strata, which are mostly of definite Wuchiapingian age but probably also include some representing the succeeding last stage of the Permian, the Changhsingian.

From the analysis of zircons, Han et al. (2011) concluded that Khanka–Jiamusu–Bureya originally formed parts of the Tarim palaeocontinent, but left it in the Neoproterozoic at about 800 Ma. However, even if that were true, Khanka–Jiamusu–Bureya and Tarim appear to have been some distance apart by the beginning of the Cambrian. Dacheng et al. (2004) documented the accretion of the Khanka Terrane to North China in the Late Permian and Early Triassic. From diverse ages and provenances of zircons, Zhou et al. (2010) concluded that the Khanka–Jiamusu–Bureya microcontinent Assemblage could have been originally derived from either Siberia or Gondwana, but was not originally related to either North China or South China in the Lower Palaeozoic; however, it is not within the area of our Lower Palaeozoic maps and its positions then are quite unclear. The Early Permian floras of Dunay River and Cape Obrucheva, both in South Primorye (Fig. 22), are of Angaran, rather than Cathaysian or Gondwanan composition (Tashi and Burago, 1974; Zimina, 1977). Parfenov et al. (2009) concluded that what they termed the Bureya–Jiamusi Superterrane accreted to North China in the Late Permian and to Siberia in the Late Jurassic. However, other authors, including Metcalfe (2011b) and Shi (2006) show more or less continuous land between North China and Siberia, including Khanka–Jiamusu–Bureya, as having developed before the Late Permian, and the topic is discussed further in Section 15.3 below.

3. Central Asian terranes

Today's Kazakhstan and adjacent areas extending eastwards into western China and southwestern Mongolia are made up of many Palaeozoic terranes in the CAOB, apart from the northeastern area of Kazakhstan, which was part of peri-Siberia. The terranes were largely independent in the Lower Palaeozoic, but those in the west had gradually merged to form the Kazakhstania continent by the Upper Palaeozoic. That Tarim itself was an independent and substantial continent during the Neoproterozoic and Palaeozoic is agreed by most modern authors, but there is less agreement on the adjacent Ala Shan, Qaidam–Qilian and Kunlun terranes; but, since they are composite, that disagreement is unsurprising. Because the Palaeoasian Ocean was so large in the Palaeozoic, Kazakhstania and most of the central Asian terranes are outside the palaeogeographical maps presented in this paper, and are thus only briefly summarised here. However, the eastern ends of the Atasu–Zhamshi and the South Tien Shan terranes today are within Fig. 1, to the north and south of Junggar respectively. The geographical Tien (or Tian) Shan Mountains today are made up of several different Palaeozoic terranes divided by approximately east–west trending major thrust faults, chiefly of Late Carboniferous to Permian age, and many of which also have a substantial strike-slip component. The term 'Tien Shan' has been used in many varied ways for differing Palaeozoic tectonic units.

3.1. Tarim and South Tien Shan

Tarim is mostly within China and includes most of the Taklimakan Desert, which has the Tien Shan Mountains to its north and the Kunlun Mountains to its south. Its geology was summarised in Zhou and Chen (1992), Zhou and Dean (1996), Carroll et al. (2001), and Daukeev et al. (2002). The surface rocks in the centre of Tarim are Cenozoic, although boreholes there have penetrated to the Palaeozoic.

The northern part of Tarim is an old craton and includes Archaean (over 3.2 Ga) to Lower Cambrian rocks (Xiao et al., 2008), over which lie dominantly carbonate Cambrian and Ordovician sequences. A Late Ordovician and Early Silurian rapid subsidence was suggested by Carroll et al. (2001), and Latest Silurian to earliest Carboniferous rocks are absent on the craton, which was therefore presumably land then. Pirajno et al. (2008) described the extensive Permian volcanics. Today's northern margin of Tarim was passive for most of the Palaeozoic (Xiao et al., 2008).

Zhou et al. (1998b) described a Middle Ordovician (Darriwilian) trilobite fauna from Tarim and noted that 89% of the species there are also known from South China. Zhou et al. (2001b) listed a variety of Silurian to Late Carboniferous fossils from that northern margin, including very diverse Early and Middle Carboniferous brachiopod and coral faunas. Biske et al. (2003) recorded Late Devonian (Famennian) to Upper Carboniferous (Bashkirian) carbonate and clastic sediments. Those are followed upwards by flysch sedimentation during the subduction of Tarim under the active southern margin of Kazakhstania, which began in the Middle Carboniferous and ended in the Late Carboniferous at some time after 310 Ma (Windley et al., 2007). In contrast, the southern margin of Tarim was very tectonically active, and there was an Andean-type active margin there, starting in the Early to Middle Ordovician with progressive accretion of island arcs (de Jong et al., 2006) and ending with a Triassic (214 Ma) granite stitching Tarim and Kunlun. The southeastern boundary of Tarim is the Kun Lun Suture at the Altyn Tagh Fault Zone, a substantial strike-slip fault which divides Tarim from the Qaidam, Kunlun and Ala Shan terranes, and whose lateral displacement was over 400 km (Yang et al., 2001).

As reviewed by Rojas-Agramonte et al. (2011), the origins of Tarim are much disputed, with different authors suggesting that it was derived from various sectors of the Gondwanan margin at very different times varying from the Middle Proterozoic up to the Cambrian; and the rather sparse palaeomagnetic evidence is mixed and not definitive. Wilhem et al. (2012) show it as united with North China from Ordovician times to beyond the close of the Palaeozoic. However, as we show on Figs. 3 and 4, Tarim does not seem to have been close to Gondwana at 510 Ma, at the start of the Upper Cambrian. Tarim is within our reconstructions from the Middle Cambrian to the Early Devonian, after which it lays outside the area further to the west. We conclude that it was more probably separate from North China than united with it.

South Tien Shan is another elongate terrane unit (termed the Central Tienshan microcontinent by Wilhem et al., 2012) which stretches eastwards into northwestern China. It fringes Tarim to the latter's north, and the two units are separated by the South Tianshan Suture Zone (Qian et al., 2009). Between Junggar and Tarim it is the same as the Central Tien Shan Terrane of Zhou et al. (2001a) and Wang et al. (2007), and in northwest China includes the Narat Terrane of Zhou and Dean (1996). The Tien Shan Range to the north of Tarim is mostly made up of a complex series of nappes formed after the closure of the Turkestan Ocean between Tarim and Kazakhstania in the Middle Carboniferous (Burtman, 2008; Xiao et al., 2010a), and the nappes include a variety of Cambrian to Late Carboniferous fossils itemized by Zhou et al. (2001a, 2001b). In particular, the Lower Ordovician trilobites recorded mostly indicate deposition under deeper-water, but the list includes *Neohedina* and *Inkouia*, both of which are otherwise considered as endemic to North and South China. The lower nappes (which include the central Tien Shan unit of Zhou et al., 2001a) were originally parts of the passive northern margin of Tarim, which was subducted. The upper nappes formed as an accretionary prism at the margin of Kazakhstania and were obducted over Tarim. However, both Tarim and South Tien Shan lay off the west of our map areas from Devonian times onwards, and, since its detailed substance and configuration are unknown, South Tien Shan is not identified separately within the Tarim Terrane area on the Lower Palaeozoic reconstructions (Figs. 3–12).

3.2. Junggar

The Junggar Basin lies to the north of the Tarim Basin, and is a relatively small composite terrane which was welded to Tarim in the Devonian and Carboniferous (Charvet et al., 2007). Western Junggar is made up of several terranes which were originally separate at different times in the Palaeozoic (Buckman and Aitchison, 2004). Although Zhou and Dean (1996) and Li (2006), thought that Junggar's basement is of Precambrian age, Zhou et al. (2001a: their north Tian Shan area) and Xiao et al. (2008, 2009b) all concluded that there is no Precambrian, and that Junggar is an aggregation of Cambrian to Permian volcanic arcs, accretionary prisms and segments of obducted ocean floor, all intruded by later granites. The Ordovician (Darriwilian and later) rocks there consist of deeper-water shelf sediments with some Katian volcanics. Devonian volcanic rocks, including ignimbrites, were intermittently laid down from the Lochkovian to the Famennian with associated Lower Devonian shallower water sediments, and there are also strata of deeper-water origins of Frasnian and Famennian ages which host the conodonts and radiolaria listed by Zhou et al. (2001a). The Permian is largely terrestrial, with many interspersed volcanics, apart from a brief shallow-marine carbonate incursion during the Late Kungurian (Daukeev et al., 2002). Zhou et al. (2001b) concluded that Tarim (what they termed ‘Central Tien Shan’) and Junggar had amalgamated before the latest Carboniferous, whilst Xiao et al. (2008) thought that Tarim did not join the others until the end of the Permian. Wan et al. (2011) demonstrated that the Devonian Japanese-style Chinese Altai Arc accreted to the Mariana-style East Junggar Arc with subduction-accretion along the Erqis Fault Zone from the Middle Devonian to the Late Carboniferous. Shen et al. (2011) recognised two distinct groups of A-type granites in the Altay Range to the east of the Junggar Basin, the first Late Devonian (382–367 Ma), and the second Late Carboniferous to Early Permian (308–291 Ma). However, our maps only include Tarim up to Early Devonian times, after which it lay outside them to the west of their areas, and thus its union with Junggar was too late to be shown on them.

3.3. Qaidam–Qilian

The Qaidam (or Chaidam) Block lies to the southeast of Tarim and south of Ala Shan, and northwest of it lies the Qilian area. Both Qaidam and Qilian display a variety of independent Palaeozoic units, but we combine the two units here and recognise a composite Qilian–Quaidam Terrane. Qaidam includes (1) the Cambrian to Early Ordovician Hexi Corridor, a continental slope, (2) the North Qilian Belt of Middle Cambrian and Ordovician ophiolites, intra-continental volcanics and olisthostromes, and shallow-water clastics and carbonates with a North China trilobite fauna (Zhou and Dean, 1996); (3), the South Qilian–Laji (or Quanji) Block, a Proterozoic cratonic fragment with overlying Palaeozoic to Mesozoic sedimentary rocks at the boundary between the Qilian orogenic belt and North Qaidam, (4), the Qaidam Massif, which includes the Olonbulag District, with Cambrian and Early Ordovician carbonates, again with North Chinese Province trilobites, unconformably overlain by Cenozoic deposits, and (5), the poorly exposed Qimantag belt, which includes Lower Palaeozoic clastic and volcanic rocks. A possible eastward extension of the Qaidam–Qilian complex is the small Wudang Block shown to the south of North China by Chen et al. (2010, Fig. 3).

Zhang et al. (2009) and Song et al. (2009a, 2009b) described intense Late Cambrian and early Ordovician metamorphic activity in Qaidam, with eclogites dated as peaking between 504 and 480 Ma: activity which continued in North Qaidam until the Early Silurian (431 Ma). There are also Lower Silurian (428 Ma) granites, and Carboniferous (Tournaisian and Visean) shallow-water marine rocks, some with rich faunas of corals and brachiopods (Chen et al., 2003). There are no marine rocks between the Early Ordovician and the Early Carboniferous, although in the Qaidam Basin there are continental Early Devonian molasse deposits. The Carboniferous was generally quieter there, with marine clastics and carbonates deposited over much of the terrane. However, Ruan and Liaio (in Zhou and Dean, 1996) reported rifting from Late Devonian times onwards which continued through the Carboniferous to form the boundary between the South and Middle Qilian Mountains to the north and the Qaidam and West Qinlin Mountains to the south.

Zhou and Dean (1996) and Xiao et al. (2009a) distinguished North, Central and South divisions within Qilian, of which only the Central and South units had Precambrian basements, but all of which included separate volcanic island arcs from the Late Cambrian to the Early Silurian. Those units merged with each other in the Late Silurian and subsequently with the Alax Block in the Ala Shan Terrane in the Late Devonian from 380 to 360 Ma (Frasnian and Famennian) as part of the same series of tectonic events in which Ala Shan accreted to Qaidam.

Yin et al. (2007) reviewed several models for Qaidam–Qilian, and concluded that there was a Neoproterozoic Kunlun–Qaidam microcontinent with passive margins until about 520 Ma (Middle Cambrian) after which south-dipping subduction of the Qilian oceanic

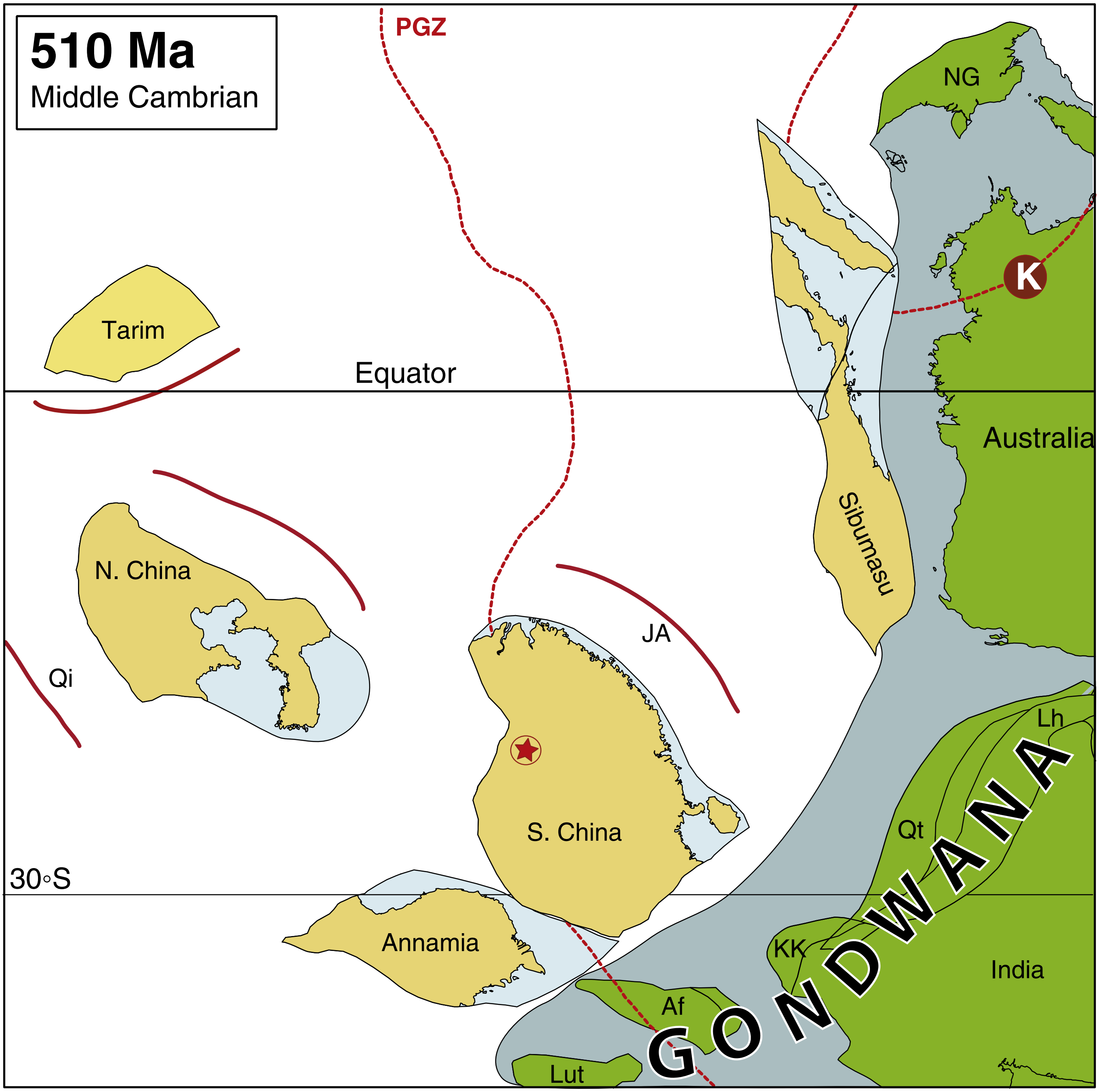

Fig. 3. Distribution of major tectonic units in the latest Middle Cambrian at 510 Ma. Red stars are kimberlites (K is the Kalkarindi LIP). Thinner stippled red lines show the plume generation zones (PGZs) at the core–mantle boundary (Torsvik et al., 2008, 2010), the deep source region for most LIPs and kimberlites. The present-day outlines of lands and seas are shown on each continent to aid recognition, although some did not exist in the Cambrian, for example, today's western area of Annamia. Af, Afghan Terrane; JA, Japanese arcs; KK, Karakorum; Lh, Lhasa Terrane; NG, New Guinea; PGZ, plume generation zone; Qi, arcs now in the Qaidam–Qilian Terrane; Qt, Qiangtang Terrane. Thicker red lines are subduction zones.

plate started, together with the development of a Qilian volcanic arc. That subduction continued until the Early Devonian (410 to 375 Ma), when collision of the Qilian arc and North China occurred, associated with obduction of the Qilian Melange Complex over the passive margin of North China (Song et al., 2009a, 2009b). Yan et al. (2010) described the Early Silurian to Middle Devonian phase in which Silurian clastics were deposited in the forearc basin landward of the accretionary wedge which eventually collided with North China. After that there was a tectonic pause until the Triassic. We show Qaidam–Qilian as represented by island arcs near North China on our Cambrian (510 Ma) to Early Devonian (400 Ma) maps, after which a segment of it is shown diagrammatically as forming the southwestern part of the North China Terrane Assemblage until the end of the Palaeozoic.

3.4. Kunlun

The very elongate Kunlun area lies between Tarim and Qaidam–Qilian to its north and the Qiantang Terrane of Tibet, the latter forming part of core Gondwana until the Neotethys Ocean opened in the Permian. Within the composite Kunlun Terrane we include the Songpan–Ganze Belt (or Song Gan or Songpan–Ganzi-Hou Xil Terrane) and also the Qamdo–Simao Terrane of some authors (e.g. Metcalfe, 2006). The Qamdo–Simao sector of Kunlun accreted to peri-Gondwana (Qiangtang) along the Lancangjiang Suture in the Early Triassic (Metcalfe, 2006; Chen et al., 2010).

Xiao et al. (2002) described the history around arc–ophiolite obduction in the West Kunlun Range (on the northern periphery of

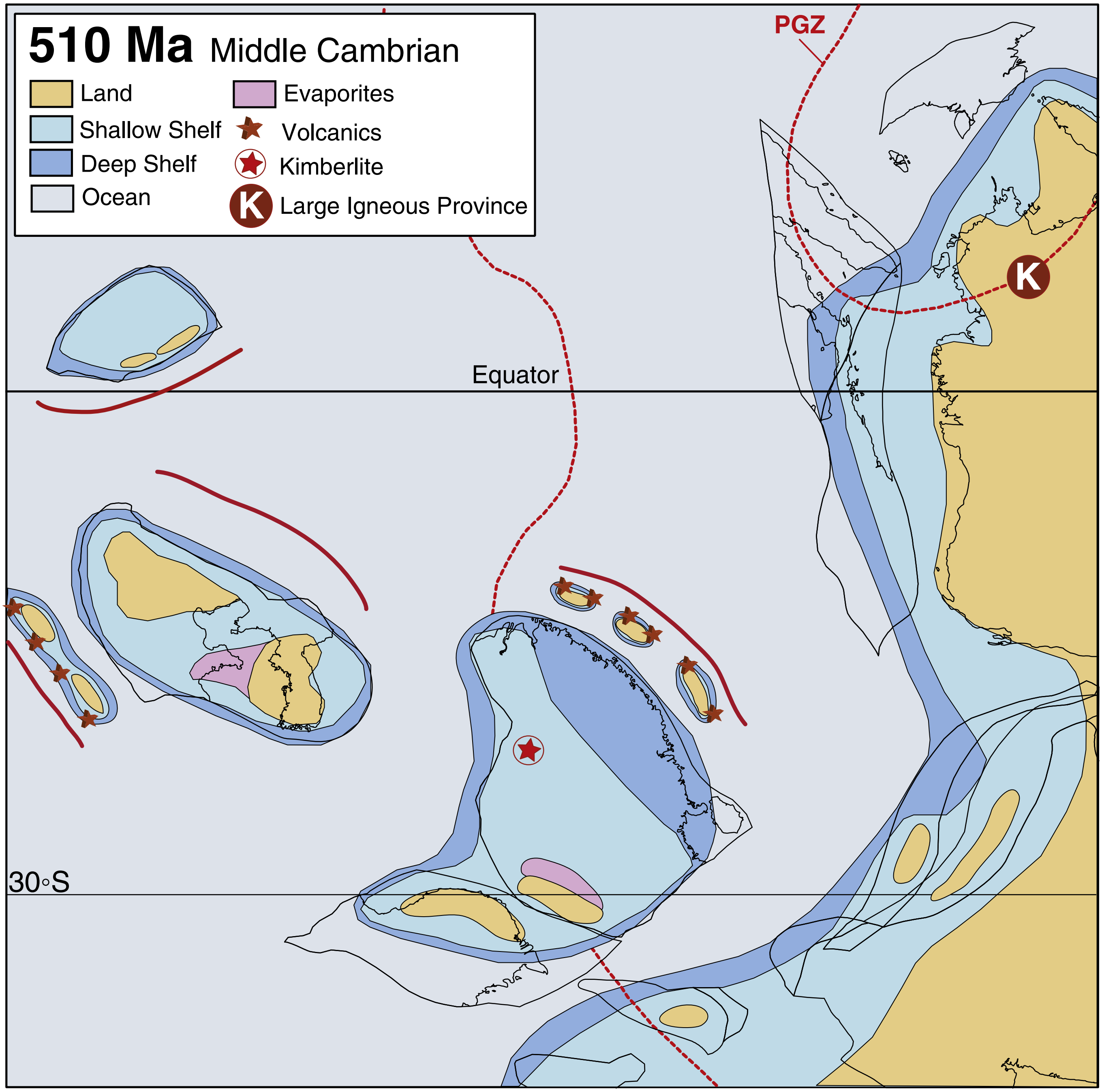

Fig. 4. Palaeogeography in the latest Middle Cambrian at 510 Ma. Land, shallow and deeper shelf areas are shown. Thinner red lines and PGZ, plume generation zone, Thicker red lines are subduction zones.

the Tibet Plateau) on to the Tarim continent. The turbidites there contained both Late Ordovician to Early Silurian and also Late Devonian to Early Carboniferous radiolarians, representing old ocean floor. The whole Kunlun Belt consists of the remnants of Carboniferous to Triassic island arcs superimposed on Lower Palaeozoic arcs, largely of Ordovician age (490–450 Ma), into which Middle Devonian (389–384 Ma) batholiths were intruded (de Jong et al., 2006), all of which were eventually accreted to the southern margin of Tarim. Daukeev et al. (2002) provided sections through the Carboniferous rocks of the East Kunlun and Muztag areas. However, in the Chinese sector of northeast Kunlun, only Ordovician fossils are securely dated (Zhou and Dean, 1996).

In the east there is Proterozoic basement which is apparently similar to the basement rocks of the Qaidam block, and Metcalfe (2006) concluded that Kunlun may represent an accretionary wedge on the southern margin of Qaidam. Daukeev et al. (2002)

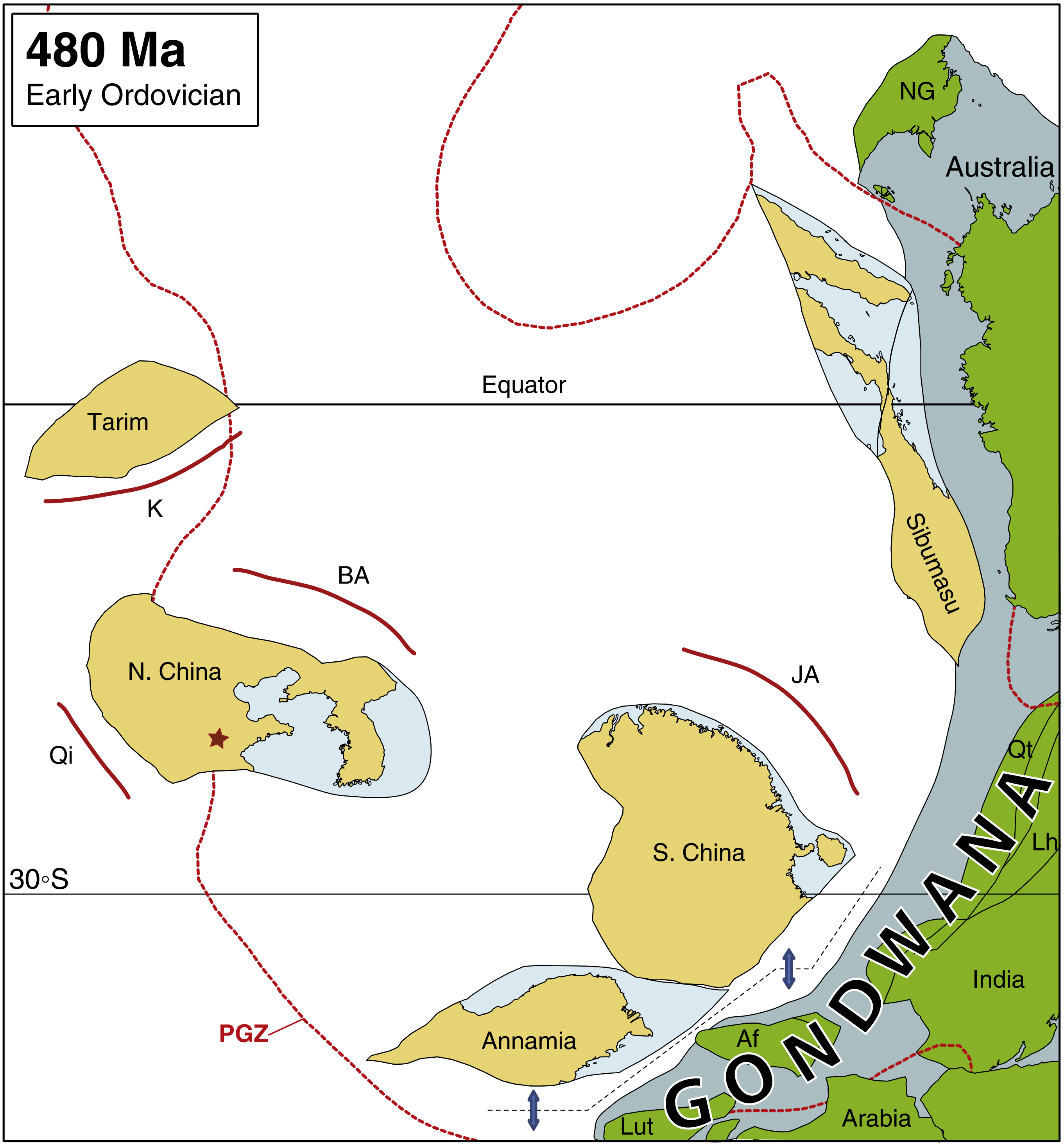

Fig. 5. Distribution of major tectonic units in the Early Ordovician (Late Tremadocian) at 480 Ma. The present-day outlines of lands and seas are shown on each continent to aid recognition, although some did not exist in the Cambrian, for example, today's western area of Annamia. Af, Afghan Terrane; BA, Bainaimiao Arc; JA, Japanese arcs; K, arcs now in the Kunlun Terrane; Lh, Lhasa Terrane; NG, New Guinea; PGZ (and thinner red lines), plume generation zone; Qi, arcs now in the Qaidam–Qilian Terrane; Qt, Qiangtang Terrane. Thicker red lines are subduction zones.

provided a section in which Lower Cambrian ignimbrites overlie Vendian rocks and are succeeded by Middle Cambrian deeper-water shelf sediments and Upper Cambrian shallower-water marine sediments; and another for the Carboniferous of the Muztag area, in which Carboniferous (Upper Visean to Kazimovian) shallow-water marine sediments unconformably overlie Middle Silurian rocks and are succeeded by Latest Carboniferous (Gzhelian) sandstones of deeper-water origin. Although Kunlun occupies a substantial area on Fig. 1, the terrane is not shown as a separate entity on our maps; for example, its accretion did not appear to have taken place until after Tarim had moved outside the area of our reconstructions in the Middle Devonian. However, it is represented by an arc shown on today's southern margin of Tarim in our Lower Palaeozoic maps.

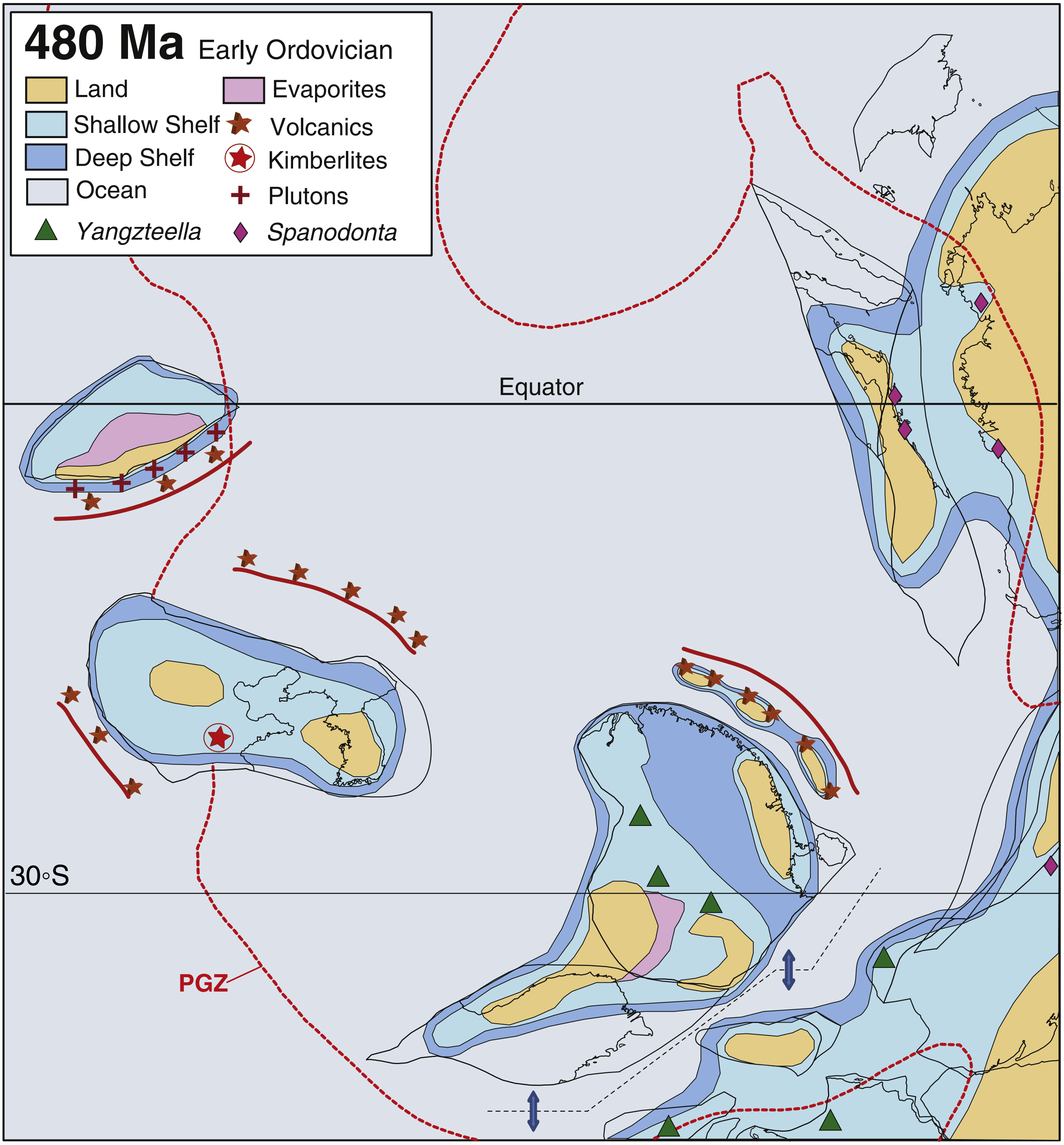

Fig. 6. Palaeogeography in the Early Ordovician (Late Tremadocian) at 480 Ma. The present-day outlines of lands and seas are shown on each continent to aid recognition, although some did not exist in the Ordovician, for example, today's western area of Annamia. Thicker red lines are subduction zones. Also shown are the sites of two slightly later (Floian–Dapingian) brachiopods, the equatorial plectambonitoid *Spanodonta*, and the more temperate pentameride *Yangzteella*. Thinner red lines and PGZ, plume generation zones.

3.5. Ala Shan

This composite terrane spans the China–Mongolia border, and of all the many disparate units considered in this paper, it is the most heterogeneous. The parts within China, termed Badainjaria by Rong et al. (2003), are interpreted differently: e.g. Xiao et al. (2009a) included it within North China, and Metcalfe (2006) showed a smaller area than here (Fig. 1). We include within Ala Shan the Beishan and Liuyan Terranes as well as the Dunhuang and Alax (or Dunhuang–Alexa) Massifs and Altun Faulted Block, all described by Zhou and Dean (1996) and Xiao et al. (2010b). In its northern sector we include the Hanshan microcontinent of Beishan and the Dongqiyishan Arc of Yue et al. (2001): the latter represents a Cambrian to Middle Ordovician passive continental margin yielding trilobites and nautiloids of general Chinese affinity overlain by Latest Ordovician to Middle Permian volcanic arc rocks and associated sediments and fossils before the deposition of Middle Permian and later rocks with plants of Cathaysian affinity. The sinistral Altyn Tagh Fault, between Tarim and the Dunhuang sector of Ala Shan to its north and Kunlun and Qaidam–Qilian to its south, has a displacement estimated at over 400 km (Song et al., 2009a, 2009b). The area within Inner Mongolia includes Early Devonian (Emsian) brachiopods of which five of the 15 genera present are endemic (Rong and Zhang, 1994). We follow Xiao et al. (2009a) in including the Alax (or Alxa) Massif within Ala Shan rather than North China. Alax includes Archaean and Proterozoic rocks (Wang et al., 2007; Song et al., 2009a, 2009b) and Cambrian to Middle Ordovician rocks are exposed in the Dunhuang, Hanshan and Yagan areas. Zhang et al. (2011a) analysed the zircons from Middle Ordovician turbidites in the Alax Massif and concluded that they were deposited in a foreland basin peripheral to the North Qilian Block and that those zircons were derived from the Alax Massif, the North Qilian Block and the Dunhuang Massif, but not the North China palaeocontinent; and thus the Alax Massif and the Ordos Massif of North China did not unite until some time after the Ordovician. This contrasts with the conclusion of Wilhem et al. (2012), who suggested that Tarim, Beishan and North China were united, and shared a continuous passive northern margin in the Cambrian and Ordovician. We also place the Eastern Tien Shan Arc of various authors within Ala Shan.

Within Mongolia, we include within Ala Shan the Atasbogd, Hashaat and Tsagaan Uul terranes (Units 37 to 39 of Badarch et al., 2002), and also the Devonian and Carboniferous Dananhu volcanic island arc rocks which surround the largely Cenozoic Tuha (or Tur-Ha, Turfan or Turpan-Hami) Basin, although Pirajno et al. (2008) recognised an independent Palaeozoic Turpan Terrane immediately to the southeast of Junggar and northeast of Tarim there. Tu-Ha was described by Zhang et al. (2008), who concluded that collision between South Tien Shan, Junggar and Tarim occurred progressively during the Latest Carboniferous to Early Permian, between 300 and 280 Ma. Wartes et al. (2002) described the various post-collisional non-marine sediments

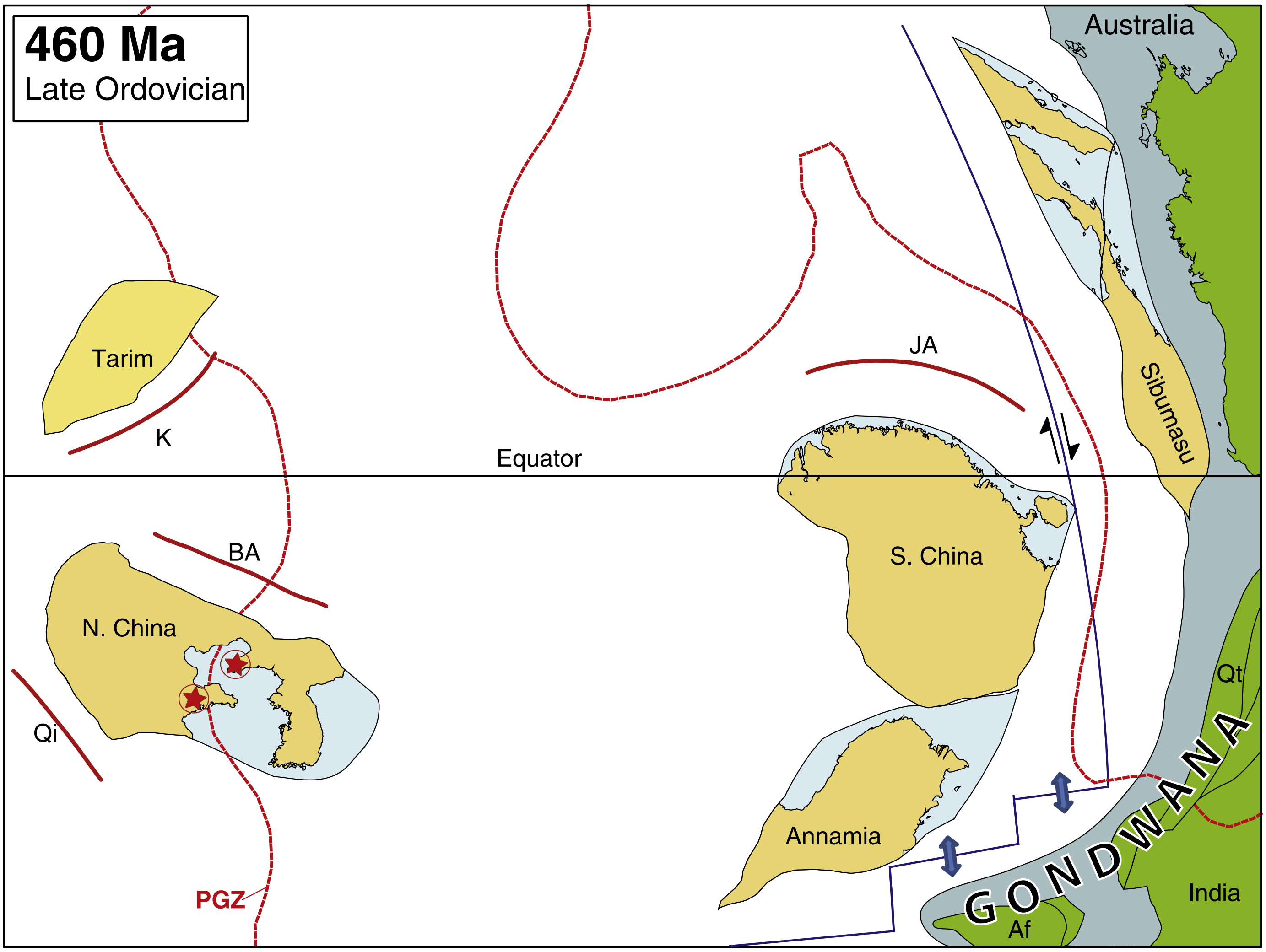

Fig. 7. Distribution of major tectonic units in the Late Ordovician (Sandbian; Early Caradoc) at 460 Ma. Af, Afghan Terrane; BA, Bainaimiao Arc; JA, Japanese arcs; K, arcs now in the Kunlun Terrane; PGZ (and thinner red lines), plume generation zone; Qi, arcs now in the Qaidam–Qilian Terrane; Qt, Qiangtang Terrane. Thicker red lines are subduction zones.

and their contained spores and macrofloras collected in Tu-Ha, from which they deduced changes in the configurations of the various basins, many changed through contemporaneous faulting: they also documented the numerous Permian volcanic flows. There is a Late Devonian stitching pluton between Ala Shan and Qilian dated at about 370 Ma (Xiao et al., 2009a). Ala Shan did not merge with Qilian and Tarim until after Tarim had moved outside the western margin of our maps; however, even if our maps had covered that area, Ala Shan would not be depicted as an integral block, but as a series of disparate microcontinents and island arcs throughout the Palaeozoic.

3.6. Gurvansayhan

The Gurvansayhan Terrane accreted to part of Ala Shan in the Late Permian at about 260 Ma and to the Gobi Altai–Mandalovoo terranes of peri-Siberia at about the same time, and it seems logical to place both Gurvansayhan and Ala Shan within the eastern sector of the 'Kazakh terranes' group, which is also a further reason for rejecting the hypothesis that the Axa Block in the east of Ala Shan was part of the North China Craton, as postulated by some authors (e.g. Xiao et al., 2009a). Badarch et al. (2002) defined and described the Gurvansayhan Terrane (their Unit 35), which occupies a broad belt within south-central Mongolia, which we have combined with the Edren Terrane (their Unit 32) in a similar structural position into a more loosely-defined Gurvansayhan Terrane. Gurvansayhan (or Gurvansaikhan of Batkhishig et al., 2010) represents two or more island arcs, whose rocks commence with a Late Cambrian ophiolite, above which there are a great variety of lithologies, including Ordovician to Silurian greenschist facies, Upper Silurian to Lower Devonian radiolarian cherts and tholeiitic pillow basalts, and Middle Devonian to Lower Carboniferous volcaniclastic rocks, and Late Devonian (Frasnian) cherts. One of the arcs, the Yuanbaoshan Arc, was reviewed by Yue et al. (2001), who described Middle Ordovician and Silurian volcanic arcs overlying Cambrian to lower Ordovician sediments deposited on a passive continental margin, although which continent or microcontinent is uncertain. After fossiliferous Devonian backarc basin sediments were laid down, volcanism resumed in the Carboniferous and earlier Permian before the area became entirely continental from then on into the Mesozoic. The structure is complex, with many imbricate thrust sheets, and it appears to have accreted to many of its adjacent terranes in the Late Carboniferous, although it did not accrete to the Northeast China–Primorye Terrane Assemblage (placed here within Ala Shan) to its south until the Permian (Jian et al., 2008). Batkhishig et al. (2010) dated the Shuteen Complex island arc andesites at 336 Ma and subsequent associated granites at 321 Ma, both Middle Carboniferous. Westwards from the restricted Gurvansayhan Terrane, the Edren Terrane consists of a metamorphosed Devonian island arc, made up

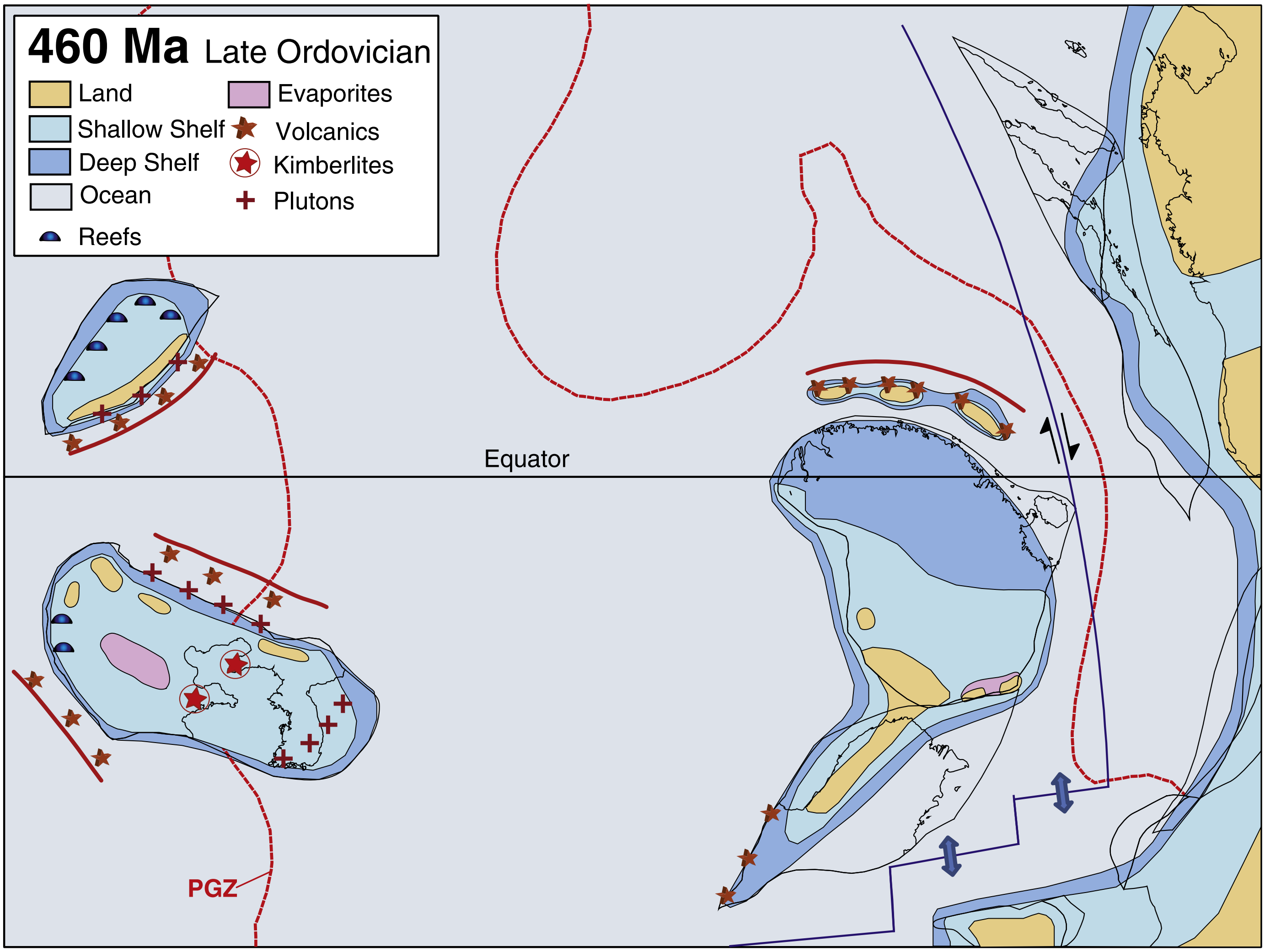

Fig. 8. Palaeogeography in the Late Ordovician (Sandbian; Early Caradoc) at 460 Ma. The present-day outlines of lands and seas are shown on each continent to aid recognition, although some did not exist in the Ordovician, for example, today's western area of Annamia. Thicker red lines are subduction zones. Thinner red lines and PGZ, plume generation zones.

of clastics with minor cherts interbedded with volcanic rocks succeeded by Carboniferous sedimentary rocks, all intruded by Permian alkaline granites (Badarch et al., 2002). Gurvansayhan lay outside our map reconstruction areas somewhere between North China and peri-Siberia; however, the fact that it has yielded Late Carboniferous floras of Angaran affinity (Yue et al., 2001) indicates that it was probably nearer Siberia than North China.

4. Northeastern Gondwana and Siberia

Gondwana was by far the largest continent, which we term a superterrane (although it has often been called a supercontinent) in the Lower Palaeozoic, and its northeastern and eastern margins form the southern sector of the area. It included India, West Burma, the Tibetan terranes, Sibumasu, Annamia, and East Malaya at various times. West Burma, seen to the west of Sibumasu in Fig. 1, and separated from it by the Mesozoic Shan Boundary Fault, was originally part of Antarctic Gondwana. It rifted from core Gondwana in the Late Triassic and accreted to Sibumasu in the Late Jurassic or Early Cretaceous (Cai and Zhang, 2009), and is not considered further here.

4.1. The Himalaya and the Tibetan terranes

The Tibetan terranes of Qiangtang and Lhasa were integral parts of the margin of northeastern Gondwana for nearly all of the Palaeozoic (as shown within some of the southern parts of our reconstructions) until they rifted from Gondwana in the opening of the Neotethys Ocean during the Permian. Despite the assertion of some authors, for example de Jong et al. (2006), that the margin was active throughout the Lower Palaeozoic, the northeastern Gondwanan margin (including the Himalaya) seems to have been passive from the Late Neoproterozoic until beyond the close of the Palaeozoic. That passivity was only interrupted by a Late Cambrian to Early Ordovician tectonic event, including the intrusion of some Late Cambrian granites, in the eastern Himalaya, as reviewed by Yin (2006). That event was of uncertain cause, although Cawood et al. (2007) has suggested that it might represent the accretion of putative ribbon-like microcontinents, possibly represented by the later Lhasa or Qiantang terranes. Harper et al. (2011) documented shallow shelf brachiopods and other fossils of Middle Ordovican (Darriwilian) age demonstrating the presence of low latitude faunas in Tibet near Mount Everest which were deposited well south of the area which subsequently became the Tibetan terranes. However, rifting preceded the opening of the Palaeotethys Ocean in the earliest Devonian, and, after a period of relative quiescence, the Neotethys Ocean opened during the Permian (Metcalfe, 2011a). The sources for the sectors of Gondwana shown on the margins of our new palaeogeographic maps are Torsvik and Cocks (2009, 2011), Veevers (2004), and Li and Powell (2001).

Palaeozoic outcrops are scattered, but in the eastern Himalaya there are two substantial Palaeozoic areas, Xainza and Nyalam. Chen et al. (2010) noted thick shallow-water carbonates through the Ordovician in Xainza and Katian carbonates succeeded by Late Ordovician (Hirnantian) and Early Silurian graptolitic shales in Nyalam, both unconformable on a Precambrian basement. However, in other sites near Nyalam there are Lower and Middle Cambrian rocks, many bearing trilobites (Myrow et al., 2008). The Silurian shales are succeeded by deeper-water limestones with nautiloids and some brachiopods which continue up in to the Devonian (Rong et al., 2003). Middle

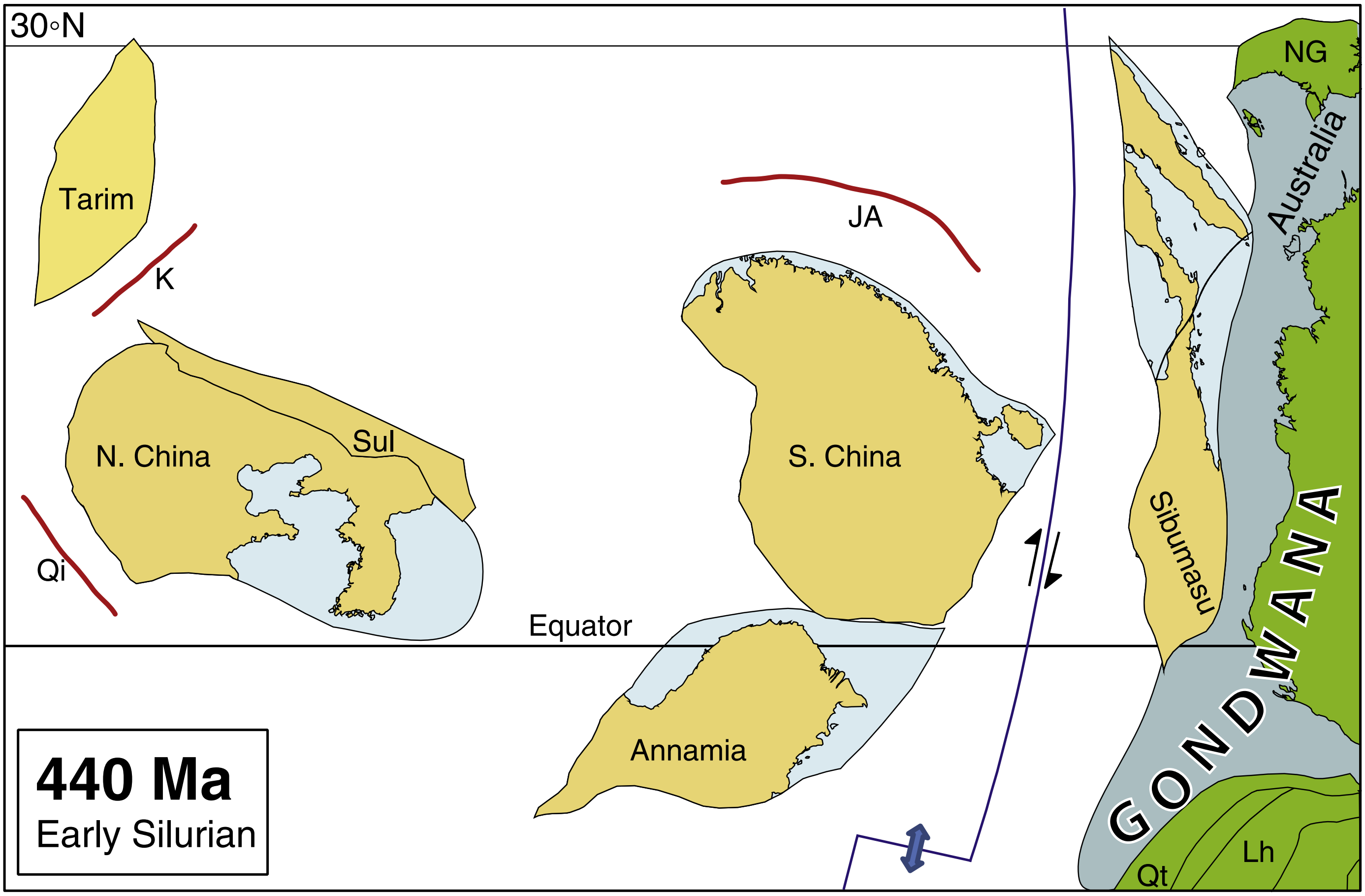

Fig. 9. Distribution of major tectonic units in the Early Silurian (Llandovery: Rhuddanian) at 440 Ma. JA, Japanese arcs; K, arcs now in the Kunlun Terrane; Lh, Lhasa Terrane; NG, New Guinea; Qi, arcs now in the Qaidam–Qilian Terrane; Qt, Qiangtang Terrane; Sul, Sulinheer. Red lines are subduction zones.

Devonian (Givetian) limestones with the distinctive brachiopod *Stringocephalus* and others are followed by Late Devonian (Frasnian and Famennian) shallow-water deposits (Liao and Ruan in Zhang et al., 2003). Reasonably complete and largely carbonate Carboniferous strata occur in both Xainza and Nyalam, and Permian successions in Nyalam and Rutog, are also recorded in Zhang et al. (2003), including volcanic rocks signalling the opening of the Neotethys Ocean. Lhasa and Qiantang appear to have been united throughout the Palaeozoic: however, having left Gondwana in the Permian, the two terranes separated in the Late Triassic but were reunited in the Early Cretaceous. It is noticeable that the Tibetan Terranes and Sibumasu left Gondwana at the same general time when the Neotethys Ocean opened, and thus various authors, such as Sengor and Natalin (1996), termed them, together with other units further west, the Cimmeria continent. Thus it is possible (but not definitely proven) that Sibumasu and the Tibetan terranes were linked as a single terrane during the Mesozoic and Tertiary: e.g., Metcalfe (2006) also shows them as united throughout the Palaeozoic.

4.2. East Malaya

The western Malaysian Peninsula is divided by the north–south trending Bentong–Raub Suture between Sibumasu to the west and the East Malaya Terrane to the east (Metcalfe, 1988, 2006). A Proterozoic basement is overlain by Silurian and Devonian deepwater sediments with radiolarian cherts (and no terrane-diagnostic faunas) which pass up in to shallow marine volcanoclastics and limestones of Carboniferous to Triassic age. Because of the intervening South China Sea and Gulf of Thailand, it is uncertain whether or not East Malaya was a separate Palaeozoic terrane or microcontinent or whether it was a southern extension of Annamia as postulated by Metcalfe (2006), who concluded that it left Gondwana with Annamia in the opening of the Palaeotethys Ocean in the Lower Devonian. It is not shown on our maps. The Bentong–Raub Suture represents the closure between East Malaya and Sibumasu in the Early Triassic.

4.3. Sibumasu

Sibumasu (often termed the Shan–Thai Block), is an elongate terrane today stretching from northeast Burma, through Thailand and western Malaysia to Indonesia (Sumatra), and it has very varied geology reviewed by, among others, Hutchison (1996) and Ridd et al. (2011). It was discussed by Torsvik and Cocks (2009), where we reversed our previous belief (Cocks and Torsvik, 2002) that it was an independent terrane or microcontinent during most of the Palaeozoic; and we now follow various authors, for example Metcalfe (2006), who considered Sibumasu to have been an integral part of the main Gondwana superterrane until the opening of the Neotethys Ocean in the Early Permian. Ridd (2009) documented the initial rifting in the pre-Middle Permian Kaeng Krachan Group of Thailand to form what he termed the Phuket Terrane. Sibumasu subsequently accreted to Annamia during the final closure of the Palaeotethys Ocean in the Middle to Late Triassic along the Inthanon Suture Zone, within which are seen Carboniferous and Permian limestones deposited on sea mounts and Permian basalts, all representing an oceanic environment (Sone and Metcalfe, 2008). Sibumasu was much distorted by the intrusion of substantial Permo-Triassic granites, which, together with its later partial subduction below Annamia in the Triassic (Sone and Metcalfe, 2008), makes its outline on our Palaeozoic reconstructions particularly arbitrary.

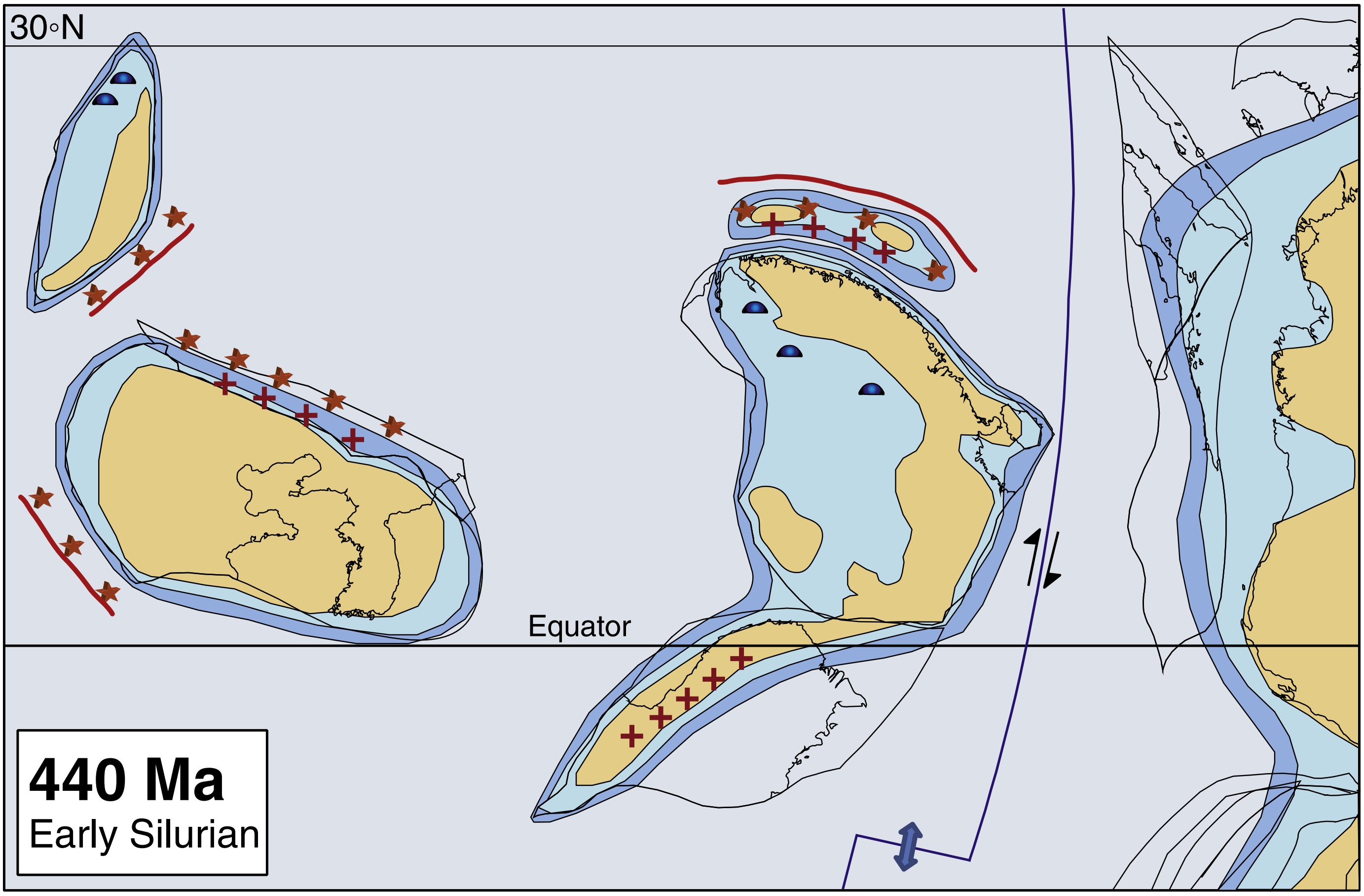

Fig. 10. Palaeogeography in the Early Silurian (Llandovery: Rhuddanian) at 440 Ma. The present-day outlines of lands and seas are shown on each continent to aid recognition, although some did not exist in the Early Silurian, for example, today's western area of Annamia. Red lines are subduction zones.

Also included within Sibumasu is the fault-bounded Baoshan Block of Wang et al. (2001), which is located in southwestern China and Burma at around 99° E and 24° N, and which contains Upper Devonian nodular limestones, which are unconformably overlain by Lower Carboniferous (Tournaisian to Serpukhovian) warm-water carbonates with corals and brachiopods in the north and deeper-water mudstones and argillaceous carbonates to their south, as well as distinctive Permian fusulinid foraminiferans (Ueno, 2003). There are also Late Carboniferous and Early Permian diamictites (Fig. 22), the latter endorsing the Gondwanan origins of Baoshan. In the whole of Sibumasu, notably including Malaysia and the Baoshan Block, the floras are of mixed Gondwanan and Cathaysian affinities up to the Early Permian (Sakmarian), but in the Late Permian are entirely Cathaysian. Lower Permian (Artinskian) basalts probably represent the Neotethys Ocean opening.

Within Sibumasu there are Ordovician trilobites described by Fortey (1997) from southern Thailand, and the Cambrian to Devonian faunas and biostratigraphy in the northern parts of the West Malaysian Peninsula and southern Thailand were reviewed by Cocks et al. (2005). Cocks and Zhan (1998) revised the Late Ordovician (Sandbian) brachiopod faunas of the Sibumasu part of Burma (Myanmar) and concluded that their closest affinities lay with South China.

4.4. Siberia and peri-Siberia

Siberia was a large continent throughout the Palaeozoic until its merger with the Kazakhstania sector of Pangea in the Permian. Its craton has many Precambrian rocks, of which much of the Neoproterozoic (whose latest parts are termed there Riphean and Vendian) is surprisingly undeformed. Surrounding it are the numerous terranes of peri-Siberia which are of very varied size and which accreted to the craton at various times in the Palaeozoic, particularly the Altai-Sayan and Mongolian areas (Cocks and Torsvik, 2007; Fig. 8; Wilhem et al., 2012).

Since Siberia was inverted throughout the Palaeozoic, the peri-Siberian and many Mongolian terranes which are today to the south of Siberia then lay to its north, facing the very large Panthalassic Ocean. These terranes include what we named the Ertix Terrane, which includes some of the units in Mongolia described by Badarch et al. (2002), and also the Zhaman–Sarysu accretionary wedge of Windley et al. (2007); as well as much of the Northern Xinjiang Region of northwestern China reviewed by Zhou et al. (2007), and the Chinese Altay (including the Erqis accretionary complex) of Xiao et al. (2008, 2009b). However, the more southerly Mongolian terranes today were not associated with Siberia and their Palaeozoic positions are reviewed above in Sections 2.5 and 2.6.

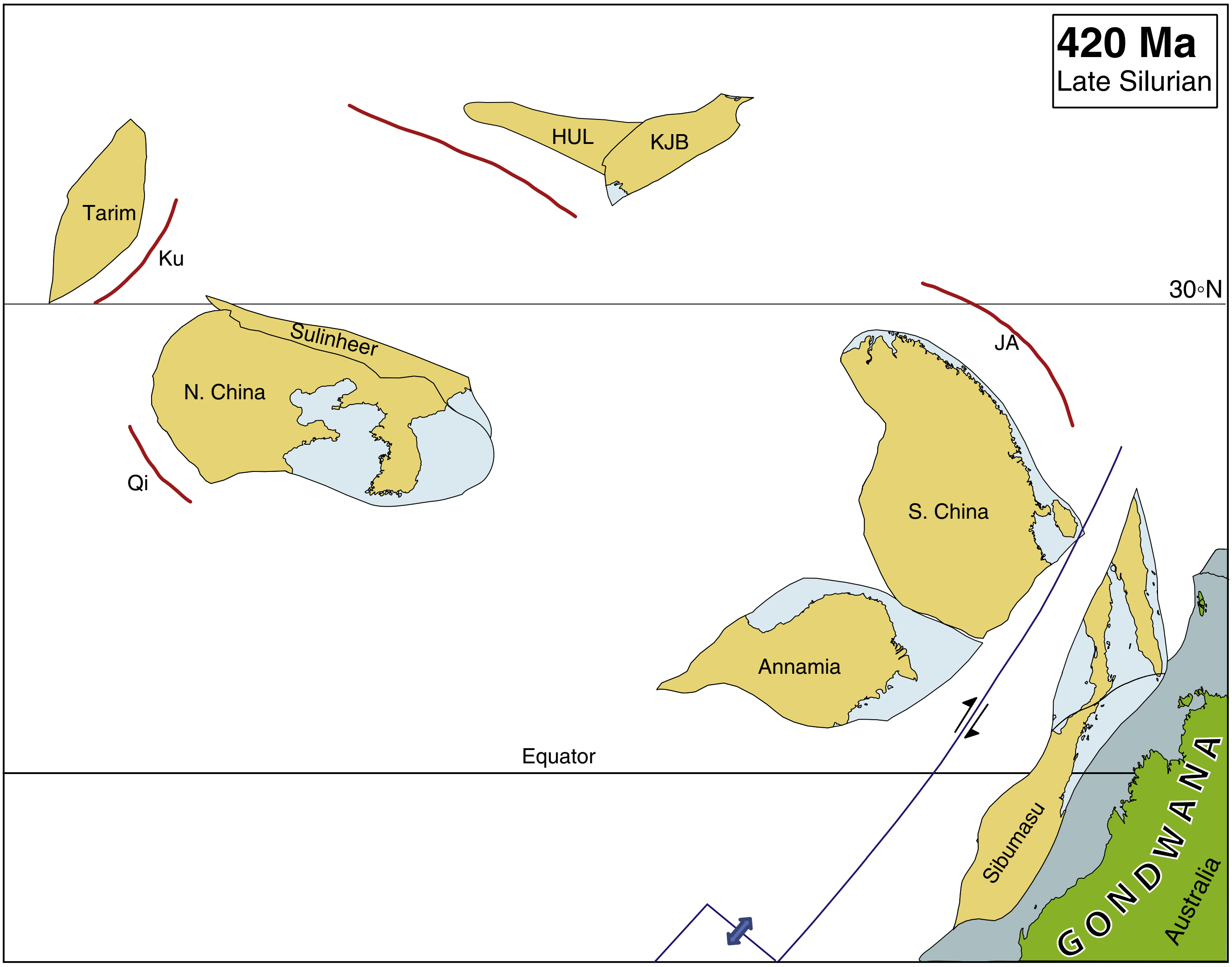

Fig. 11. Distribution of major tectonic units in the Late Silurian (Late Ludlow) at 420 Ma. HUL, Hutag Uul–Songliao; JA, Japanese arcs; KJB, Khanka–Jiamusu–Bureya; Ku, arcs now in the Kunlun Terrane; Qi, arcs now in the Qaidam–Qilian Terrane; Qt, Qiangtang Terrane. Red lines are subduction zones.

The southern border of the united Siberia and peri-Siberia is formed today of a series of very substantial arcuate strike-slip faults running through southern Siberia, Mongolia and northern China (Sengor and Natalin, 1996), including the Gornostaev Shear Zone. Those faults were highly active during the final rotation of Siberia as it became part of Pangea during the Mesozoic, but that rotation had commenced during the Late Palaeozoic. The End-Permian (250 Ma) map of Siberia (Cocks and Torsvik, 2007; Fig. 15) shows that at that time the Mongolian sector of peri-Siberia had accreted to Junggar, Tien Shan and Tarim and that the Eastern Asian terranes discussed here, principally the enlarged North China continent and associated terrane group lay in the Palaeoasian Ocean near Tarim.

Badarch et al. (2002, p. 88) and Windley et al. (2007) show the 'topographic and structural Boundary' line which they term 'traditionally defined' as the Main Mongolian Lineament, which runs to the north of the Gobi Altai Terrane, their Unit 33. However, that lineament is simply a boundary between the dominantly Precambrian and Lower Palaeozoic rocks to the north from the mainly Upper Palaeozoic rocks to the south, and it does not coincide with the boundary suture between peri-Siberia to the north and the central Asian terranes to the south. For example, Badarch et al. (2002, Fig. 12) correctly stated that Gobi Altai was amalgamated with the Mandalovoo Terrane before the Devonian, but, since, as noted by Cocks and Torsvik (2007, p. 48), the distinctive peri-Siberian *Tuvaella* brachiopod Fauna is found in Mandalovoo, that demonstrates that those two terranes were parts of peri-Siberia, not central Asia, prior to Siberia's Permian to Mesozoic progressive union with the rest of Pangea. Thus the fundamental tectonic line between peri-Siberia and the other central Asian terranes in Mongolia must be located to the south, not the north, of the Gobi Altai Terrane, as shown in Cocks and Torsvik (2007), rather than at the Main Mongolian Lineament, and it lies at the border of the Gurvansayhan Terrane (to the south of Mandalovoo). The latter terrane is bounded to its north by the arcuate series of strike-slip faults which define today's southern boundary of peri-Siberia (Cocks and Torsvik, 2007).

At the southeast corner of the Gobi Altai Terrane lies the Tseel Terrane (Unit 5 of Badarch et al., 2002). That terrane was revised by Kröner et al. (2007), who discovered that there are no Precambrian rocks there (although they were previously reported), but the terrane consists of a Lower Devonian (397 Ma) arc with subsequent metamorphism and granitoids intruded until the latest Devonian (Famennian) at 360 Ma. Kröner et al. (2007, Fig. 17) show the Main Mongolian Lineament to the north of the Tseel Terrane. We do not know whether or not the Tseel Terrane, like Gobi Altai, formed part of peri-Siberia; or whether, like the Edren Terrane, it was part of the Gurvansayhan Terrane complex and thus part of the Central Asian

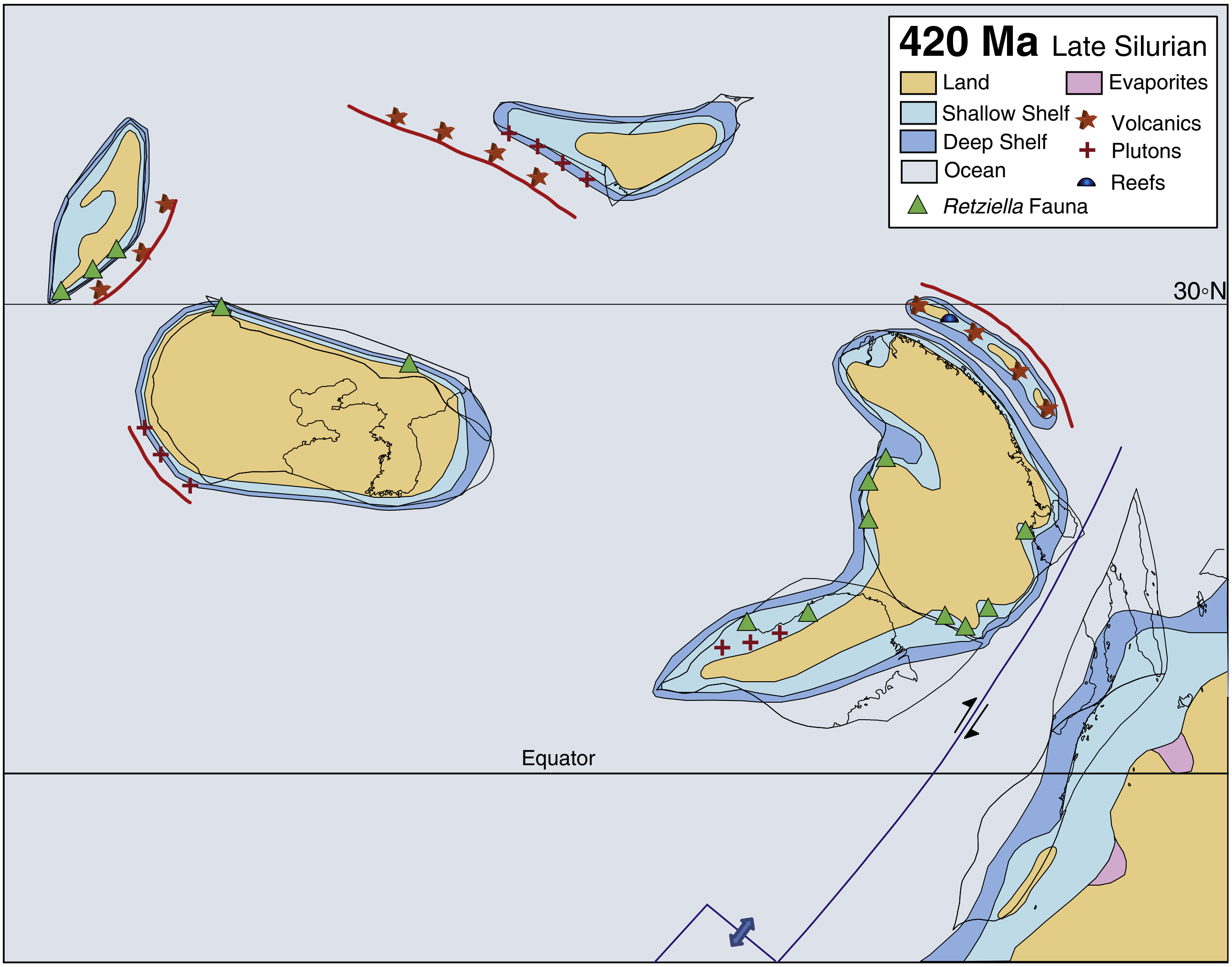

Fig. 12. Palaeogeography in the Late Silurian (Late Ludlow) at 420 Ma. Red lines are subduction zones. The *Retziella* Faunas are brachiopods characterised by Rong et al. (1995).

terranes; however, in either case it must have lain off the northern margin of the maps in this paper. In any case, the tectonics of the southern margins of peri-Siberia were very complex.

4.5. Nuhetdavaa Terrane

Between the Hutag Uul–Songliao Terrane and the Gobi Altay–Mandalovoo Terrane of peri-Siberia lies the Xinlin–Xiguitu Fault Zone. We have combined the Hinggan (or Xing'an) Terrane of various authors, which includes the Dong Ujumqin Belt within China (Yue et al., 2001; Wu et al., 2011), with its westwards extension into Mongolia, which was termed the Nuhetdavaa Terrane by Badarch et al. (2002: their Unit 40). The terrane includes the Turan Unit (M6) of the 'Manchurides' of Sengor and Natalin (1996). Li (2006) showed a large area which he termed the 'South Mongolian–Central Khingan Orogenic Belt' bounded by the main Mongolian Lineament to the northwest and a 'Burean–Jiamusu Palaeoplate' to its southeast, and to the southwestern end of the latter is attached the 'Suolunshan–Central Jilin Orogenic Belt'. The Nuhetdavaa Terrane straddles today's southeastern boundary of Mongolia and Inner Mongolia, China. It is composed of Neoproterozoic metamorphic rocks, Cambrian to Silurian sediments, Devonian volcanics and minor sediments, including coralliferous limestones, and Lower Carboniferous shallower water sedimentary rocks, all intruded by Silurian, Carboniferous, Permian and later plutons. Badarch et al. (2002) also concluded that Nuhetdavaa continued eastwards into China as the Dong Ujimqin Belt. Yue et al. (2001) reviewed that belt, which consists of remnants of Cambrian to Middle Ordovician passive continental margin rocks which have yielded faunas of general Chinese affinity, which are unconformably overlain by Silurian arc rocks and associated sediments, followed by Devonian back-arc sediments; then, after a further unconformity, Middle Carboniferous and Permian arc rocks, followed by Late Permian terrestrial rocks. Li et al. (2011) reviewed the Xilin Gol Complex of Inner Mongolia, China, which we have arbitrarily included within the Nuhetdavaa Terrane, and concluded that subduction started at Cambrian–Ordovician boundary time at 490 Ma, and oceanic island arcs were active in the Ordovician (around 452 Ma) and the Early Carboniferous at around 339 Ma. Wu et al. (2011) dated granites from the Chinese sector, and identified six as Ordovician, one as Devonian, twelve as Carboniferous and six as Permian.

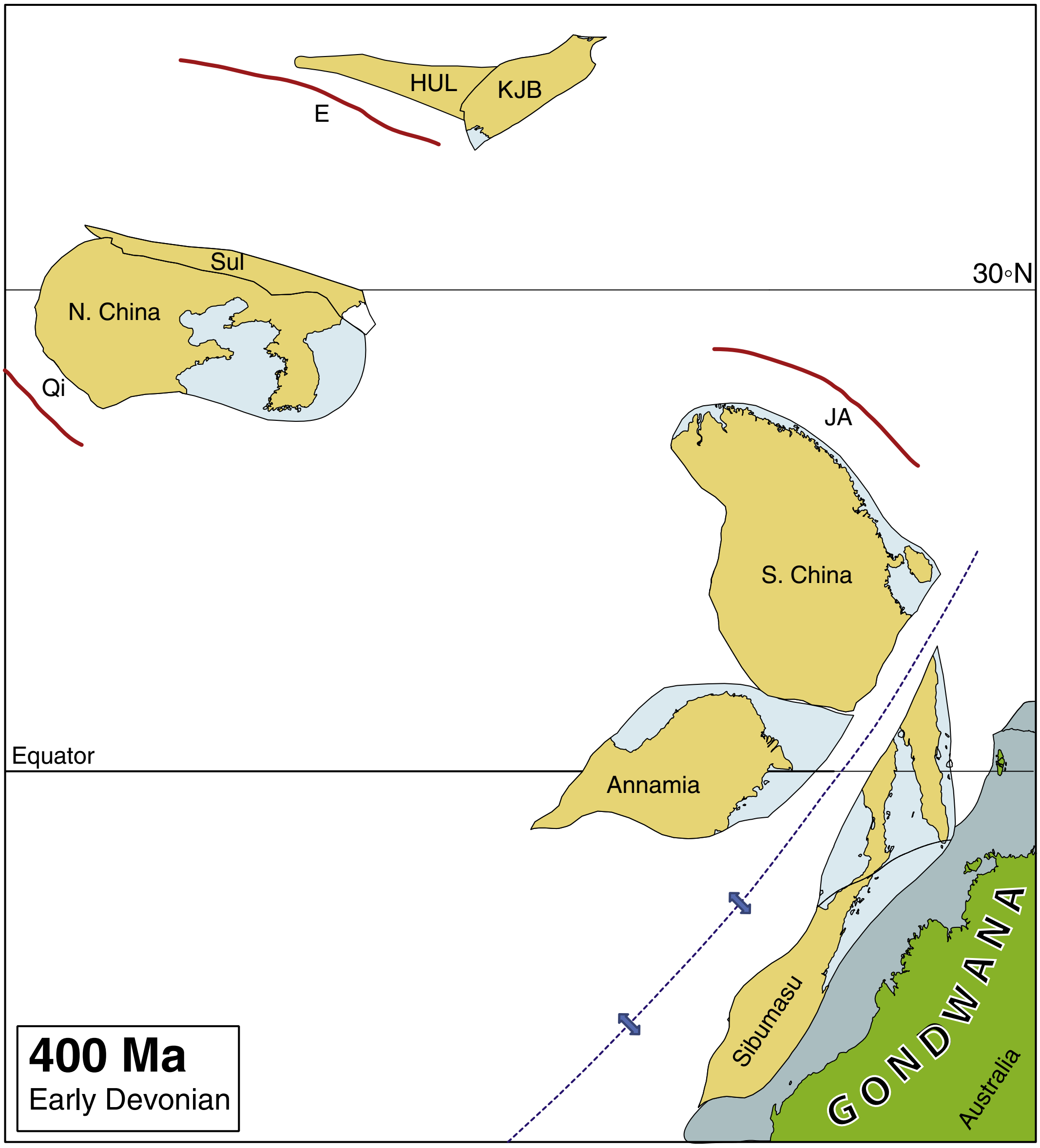

Fig. 13. Distribution of major tectonic units in the Early Devonian (Emsian) at 400 Ma. E, Enshoo Arc; HUL, Hutag Uul–Songliao; JA, Japanese arcs; KJB, Khanka–Jiamusu–Bureya; Qi, arcs now in the Qaidam–Qilian Terrane; Sul, Sulinheer. Red lines are subduction zones.

In the west of the terrane, the Hing–Nuhet area contains Carboniferous calc-alkaline plutons and there is an extensive belt of Early Permian (289–287 Ma) calc-alkaline volcanics, reflecting the shift from an earlier volcanic arc to a later post-collisional continental extension regime (Zhang et al. (2011b)). Wilhem et al. (2012, Fig. 5) linked Nuhetdavaa with the adjacent Enshoo Terrane and also Songliao (Section 2.5 here) from the Cambrian onwards. The whole area was much deformed in the Permian prior to the accretion of Siberia to the terranes to its south, during which there was much compression, as well as rotation and associated strike-slip faulting. This was extremely complex, and largely outside the scope of this paper, but the final accretion of the enlarged North China continent and associated terranes to Siberia did not take place until the Jurassic at around 150 Ma. However, the fact that Yue et al. (2001) recorded the characteristically Siberian Silurian brachiopod *Tuvaella* and also Late Carboniferous plants of the Angaran Province, indicates firmly that Nuhetdavaa formed part of peri-Siberia throughout Palaeozoic times, and Wu et al. (2011) depicted it as accreted to Siberia at about Cambrian–Ordovician boundary time at 490 Ma.

5. Palaeomagnetic review

The main anchor for our reconstructions has been Gondwana, for which a comprehensive Apparent Polar Wander (APW) path is now known throughout Palaeozoic times (Torsvik and Cocks, 2011; Torsvik et al., 2012). Comparably, Siberia, which lay off our maps to the north, is also confidently placed. However, the remainder of the areas considered in the present paper are not so well positioned, although South China and North China have yielded some palaeomagnetic data (Fig. 2), as briefly reviewed below. Reliable palaeomagnetic data from Tarim are only available from the Middle Devonian and onwards, when Tarim is off our maps.

5.1. South China

The Cambrian to Early Triassic from South China include 33 poles, but 28 of these are Permian–Early Triassic in age and thus lower-mid Palaeozoic poles are almost absent. 11 poles, including all the Lower Palaeozoic poles (Late Cambrian–Silurian), are derived from clastic

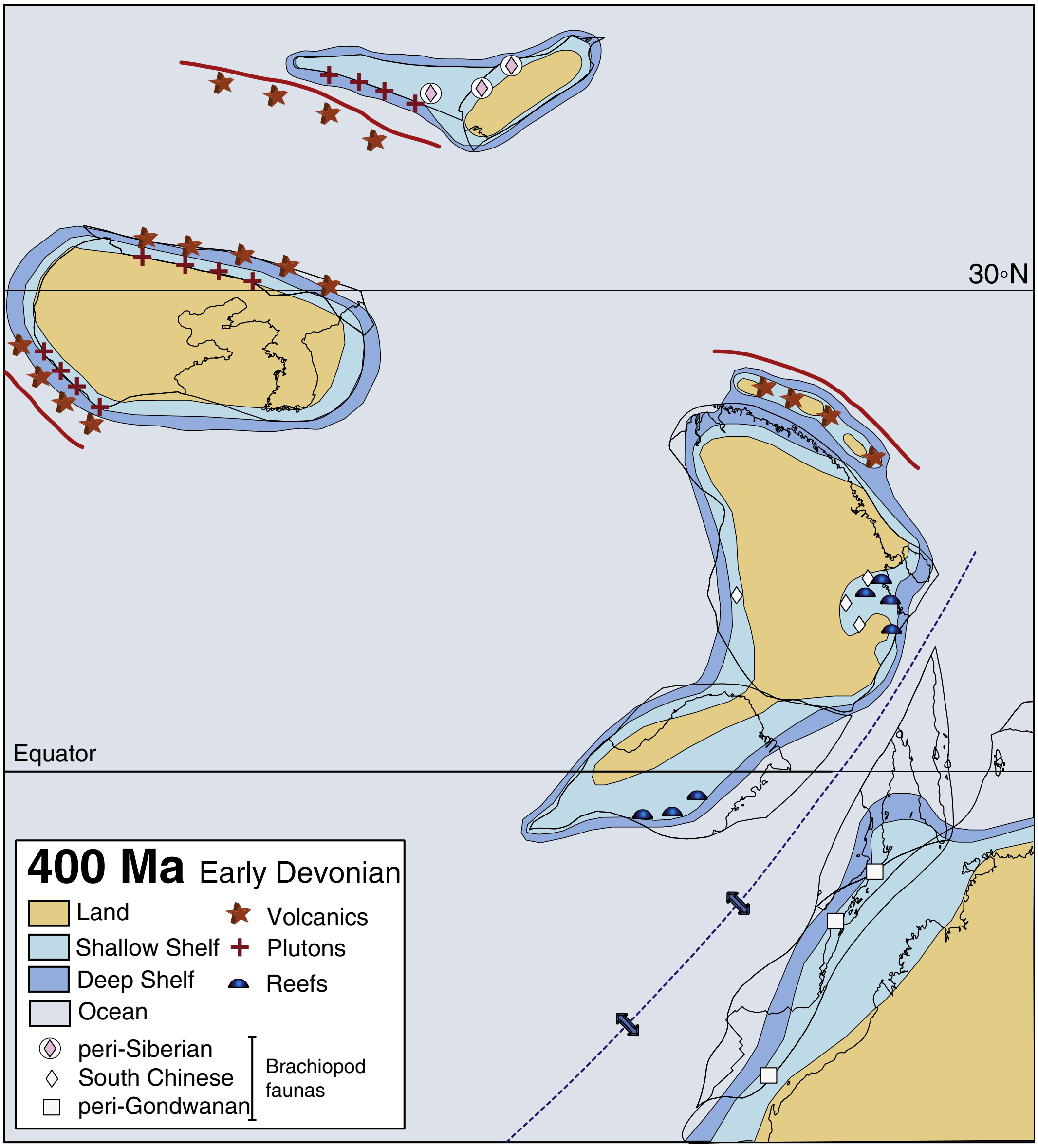

Fig. 14. Palaeogeography in the Early Devonian (Emsian) at 400 Ma. Red lines are subduction zones. Also plotted are representative brachiopod localities: all were within the Old World Realm, but they have yielded sufficient proportions of endemic genera to define various regions (see text).

sediments, and all have been corrected for potential inclination shallowing using a fixed flattening (*f*) factor ($f = 0.6$). A similar correction is applied to poles from all other continents used in our analysis, e.g. North China (updated from Cocks and Torsvik, 2002; Torsvik and Cocks, 2004) and Gondwana (Torsvik et al., 2012). Apparent polar wander (APW) paths (Fig. 2, Table 1) were generated using the spherical spline method (Torsvik et al., 1996) but, due to severe interpolation in the Lower and Upper Palaeozoic, many poles were actually not used in our reconstructions. There are two lower Palaeozoic poles, one Late Cambrian (510) suggesting an equatorial latitude, whilst the Early Ordovician pole (ca. 480 Ma) suggests a palaeolatitude of about 50° South (or possibly North!) before returning to lower latitudes by the Mid-Silurian. South China is commonly portrayed in two different positions relative to Gondwana, either next to Australia (Torsvik and Cocks, 2009) or next to India/Pakistan (Torsvik et al., 2009). Thus we have decided not to use the sparse Cambrian and Ordovician poles, and have positioned the combined South China–Annamia continent outboard of Pakistan/Arabia in the Cambrian, as discussed in Torsvik et al. (2009) and in Section 15.2 below. The continent migrated along the Gondwanan margin, and reached a position offshore of eastern Australia by the Late Ordovician. Reliable palaeomagnetic poles were used for 440 to 400 Ma reconstructions; however, there are no good data between 370 and 310 Ma, but South China is shown in its most likely position outboard of Australia. The 280 and 250 Ma maps are again supported by strong palaeomagnetic data.

5.2. North China

Our North China selection includes 23 poles of which 12 are Late Permian–early Triassic. 15 sedimentary poles are corrected for potential inclination shallowing effects. APW (Fig. 2, Table 1) is much smaller for North China and the APW paths are widely different for the Palaeozoic. All our reconstructions for North China are based on the generated APW path. North China was mostly confined to palaeolatitudes within 20° from the Equator. When both South and North China latitudes are based on APW paths (at 250, 280, 400, 420, and 440 Ma), they always plot near each other in latitude but their orientations are different (as also seen in the APW paths) and their relative longitudes have been guessed.

6. Palaeogeographical evolution

There follows palaeogeographical maps at eleven periods through the Palaeozoic, in which establishing kinematic continuity between

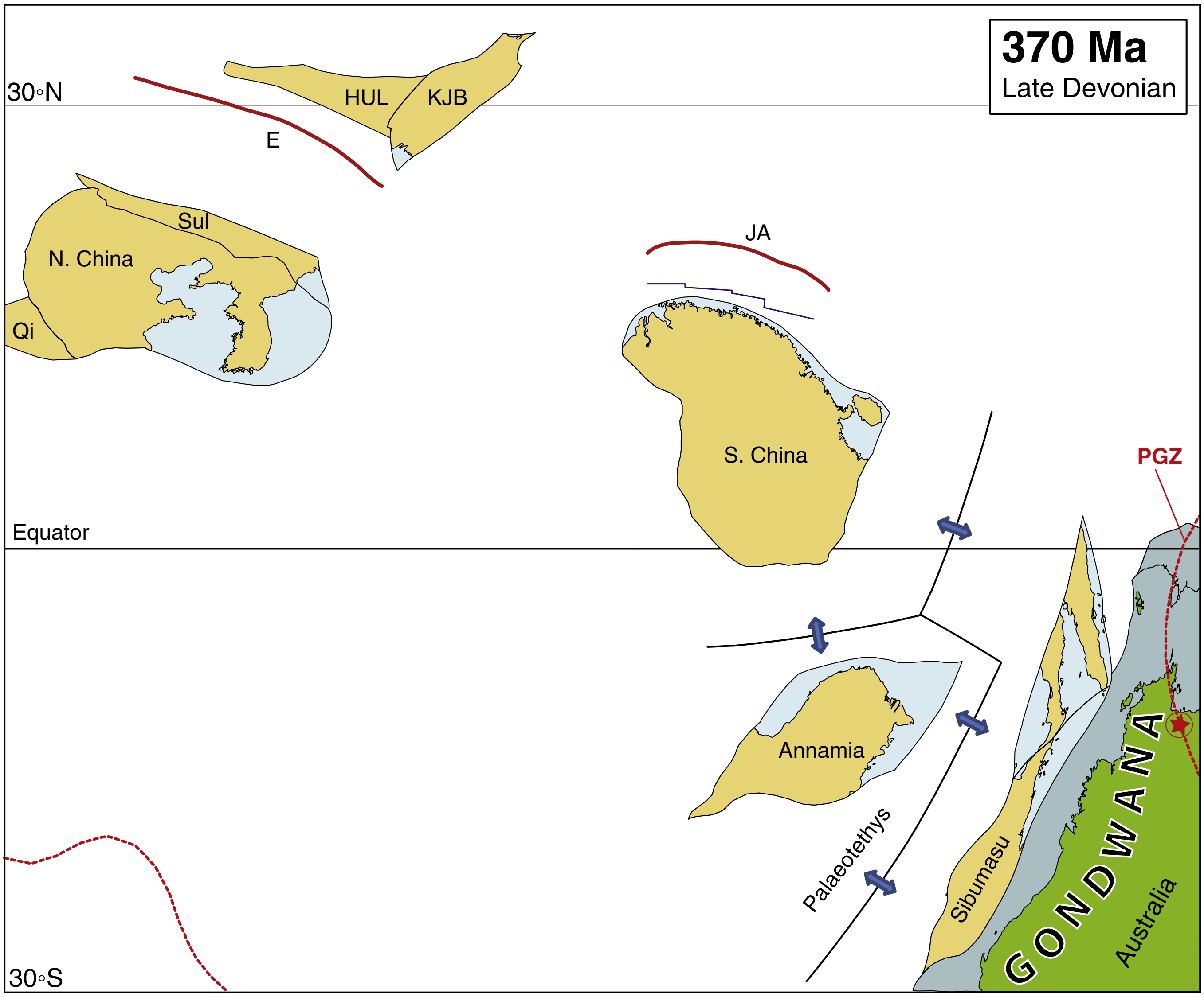

Fig. 15. Distribution of major tectonic units in the Late Devonian (Famennian) at 370 Ma. E, Enshoo Arc; HUL, Hutag Uul–Songliao; JA, Japanese arcs; KJB, Khanka–Jiamusu–Bureya; PGZ and thinner red lines, plume generation zones; Qi, Qaidam–Qilian Terrane; Sul, Sulinheer. Thicker red lines are subduction zones.

the construction of successive maps has been paramount. The main continental units are shown as they exist today, with outlines largely defined by post-Palaeozoic tectonism, and modern seas and land outlines have been drawn upon them to aid recognition. That is apart from North China, which we show as enlarged eastwards throughout all the Palaeozoic because the Lower Palaeozoic shallow- to deep-water facies show that the eastern end of the continent was truncated by post-Palaeozoic faulting. However, there are sometimes wide discrepancies between those modern boundaries and the ancient units; for example, the western (Thai) sector of Annamia simply did not exist in the Cambrian (Ridd et al., 2011), even though the modern Annamian outline is shown on Fig. 3 and subsequent figures. There are two maps for each period, the first with only today's units shown and with locality names, and the second with the lands, shallow and deeper shelf seas, the sites of volcanic and plutonic igneous extrusions and intrusions, as well as some facies, such as reefs, and faunal or floral sites of biota key to interpreting the palaeogeography on some of the maps. The relative positions of the major units have been determined primarily through palaeomagnetic data, but those data vary in quality and quantity and also show only the palaeolatitudes and unit rotations of old continents, not palaeolongitudes. However, some longitudinal fixes have been obtained through the locations of Large Igneous Provinces (LIPs) and kimberlites sourced by plumes from the core–mantle plume generation zone (PGZ) at the core–mantle boundary (Torsvik et al., 2008, 2010). The PGZ is shown on our maps.

Supplementing the palaeomagnetic data are analyses of the biofacies which show how similar or different are the biota of adjacent terranes. Particularly useful have been marine macrobenthos such as trilobites and brachiopods, many of which were reviewed for the Ordovician and Silurian by Fortey and Cocks (2003), and terrestrial floras in the Carboniferous and Permian. Also critical to our map reconstructions is parsimony when charting subduction zones and spreading centres; for example, it is best to suppose only two major Palaeozoic rifting events at the north-eastern Gondwanan margin, the Palaeotethys Ocean opening in the Early Devonian, and the Neotethys Ocean opening in the Permian, rather than concluding that the various continental blocks left Gondwana at separate times.

One of the most difficult problems has been to assess the significance of the numerous analyses of Precambrian zircons that have been published from many areas across the region. Those areas with many peaks in the zircon occurrences indicate sources from a large continental area, the most obvious of which is the superterrane of Gondwana, and such multiple zircon peaks are to be found in Tarim, North China and South China, as well as in some microcontinents with Precambrian cores within them. We think it is the most likely that the zircons did indeed originate from Gondwana, but there

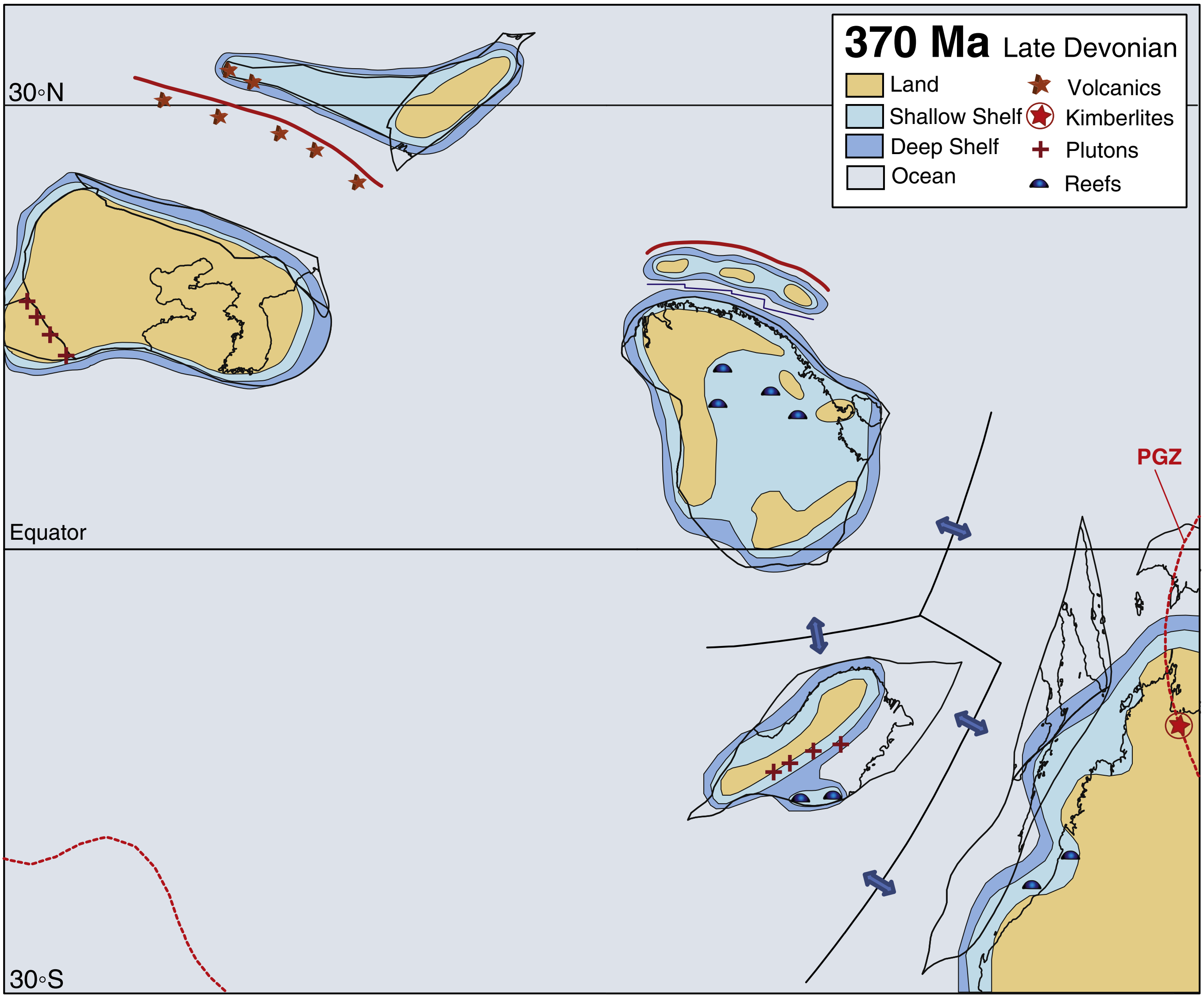

Fig. 16. Palaeogeography in the Late Devonian (Famennian) at 370 Ma. Thinner red lines and PGZ, plume generation zones, thicker red lines are subduction zones.

seems to be no way of telling when in the Precambrian those continents rifted away from Gondwana and thus where those important continents were at the beginning of the Palaeozoic, which is one of the reasons why the earliest reconstruction here is of the Late Middle Cambrian. The relative positions of North China, South China and Annamia are discussed further in Sections 15.1 and 15.2.

Because our maps are on a relatively small scale, and because all the units have been much affected by subsequent tectonism, they must be seen as simplifications. Further uncertainties, particularly in the region today west and southwest of the North China continent where many authors have published differing conclusions, are the polarity directions of the many subduction zones in varied areas and times, and, as a result, all our subduction zones are shown as broad bands without indicated polarity on Figs. 3 to 24, rather than with an arbitrarily-designated polarity.

The Siberia and North China (Fig. 2) continents have yielded a substantial amount of palaeomagnetic data, which demonstrates that they were more than 25° of latitude apart at the end of the Palaeozoic at 250 Ma, and their palaeogeographical relationships are discussed in Section 15.3.

7. Precambrian prelude

All of the major global continental units in the region have at least a proportion of Precambrian basements, many of Archaean and Palaeoproterozoic ages, but the overall palaeogeography remains extremely speculative. Most of them apparently formed parts of the Rodinia supercontinent, which probably assembled between 1.2 and 1.0 Ga. Rodinia broke up at about 800 Ma (Torsvik, 2003; Torsvik and Cocks, 2011); however, the relative positions of the various continents to each other between then and the start of the Cambrian are poorly constrained. The assembly of Gondwana was only complete just before the end of the Precambrian and it extended then from beyond the South Pole to the Equator (Torsvik and Cocks, 2011). Siberia and most of the peri-Siberian terranes were in the southern hemisphere (Cocks and Torsvik, 2007). To the north of both of them lay the vast Panthalassic Ocean. Baltica was also south of the Equator, and Laurentia straddled the Equator.

Which Precambrian continents and microcontinents were independent in the rest of Asia is hard to be sure of, although we believe that North China, Tarim and Khanka–Jiamusu–Bureya were separate individual entities at the start of the Cambrian, and there are also Neoproterozoic and earlier rocks in Qaidam, Kunlun, and Ala Shan (Tsagan Uul) which perhaps formed smaller microcontinents within those composite units. It is probable that the combined South China and Annamia continents were at the Gondwanan margin, but whether or not they formed an integral part of the supercontinent and exactly where they were placed is uncertain. Thus the Late Neoproterozoic positions of all the continents and microcontinents with Precambrian cores considered here are very poorly constrained, apart from the core of Gondwana itself. However, it is interesting to note that Neoproterozoic glacial deposits are present in the Alax Block of Ala Shan, Tarim and South China, but not in North China (Lu et al., 2008).

8. Cambrian

To attempt palaeogeographical reconstructions for the Early Cambrian is even more difficult for eastern Asia than in most other

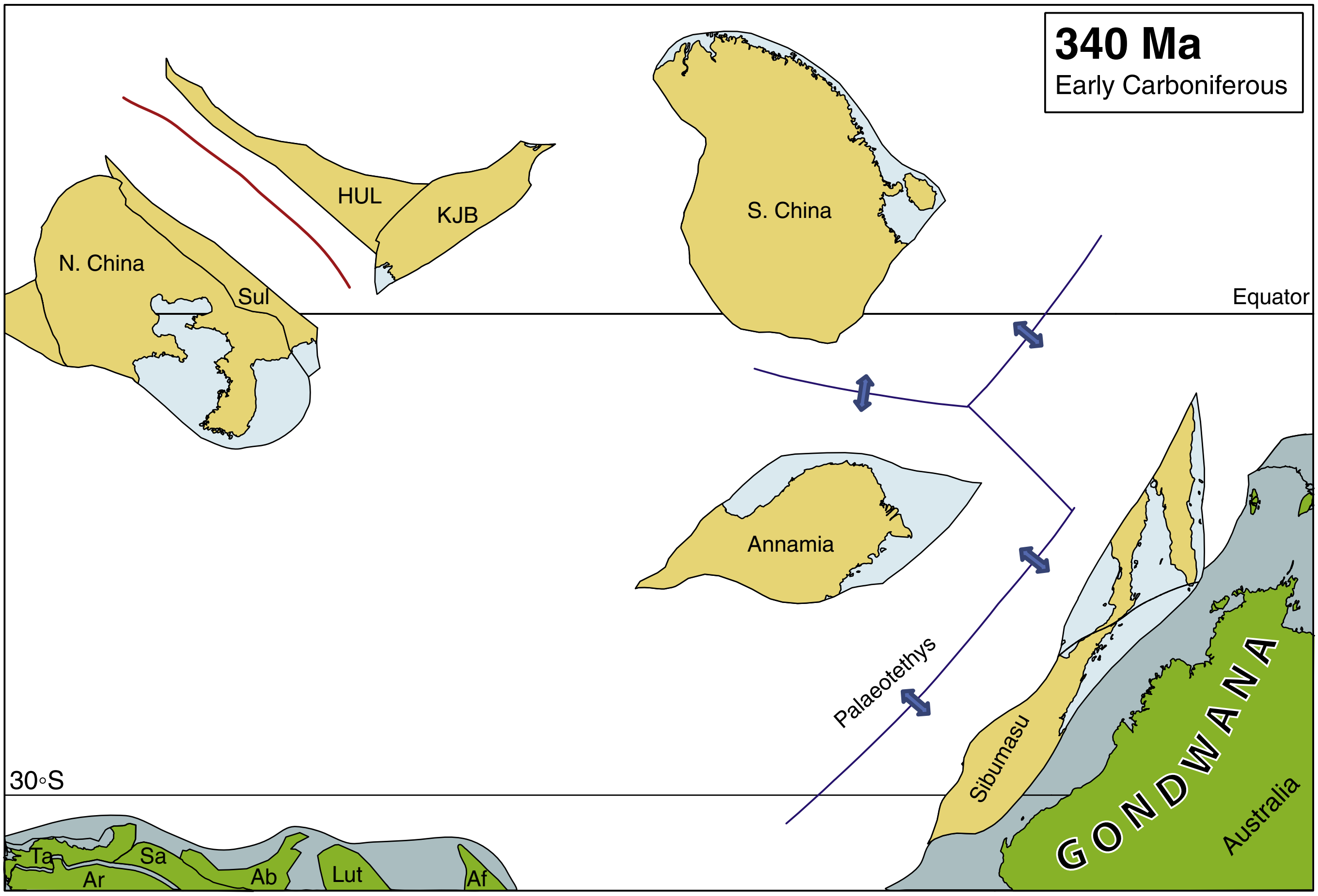

Fig. 17. Distribution of major tectonic units in the Early Carboniferous (Visean) at 340 Ma. Af, Afghan Terrane; Ab, Alborz Terrane; Ar, Arabia; HUL, Hutag Uul–Songliao; KJB, Khanka–Jiamusu–Bureya; Sa, Sanand Terrane: Ta, Taurides Terrane. Red lines are subduction zones.

parts of the world, which is why our earliest reconstruction here (Figs. 3 and 4) is for the latest Middle Cambrian at 510 Ma, although Torsvik and Cocks (in press) have generated tentative global maps at 10 my intervals from 540 Ma onwards. Our reconstruction is based on palaeomagnetic data for only the main Gondwanan superterrane and North China. There is only a single Late Cambrian pole for South China, which places it on the Equator, but there is in addition another single pole for the Early Ordovician that places the same continent at around 45° S, and so thus we cannot use such disparate palaeomagnetic data for positioning that continent at either of those ages. Thus we have placed South China in a similar position to that in Torsvik et al. (2009), relying largely on faunal and sedimentological data, and added Annamia to it, as discussed in Section 15.1. We show the centre of the 510 Ma Kalkarindi Large Igneous Province (LIP) in western Australia, and also the Penggjiabang kimberlite in South China. The latter was originally considered as of Carboniferous age, but is now known to be Cambrian (estimated at 508 Ma by Zhang et al., 2001). The relative longitude between Gondwana and South China is calibrated by locating the LIP and the kimberlite above the plume generation zone (PGZ), as explained by Torsvik et al. (2008), and assuming that the two and approximately antipodal large low-shear velocity provinces at the core–mantle boundary have remained stable for the entire Phanerozoic. The Qaidam–Qilian microcontinent depicted by Song et al. (2009a) is placed schematically to the southwest of North China, but its substance and scale are quite unconstrained.

8.1. Tectonics and igneous activity

Much of the region was affected by Late Neoproterozoic (Ediacaran) to Early Cambrian tectonic activity, including the Early (539 Ma) and Middle (526 Ma) Cambrian volcanics in South China (Compston et al., 2008), and Findlay (1998) found the remnants of a Cambrian island arc in rocks (within the Song Ma Suture Zone) which accreted to South China before the Devonian. In the Hutag Uul–Songliao Terrane there are Late Cambrian to Ordovician (498–461 Ma) near-trench plutons and juvenile arc crust (Jian et al., 2008). Wilde et al. (2003) described Early to Middle Cambrian (525–515 Ma) granitoids in the Khanka–Jiamusu–Bureya Terrane. Off our reconstruction to the west, Junggar was an aggregation of Cambrian and later island arcs (Xiao et al., 2009b), and Qaidam–Qilian includes Middle Cambrian ophiolites (Yin et al., 2007) which were formed near the southwestern margin of North China. Lower Cambrian ignimbrites have been found in the east of Kunlun (Daukeev et al. 2002). The Songshugou ultramafic massif in the Qinling orogenic belt, which is today between North and South China, has been dated to 510 Ma (Middle Cambrian) by Liu et al. (2009), although it is uncertain where that massif lay in the Cambrian. Both the Himalayan margin of Gondwana and North China have yielded zircons indicating a tectonic event at 500 Ma, but it is not agreed where North China was situated; for example, McKenzie et al. (2011) placed it as bordering today's northeastern India. However, for various reasons discussed further in Section 15.2, we place North China at some distance away from Gondwana in this paper. As also discussed in Section 15, Annamia and South China were a combined continent situated off north-central Gondwana, perhaps near Afghanistan; however, the western (Thai) part of the Annamia continent did not exist at the time (Ridd et al., 2011). Whether the eastwards-moving strike-slip faulting which transported Annamia–South China from Afghanistan to Australia commenced in the Cambrian or at some time in the Ordovician is unconstrained; we show it from our 480 Ma reconstruction onwards. At some time before 520 Ma, the Cathaysian margin of southeastern

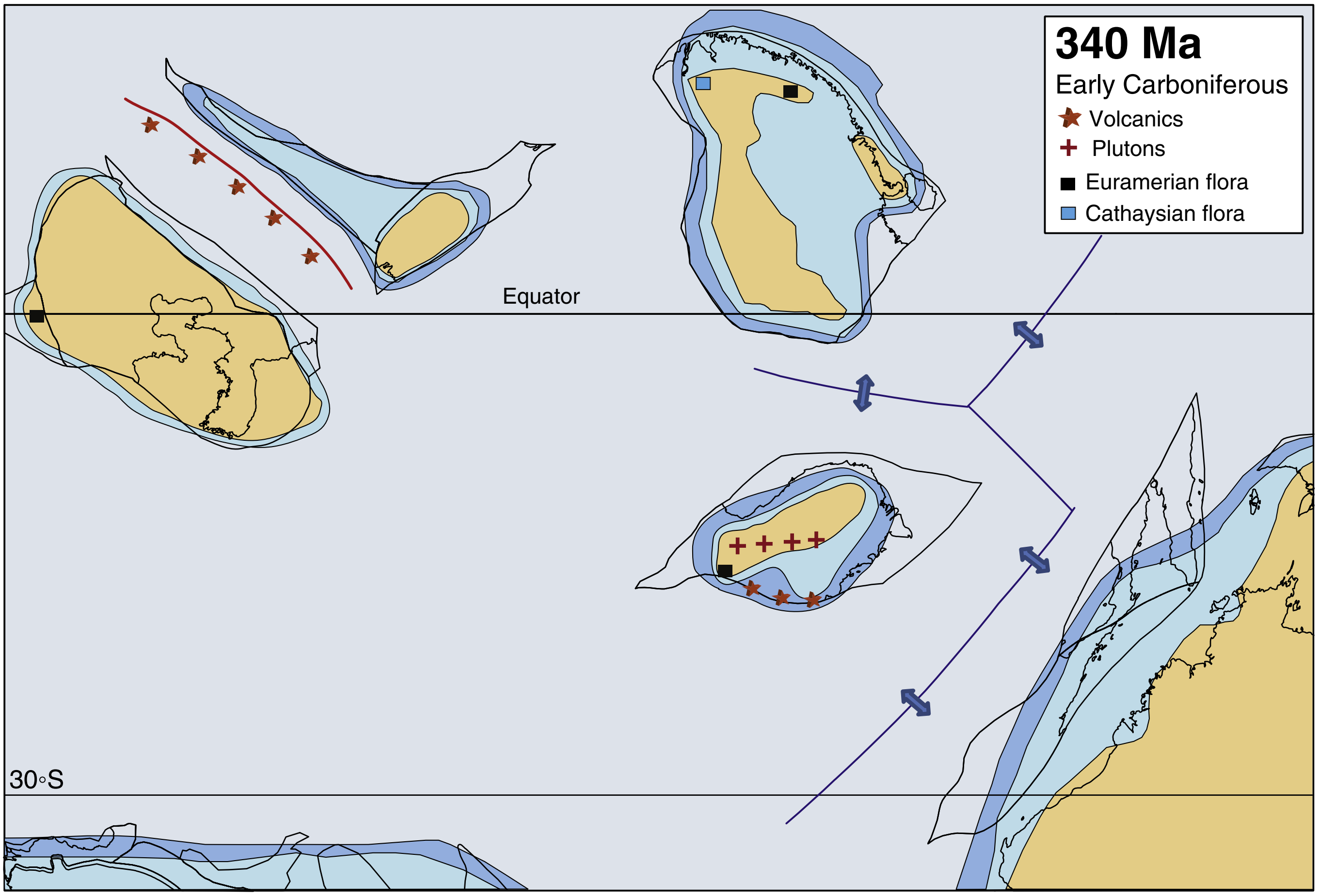

Fig. 18. Palaeogeography in the Early Carboniferous (Visean) at 340 Ma. Red lines are subduction zones. Provincial floras are shown from newly-reviewed data.

South China changed from passive to active, and the first parts of what are today identified as the Japanese terranes were deposited there (Isozaki et al., 2010).

8.2. Facies and faunas

Holmer et al. (2001) described the Cambrian to Early Ordovician brachiopod faunas from the Karatau–Naryn and Chu–Ili Terranes of Kazakhstan, and concluded that many of those faunas were very similar to some in South China; however, those similarities probably reflect the comparable low palaeolatitudes of the two terrane groups and the lengthy larval stages of most inarticulated brachiopods, rather than the close proximity of those terranes in the Cambrian. The joint presence of trilobites such as *Neoanomocarella asiatica*, *Parablackwelderia jimaensis*, *Sudanomocarina sinindica*, *Fuchoia bulba*, *Fuchoia oratolimba* and *Redlichia noetlingi* in both the Himalaya and South China (N.C. Hughes personal communication, 2011, and the data in Peng et al., 2009) also lends support to the revised position of South China in the Cambrian from straddling the Equator near Australia, as shown by Torsvik and Cocks (2009), to a slightly higher palaeolatitude but moved laterally a considerable distance so as to be offboard from India (Torsvik et al., 2009), who we follow in Figs. 3 and 4. As can be seen from the Cambrian conodonts analysed by Jeong and Lee (2000) and the trilobites reviewed by Choi et al. (2003) and McKenzie et al. (2011), North China (including Korea), South China and the Himalaya were all then in a largely similar faunal province, and thus North China and probably Tarim were not too distant from South China–Annamia and Gondwana.

Zhang (in Zhang et al., 2003) discussed the faunal provinces seen in the various divisions of China, noting that the Early Cambrian trilobites of South China were the most diverse in the world, epitomising the Redlichiid (or Perigondwanan) Realm, within which North China and Tarim, as well as the northeastern margin of Gondwana, were also placed.

9. Ordovician

We present two palaeogeographical reconstructions, for the Early Ordovician (Late Tremadocian) at 480 Ma (Figs. 5 and 6), and the Late Ordovician (Sandbian: Early Caradoc) at 460 Ma (Figs. 7 and 8). As in the Cambrian, both Gondwana and North China are sited through palaeomagnetic data, with North China located above the PGZ based on kimberlites ranging between 484 Ma at Hongqi and 465 Ma at Menhyin (Dobbs et al., 1994; Zhang et al., 2010). South China and Annamia are not located through using palaeomagnetic data, which again does not at present seem satisfactory in those areas.

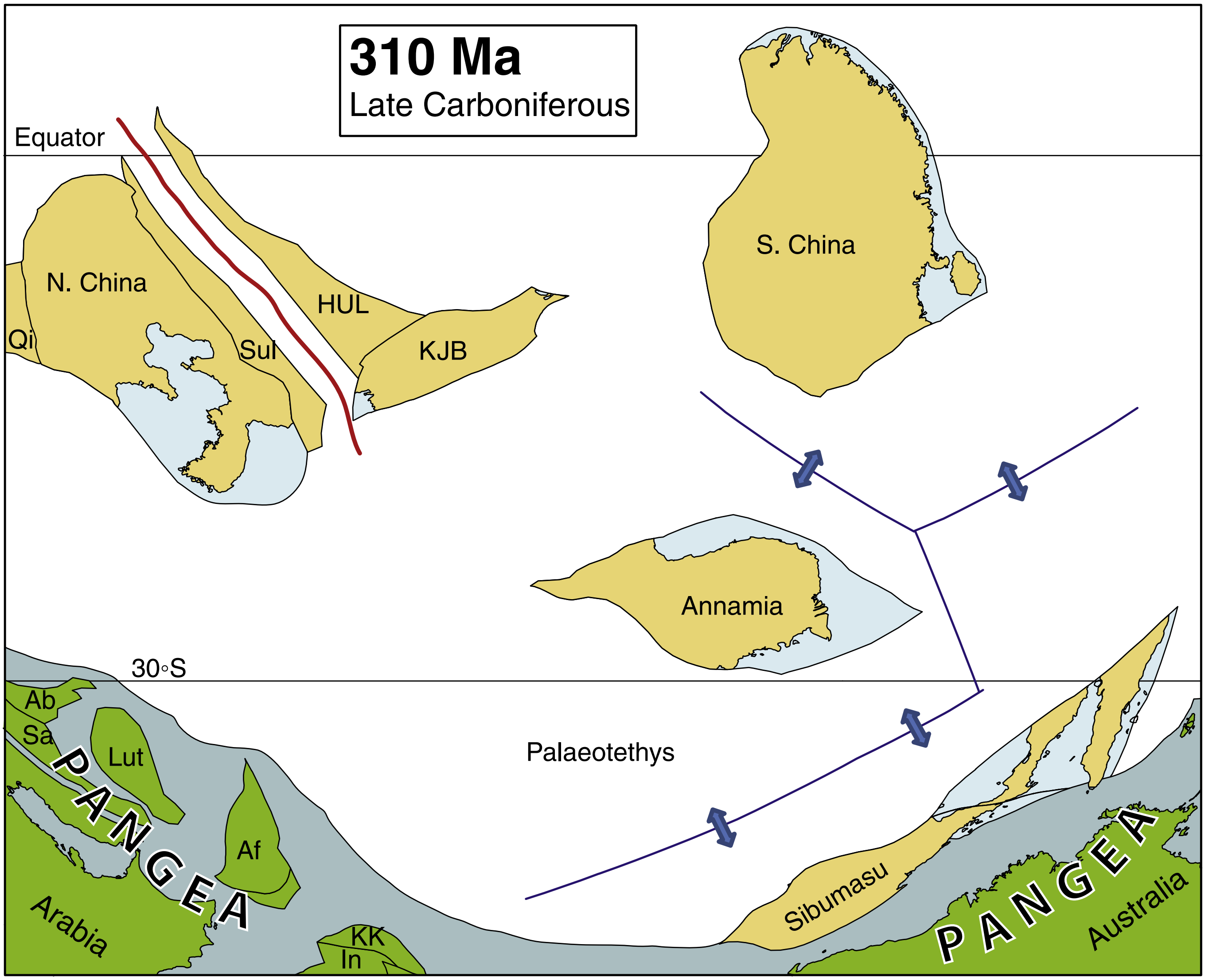

Fig. 19. Distribution of major tectonic units in the Late Carboniferous (Moscovian) at 310 Ma. Ab, Alborz Terrane; Af, Afghan Terrane; HUL, Hutag Uul–Songliao; In, India; JA, Japanese arcs; KJB, Khanka–Jiamusu–Bureya; KK, Karakorum Terrane; Lh, Lhasa Terrane; Qi, Qaidam–Qilian Terrane; Sa, Sanand Terrane; Sul, Sulinheer. Red lines are subduction zones.

9.1. Tectonics and igneous activity

Arc activity continued apace in many areas. Within the wide Mesozoic (Triassic and later) Song Ma Suture Zone between South China and Annamia there are remnants of a Cambrian to Ordovician island arc which accreted to South China before the Devonian (Findlay, 1998). The combined Annamia–South China continent continued its strike-slip progress northeastwards along the Gondwanan margin throughout the period. The Sulinheer sector of North China represents an arc–trench complex including Ordovician ophiolites and other volcanics intruded by Latest Ordovician and earliest Silurian (448–438) plutons (de Jong et al., 2006). The Qaidam–Qilian arc was still active off the southwestern margin of North China (Yan et al., 2010). In the Kitakami Terrane of Japan there was a Cambrian to Middle Ordovician island arc which were subsequently metamorphosed and then intruded by Late Ordovician (457–440 Ma) granites (Ehiro and Kanisawa, 1999): but it was situated off the eastern margin of South China in the Ordovician (Isozaki et al., 2010). Today's southern margin of Tarim had an Early to Middle Ordovician Andean-type active margin, with progressive accretion of island arcs (de Jong et al., 2006). The western (Thai) sector of Annamia was still non-existent throughout the Ordovician, although the Kontum Precambrian craton in the northeast of that continent had adjacent graptolite-bearing deeper-water sediments (Ridd et al., 2011).

9.2. Facies and faunas

In the Middle to Late Ordovician nearly all of North China was uplifted to form land, and extensive bauxite deposits were formed there (Wang et al., 2010), and that land persisted until Carboniferous times. In general, the substantial Tarim continent was a northward-dipping carbonate platform, which was fringed to the north by deeper-water facies that developed along the South Tienshan Mountains (Chen et al., 2010). As documented by Fortey and Cocks (2003), it was during the Early Ordovician that world-wide zoological provincialisation was at its most varied within the shallower-marine benthic faunas, particularly demonstrated by the trilobites and brachiopods. That provincialisation lessened as the Ordovician progressed; however, Nikitin et al. (2006) were able to demonstrate that the many brachiopods were still globally divided into three groupings even during the Late Ordovician; which they term the Tropical East Gondwana Realm (including Australasia, North and South China, and Kazakhstania and the rest of central Asia) distinct from both the Baltica Realm and the Laurentia–Siberia Realm. But even within those groups, there were still distinctive endemics; for example, the easily-identified and locally abundant plectambonitoidean brachiopod *Spanodonta*, first described from northwestern Australia, also occurs in comparable shallow-water

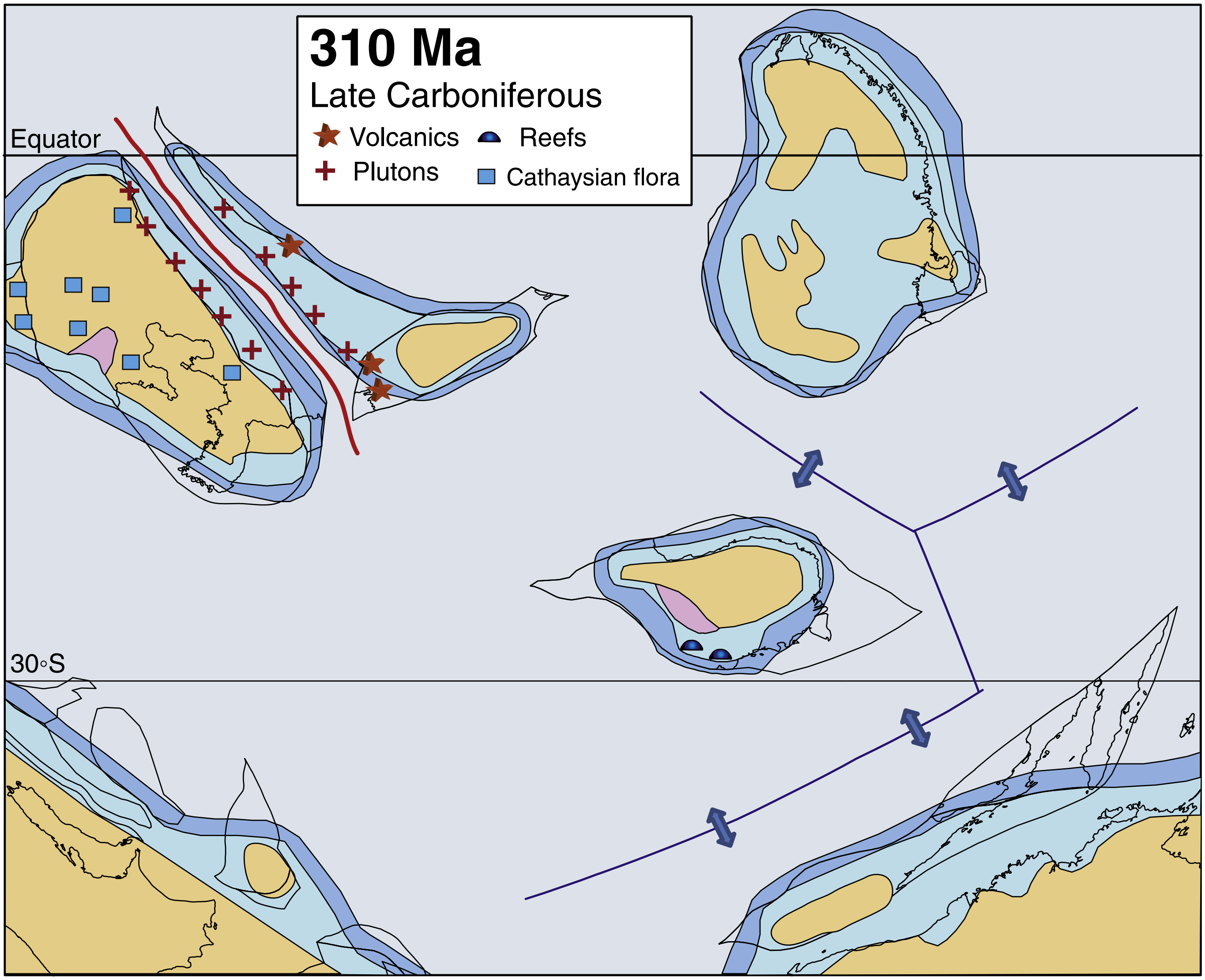

Fig. 20. Palaeogeography in the Late Carboniferous (Moscovian) at 310 Ma. Red lines are subduction zones. Provincial floras are shown from newly-reviewed data.

equatorial limestones in Sibumasu (Cocks et al., 2005), but not in South China or Annamia (Fig. 6). Also shown on Fig. 6 is the distribution of the pentameride brachiopod *Yangzteella* which was originally seen as endemic to South China, but which is now known also from Turkey, Karakorum and Iran. Furthermore, the analysis by Zhan and Cocks (1998) of Late Ordovician (Sandbian and Early Katian) brachiopod genera indicated that the diverse South China faunas did not have a high proportion of genera in common with North China, the Chu-Ili Terrane of Kazakhstan or the Australian faunas from the island arcs in New South Wales. That theme was further developed by Zhan et al. (2011), who demonstrated that the brachiopod endemism in South China grew from nothing in the Early Tremadocian (no endemics in the 8 articulated genera recorded) to over a quarter (23% to 28% endemics within a total of up to 52 articulated genera) in the Middle Ordovician (Dapingian to Darriwilian).

Zhou and Zhen (2008) undertook a cladistic analysis of all the trilobite genera found in the various parts of China at five successive Ordovician time intervals (Tremadocian, Floian to Early Darriwilian, Mid to Late Darriwilian, Sandbian to Early Katian, and Late Katian to Hirnantian). The faunas of Northern Xinjiang and Hinggan areas were peri-Siberian. But in contrast, the analysis demonstrated that, although quite different to Siberia; the North China, South China, Tarim and Qaidam–Qilian trilobites were closely related to each other throughout that period, forming a single faunal province, which the authors identified as essentially peri-Gondwanan. However, although that province was relatively uniform throughout its extensive region at the beginning and end of the Ordovician (Tremadocian and late Katian to Hirnantian); in the intervening Middle Ordovician period from the Floian to the early Katian it was divided into two contrasting subprovinces, one consisting of South China, Tarim and Annamia, and the other including North China, Sibumasu, southern Tibet (the Lhasa Terrane) and what Zhou and Zhen (2008) termed Tianshan–Beishan. That confirms in more detail the scenario suggested by Fortey and Cocks (2003), in which the Chingiz, Chu–Ili, Tien Shan and Tarim terranes were grouped together in the Sandbian (Early Caradoc) on the basis of their contained shallow marine brachiopods and distinctive trilobites such as *Taklamakania*, which was originally considered as endemic to Tarim but is now recognised as also occurring in the adjacent areas. Zhou et al. (2011), following detailed analysis of trilobite biotas, demonstrated that during the Early Floian there was a huge drowning of the very large platform area in South China, accompanied by a shoreward expansion of the deeper-water outer shelf assemblages, a deepening which continued on until the Early Darriwilian. To plot the facies within both

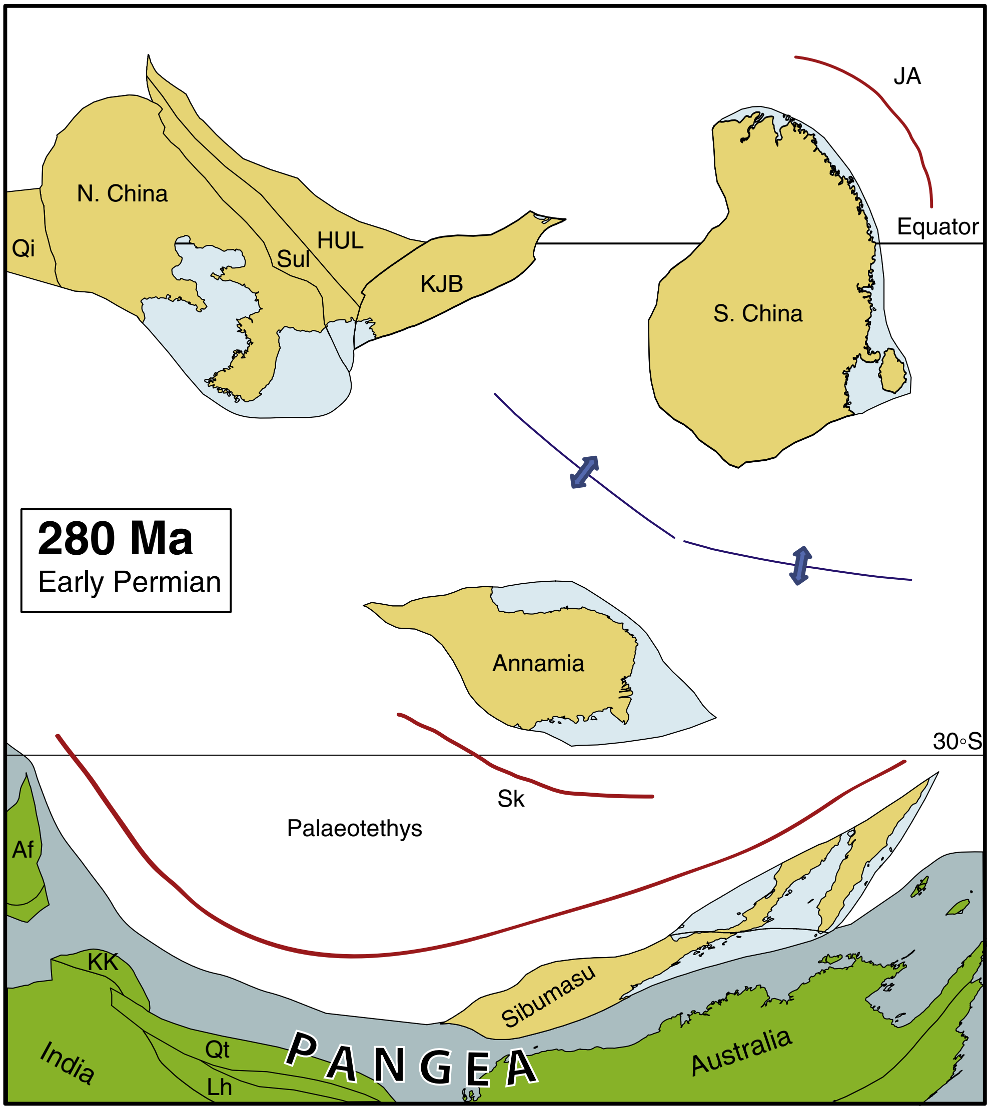

Fig. 21. Distribution of major tectonic units in the Early Permian (Artinskian) at 280 Ma. Af, Afghan Terrane; HUL, Hutag Uul–Songliao; JA, Japanese arcs; KJB, Khanka–Jiamusu–Bureya; KK, Karakorum Terrane; Lh, Lhasa Terrane; Qi, Qaidam–Qilian Terrane; Qt, Qiangtang Terrane; Sk, Sukothai and related island arcs; Sul, Sulinheer. Red lines are subduction zones.

North and South China we have largely used the maps of Chen et al. (2010).

The Dapingian–Darriwilian trilobites described by Zhou et al. (1998a) from the Chinese (Yunnan Province) sector of Ammania indicate that Annamia was probably near Gondwana, and the bivalves described by Fang and Cope (2004) from the same area also suggest affinity with South China and central Australia. As discussed in Section 15, we follow Cai and Zhang (2009) in thinking that Annamia was united only with South China in the Lower Palaeozoic, rather than agreeing with Metcalfe (e.g. 2011a, 2011b), who placed Annamia offshore of Sibumasu and attached to each other as parts of core Gondwana, together with North China, South China and Tarim.

10. Silurian

The Silurian was the shortest system in the whole Palaeozoic, lasting for only some 27 My. We present two palaeogeographical reconstructions, for the Early Llandovery (Rhuddanian) at 440 Ma (Figs. 9 and 10), and the Late Ludlow at 420 Ma (Figs. 11 and 12). Both are based on palaeomagnetic data for South China–Annamia, and North China is interpolated from data points at 464 Ma and 525 Ma. No Silurian kimberlites are known from eastern Asia.

10.1. Tectonics and igneous activity

Off the western margin of our maps, the core of the Kazakhstania continent was a largely unified area through the amalgamation of several terranes by the end of the Silurian (Windley et al., 2007), and off the southeastern margin there was substantial arc activity in eastern Australia (Percival and Glen, 2007). In contrast, there did not seem to be so much extensive tectonic activity in the region considered here as there had been in the Cambrian and Ordovician. However, Wilhem et al. (2012) suggested that Tarim may have collided obliquely with the eastern margin of the Kazakhstania continent in the Late Silurian; but the evolving history of Kazakhstan and surrounding areas is so complex and unresolved that we have shown Tarim as still independent in those times on Figs. 11 and 12.

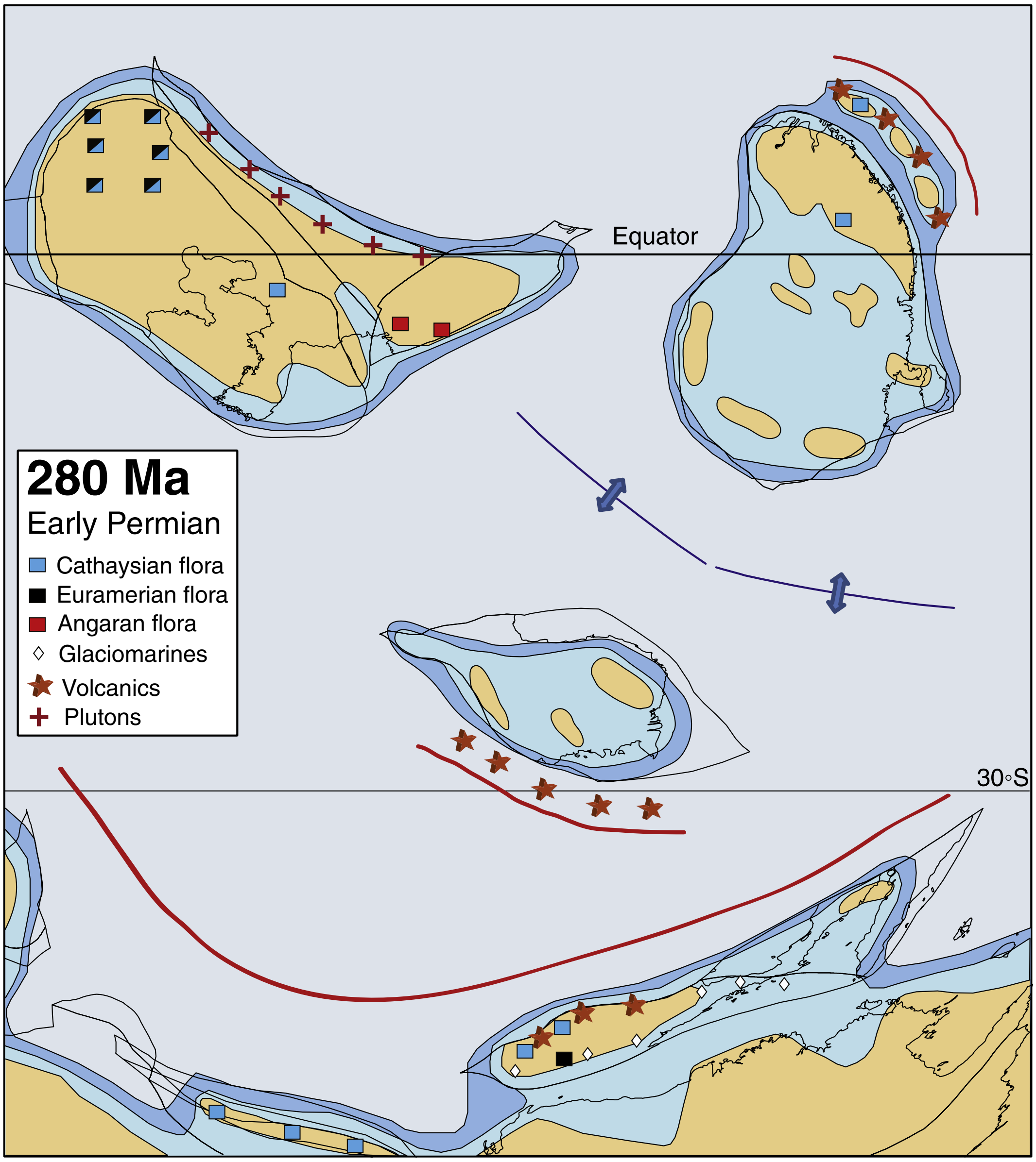

Fig. 22. Palaeogeography in the Early Permian (Artinskian) at 280 Ma. Red lines with teeth are subduction zones. Floral provinces are shown from newly-reviewed data: the sites where a combination of two provinces is found show the mix in two colours. The glaciomarine sediments in Sibumasu are plotted following Metcalfe (e.g. 1988).

In the Hutag Uul–Songliao Terrane there was Early Silurian (440–434 Ma) ridge subduction and subsequent microcontinent accretion which is preserved in the Solonker Suture Zone (Jian et al., 2008, 2010). On the southern margin of that zone, the Sulinheer Terrane had become substantial enough through the accretion together of several island arcs to identify separately on today's northern margin of North China from our Lower Silurian (440 Ma) reconstruction onwards. In the Qaidam–Qilian area adjacent to the southwestern margin of North China volcanism persisted until the earliest Silurian at about 440 Ma in northern Qilian Shan, and those volcanics were followed by sediments deposited in a forearc basin (Yan et al., 2010), all of which were subsequently intruded by 428 Ma granites (Zhang et al., 2009). At today's southwestern edge of North China, subduction continued, with the relatively small South Qinling Terrane being overridden by North Qinling (already accreted to North China), with the concommitant intrusion of numerous granulites within North Qinling, from near the start of the Silurian at about 440 Ma to about its end at 415 Ma; after which metamorphism continued in the North-South Quinling junction area up until the Early Devonian at about 400 Ma (Xiang et al., 2012). Whether or not the strike-slip movement between Gondwana and the combined Annamia–South China continued throughout the Silurian is poorly constrained, but it seems likely to have occurred, perhaps at a slower pace, since the rifting which heralded the opening of the Palaeotethys Ocean between the two continents did not commence until the Early Devonian. Carter et al. (2001) recorded Late Silurian (424 Ma) granites of uncertain significance as intruded within the Vietnam (eastern) sector of Annamia, although there are few, if any, Silurian rocks known from the western (Thai) sector of that continent (Ridd et al., 2011), which presumably remained oceanic.

10.2. Facies and faunas

Global temperatures increased slowly during the Early Silurian (Landovery) after the end of the latest Ordovician Hirnantian ice age, and there are few bioherms anywhere before the last stage of the Llandovery; for example, there are several Late Telychian bioherms in South China (Rong et al., 2003), which lay within the tropics. Copper (2002) has documented Silurian and Devonian reefs globally, and we have plotted his records on Figs. 12–16. There are no Silurian rocks known from the main North China Craton, which we therefore assume was still then land. Rong et al. (1995) analysed the Late Silurian brachiopod provincialisation in all of eastern Asia, and showed how the distinctive *Tuvaella* Fauna was confined to Siberia and peri-Siberia (off the north and east of our maps), in contrast to the *Retziella* Fauna, which was distributed over Tarim, North China, South China and Annamia, as well as the eastern margin of the Australasian sector of Gondwana (off the eastern margin of Fig. 12).

South China has numerous Silurian rocks with a wide variety of facies. Most of the earlier Llandovery is graptolitic shales, but the later parts of it, particularly the Telychian, contain abundant and diverse shallow-water marine benthic assemblages. Thirty-two sections with rocks and faunas of Telychian age in South China were reviewed in the volume edited by Holland and Bassett (2002). Telychian carbonates are confined mainly to the northwestern and southwestern margins of the Yangtze Platform and are absent in the central and eastern parts. Gonez et al. (2012) recorded a deltaic series in the Vietnamese sector of the South China continent within which are the occasional interbeds with plants similar to those from Kazakhstania and ranging from Ludlow to Pragian in age, as well as occasional layers with various brachiopods indicating marine incursions.

Young and Janvier (1999) after a comprehensive review of the Silurian and Devonian fish faunas of the region, grouped North China, South China, Annamia and Tarim together as a substantial unified continent which they termed the Asian Superterrane, placed offshore from Gondwana to its northeast and within the Panthalassic Ocean. That was chiefly because those constituent continents are the only places from which an entire order of fish, the Yunnanolepidoidei, is known. Nearly all of another fish group, the antiarchs with over 40 genera, are also recorded by them only from 'Asia', with 22 genera endemic to South China alone. However, that 'Asian Superterrane' is not supported by the rest of the geological evidence, and thus those fish must represent the varied distribution within a faunal province, rather than proving a separate continental entity.

The distribution of lands and seas of South China on our reconstructions is largely based on the data depicted on the eight successive palaeogeographical maps for the Latest Ordovician and Silurian published by Rong et al. (2003).

11. Devonian

We present two palaeogeographical reconstructions, for the Early Devonian (Emsian) at 400 Ma (Figs. 13 and 14), and the Late Devonian (Famennian) at 370 Ma (Figs. 15 and 16). There are palaeomagnetic data for North China for both maps and for the earlier reconstruction for South China–Annamia. Gondwana is based on interpolated palaeomagnetic data (Torsvik et al., 2012), and the longitude on the later map is calibrated with kimberlites from Australia.

11.1. Tectonics and igneous activity

Rocks of Devonian age are well documented from most parts of the present area; however, since it was more than twice as long as the Silurian (57 My as opposed to 27 My), there was more time for tectonic activity, of which there was a great deal. The most significant Devonian tectonic event was the opening of the Palaeotethys Ocean in the Early Devonian, which followed initial rifting in the Australian sector at the northeastern margin of the Gondwana superterrane which may have been as early as the latest Silurian and which continued westwards to the northwestern margin of Africa (Torsvik and Cocks, 2011). To the south of the Palaeotethys, Sibumasu, the Tibetan terranes and those terranes fringing India and further west all remained parts of Gondwana.

Metcalfe (2006, 2011a, 2011b) depicted Tarim, Annamia (Indochina), South China and North China as forming a single elongate and unified continent to the north of the widening Palaeotethys from the Early Devonian. Whilst agreeing that Annamia and South China were initially together as one unit, there seems to be no good reason to link them physically with North China and Tarim. As discussed in Section 15, we think that the previously-unified Annamia–South China palaeocontinent separated during the Devonian (Cai and Zhang, 2009) and the Song Ma Suture between North and South China did not close until the Jurassic. However, it is not precisely clear how the geometry and tectonics of that Devonian separation were linked to the Palaeotethys opening in the Early Devonian and whether or not those two events occurred at precisely the same time. The Palaeotethys Ocean appears to have opened before Annamia and South China separated; however, our depiction of the two units on our maps is still somewhat speculative. There is further doubt whether or not the Palaeotethys rifting is the same tectonic event which occurred much further westwards between the southern European terranes and the African sector of Gondwana, partly because the detailed timing is poorly constrained and partly because evidence of either rifting or the presence of intervening microcontinental blocks is not obvious between the two widely separated regions.

Yin et al. (2007) reviewed several models for Qaidam–Qilian, and concluded that south-dipping subduction of the Qilian oceanic plate, which had started in the Cambrian, continued until the Early Devonian (410 to 375 Ma), when collision of the Qilian Arc and North China occurred, associated with obduction of the Qilian Melange Complex over the passive margin of North China and Early Devonian metamorphism (Song et al., 2009b). However, Xiao et al. (2009a) placed the timing of the accretion as Late Devonian. Whichever is correct, we can show Qaidam–Qilian as an integral extension of North China in our Late Devonian and subsequent maps. Off our maps to the west, in the Yili area of the southwestern Tien Shan Mountains, Zhu et al. (2009) have documented substantial volcanics of Late Devonian and Carboniferous ages in the Atasu Zhamshi Terrane. Volcanic island arc rocks were active in the Gurvansayhan Terrane (Blight et al., 2010).

11.2. Facies and faunas

Cai and Zhang (2009) published summary facies maps for South China in the Early and Middle Devonian, which we have used to help compile our diagrams. Liao and Ruan (in Zhang et al., 2003) recognised, that, although both were within the Old World Realm, there were two separate faunal provinces in North China, Qaidam and Tarim on the one hand, and South China on the other. The brachiopods from the Hutag Uul–Songliao Terrane and Khanka–Jiamusu–Bureya microcontinent (Hamada, 1971; Su, 1988) can be added to the North China list. Although North China itself was largely land, the North China Province had many endemic brachiopods and corals in the Pragian and Emsian; however, the proportion of endemics dwindled from the Givetian onwards, so that by Frasnian times the whole area was within a single faunal province. Boucot and Blodgett (2001) also reviewed and augmented earlier work on brachiopod provincial zoogeography in the Early Devonian, and concluded that, in addition to the higher-latitude Malvinokaffric Realm seen in the Gondwana area off our maps to the south, for example in New Zealand, the remainder of eastern Asia lay within an overarching Old World Realm, although there is some overlap at the margins between the two realms in eastern Australia (Talent, 2000). Within the Old World Realm, various different regions can be recognised, including a separate South China Region, whose area also extended southwestwards from the South China palaeocontinent to include part of Kunlun. That fauna is also known from the northern Vietnamese sector of South China (Patte, 1926). Wang and Rong (1986) described a key Lower Emsian brachiopod fauna from Guangxi Province, South China, with many endemic genera, particularly *Dicoelostrophia*, *Eosophragmophora* and *Parathyrisina*. Overall, they found that 30% of the 81 brachiopod genera in the various Emsian localities in the South China Region were endemic.

The South China Region Emsian faunas plotted on Fig. 14 differed substantially from what Boucot and Blodgett (2001) called the ‘Balkhash–Mongolo–Okhotsk’ Region to the north, which we would term peri-Siberian, and also from the rather poorly-documented faunas described from the Hinggan Massif in the Hutag Uul–Songliao Terrane and the Khanka–Jiamusu–Bureya microcontinent (Hamada, 1971; Su, 1988), and again from the Gondwanan faunas known from its Australian and Sibumasu sectors, for example that described from southern Thailand by Boucot et al. (1999). However, as can be seen from our maps (Figs. 13–16), the relative positions of the major palaeocontinents did not change substantially during the Devonian, and thus the faunal differences in the earlier Devonian must have been due primarily to changing ocean currents or differing temperature gradients between equatorial and polar temperatures which varied substantially with time and which would thus have caused more varied local differentiation in climates. In the Late Devonian (Frasnian and Famennian) the whole area lay within one faunal province; for example, Talent (2000) reviewed the brachiopods of the Bonaparte and Canning Basins of northwestern Australia and noted that the reasonably diverse assemblages there consisted entirely of cosmopolitan genera, although a high proportion of the species were endemic. No Devonian faunas have been definitively described from the Thai sector of Annamia, where most of the probable Devonian rocks have been metamorphosed, although there are some possible Devonian corals of no provincial affinity known there from the Dok Du Formation (Ridd et al., 2011).

12. Carboniferous

We present two palaeogeographical reconstructions, for the Early Carboniferous (Visean) at 340 Ma (Figs. 17 and 18), and the Late Carboniferous (Moscovian) at 310 Ma (Figs. 19 and 20). The positions of Gondwana and North China (interpolated) are constrained by palaeomagnetic data, but South China and Annamia are not. No kimberlites are known. Gondwana formed an integral part of Pangea from 320 Ma onwards and is thus reconstructed using the new global mean pole of Torsvik et al. (2012).

12.1. Tectonics and igneous activity

The Palaeotethys Ocean between South China and Annamia to the north and Gondwana (including Sibumasu) to the south continued to widen throughout the period. Within Annamia there is an unconformity beneath the Middle Carboniferous which J. Booth and N. Sattayarak (in Ridd et al., 2011) identified as representing the first phase of the Indosinian Orogeny. Off our maps to the west, during the Middle to Late Carboniferous, the Central Tien Shan–Beishan region of northern China accreted to the Northern Xinjiang region (Zhou et al., 2007), termed the Ertix Terrane by Cocks and Torsvik (2007), indicating the initial accretion of the Kazakh continent to peri-Siberia. Substantial subduction and thrust faulting occurred to the south of South Tien Shan, particularly in the Early Carboniferous between 360 and 320 Ma, which caused much metamorphism there and culminated in the collision between South Tien Shan and Tarim in the latest Carboniferous or Early Permian (Zhou et al., 2001a; Zhang et al., 2008). Volcanic island arc rocks were active in the Gurvansayhan Terrane, to the north of which there were highly effusive plateau volcanics at 323 Ma (Serpukhovian) in the southern margin of peri-Siberia (the Gobi Altai area), giving a date for the final accretion and continental assembly within Pangea for the southeastern Mongolian area (Blight et al., 2010). In the Japanese terranes, still outboard of South China, new arc activity started after the relative quiescence of the Devonian (Tazawa, 2005).

Zhang et al. (2007) described granite plutons ranging from 302 to 304 Ma, indicating the presence of an Andean-style continental arc along the northern margin of the North China continent. In contrast, the southwestern margin, along which Qaidam–Qilian had previously been accreted, appears to have been passive.

Metcalfe (2011a, 2011b) presented a reconstruction showing South China, Tarim, Annamia and North China together in a string as the Neotethys Ocean opened, although the eastern end of North China was still attached to the Australian sector of Gondwana in the Late Devonian and Early Carboniferous (Tournaisian). By the Visean, which came shortly afterwards at 340 Ma, he showed a very different picture, with Tarim close to Kazakhstania, North China by itself, and South China and Annamia united and half-way between North China and Australasia. This is a rather different scenario from that shown in Figs. 14 to 18 here.

12.2. Facies, floras and faunas

From Namurian times, through much of the later Carboniferous and into the earliest Permian (320 to 290 Ma) there was a substantial but intermittent series of ice ages. It is by the presence of glacial sediments in Gondwana and adjacent areas (including Sibumasu and the Tibetan terranes), and the absence of those glaciogenic sediments from the Chinese terranes, Tarim and Annamia, that helped Metcalfe (e.g. 2006, Fig. 1) to ascertain the suture site of the Neotethys Ocean.

Although some floras of Devonian age have been described from the region, it was not until Carboniferous times that floral provinces can usefully be distinguished. On the Early Carboniferous reconstruction at 340 Ma (Fig. 18), Euramerian floras, including the characteristic *Lepidodendron* and *Paripteris*, are plotted as occurring in Annamia, South China and North China, and the first Cathaysian flora is recorded from South China. However, in the Late Carboniferous at 310 Ma, only Cathaysian Province floras are known from the region (Fig. 20).

Lethiers and Crasquin-Soleau (1995) published the global distribution of key end-Carboniferous to Permian ostracods, and noted how dissimilar those of eastern Asia were from the North America part of Pangea, and concluded that the prevalent ocean currents at that time probably flowed from west to east. Unfortunately there has been no overall definitive survey which might have allocated the many and often diverse brachiopod faunas known from eastern Asia into identifiable and recognised separate provinces useful in unravelling the palaeogeography. Cai and Zhang (2009) published a summary facies map for South China in the Early Carboniferous, which we have used to help compile our diagrams. In North China, Lower Carboniferous rocks are absent, and Wang et al. (2010) described bauxite deposition in the centre of North China immediately above the regional Middle Carboniferous unconformity which overlies basement of Cambrian and Ordovician ages.

Most of the Upper Carboniferous rocks of North China are nonmarine, with coals of commercial quality in places, and Cope et al. (2005) reviewed the various coal deposits present there. However, in the eastern sector of the continent Lee et al. (2010) described the Late Carboniferous (Moscovian) brachiopod associations from the Taebaeksan Basin of Korea which included the diverse *Choristites* Assemblage, and which, although generically similar to comparable communities from South China, Annamia and Tarim, has numerous species which are endemic to North China. In the Thai sector of Annamia, K. Ueno and T. Charoentitrat (in Ridd et al., 2011) documented Visean brachiopods and foraminiferans of no provincial affinity within Fammenian to Tournaisian faunas from sea mounts which were deformed before Upper Carboniferous clastic rocks were unconformably deposited upon them. The latter include coals and gypsum beds which are interbedded with marine rocks containing brachiopods and foraminiferans, and that sequence continues on upwards into the Permian. Off the northwestern border of our maps, the Carboniferous of Tarim includes a variety of turbidites and volcanic rocks, with a stable carbonate platform of marine deposits in the Tarim Basin in the southwestern part of the palaeocontinent (Wang, X. and Jin, Y., in Zhang et al., 2003).

13. Permian

We present two palaeogeographical reconstructions, for the Early Permian (Artinskian) at 280 Ma (Figs. 21 and 22), and at the Permo-Triassic boundary at 250 Ma (Figs. 23 and 24). Pangea is placed according to the mean pole of Torsvik et al. (2012), North China and South China also have good palaeomagnetic data (although the latter is only from 260 Ma onwards). There are no kimberlites recorded from the region, but the Emeishan Traps LIP of South China, which were extruded from 260 Ma, provide a longitudinal fix (Torsvik et al., 2008). Much of the palaeogeography of eastern Asia was shown in the Late Carboniferous and Permian reconstructions of Siberia (Cocks and Torsvik, 2007; Figs. 14 and 15). Ziegler et al. (1997) also reconstructed the palaeogeography at four successive periods from the earliest to the latest Permian, as well as analysing the topography and successive climates. Shi (2006) published a Middle Permian (Wordian–Capitanian) reconstruction which included the eastern Asian area.

13.1. Tectonics and igneous activity

Most of Pangea was unified prior to the start of the Permian, but a great deal of rotational movement continued along the important strike-slip faults which bordered peri-Siberia; however, that all occurred in the areas outside the northern and western margins of the maps published here.

At some stage in the period, sea-floor spreading ceased in the Palaeotethys Ocean and changed to subduction, but the precise timing is poorly constrained, although Late Permian calc-alkaline granites indicating subduction are known along the Dian–Qiong Suture Zone between Annamia and South China, as reviewed by Cai and Zhang (2009). The Neotethys (sometimes termed the Mesotethys) Ocean opened by progressive rifting during the Middle Permian at about 260 Ma within the northern rim of the main Gondwanan Craton, following earlier rifting there. Fringing the northern flank of the Neotethys, as well as Sibumasu, were the united Tibetan terranes of Qiantang and Lhasa (off Fig. 21 to the west; Metcalfe, 2006). It is uncertain whether these two groups of terranes were united to form a single very elongate continent, termed Cimmeria by some authors. North China, South China, and Annamia appeared to have stayed in the same general relationships to each other and they all slowly drifted northwards during the Permian; however, Annamia and South China both rotated gradually during the period prior to their union in today's configuration along the Ailaoshan and Song Ma Suture Zone during the Triassic. There are Lower Permian granites in the Chanthaburi Terrane at the margin of Annamia (Sone and Metcalfe, 2008), and Upper Permian arc rocks which were deposited during the first phases of the largely Triassic Indosinian Orogeny (Lepvrier et al., 2004). Near the end of the Permian, the Emeishan Large Igneous Province was intruded into South China.

Li (2006) described the Permian narrowing of what he termed the Paleo-Asian Ocean between North China on the one side and Junggar, South Gobi and the Bureya–Jiamusu microcontinent on the other side, with the Middle Permian Suolunshan Ophiolites between North China and Khinggan–Bureya defining both the position and the timing of the closure of the eastern Palaeoasian Ocean there. However, Xiao et al. (2008) presented a palaeogeographical sketch showing united Siberia and Kazakhstania joining Tarim to them both as the Palaeoasian Ocean finally closed there, and termed the sea to the east of Tarim and Siberia and between them and North China as the Palaeotethys Ocean.

Off the western margin of our maps, Wang et al. (2007) analysed the faulting in the region between Siberia, Junggar and Tarim, which centred round the Yili Block at the eastern end of the Atasu–Zhamsi Terrane, and demonstrated that the Erqiz Fault between Siberia and Junggar was sinistral, but the strike-slip faults to both north and south of the Yili Block were dextral, with lateral displacements of 600 and 1000 km respectively, further confirming what a complex series of processes and events were involved during the final adjustments of Siberia's place within Pangea. Manankov et al. (2006) gave an overview of the Permian of Mongolia. Although Zhang et al. (2007) concluded that the ocean between Siberia and North China finally closed at some time in the Sakmarian soon after 290 Ma, the palaeomagnetic data indicates decisively that that closure did not occur until well into the Mesozoic, during the Jurassic at about 150 Ma. The area between North China, Hutag Uul–Songliao and Khanka–Jiamusu–Bureya on the one hand, and the peri-Siberian terranes to their north, is discussed below in Section 15.

13.2. Facies, faunas and floras

There was substantial global climate change at about 280 Ma (Sakmarian), when the major Permo-Carboniferous glacial period ended. Although there are no glaciogenic deposits known in North and South China since they were largely in the tropics, the area was directly affected; for example, Cope et al. (2005) reviewed how in North China the earlier Permian continental deposits were coal-bearing and fluvial strata rich in plant fossils, in contrast to later fluvial red beds with many calcitic palaeosols, and a xenophytic and more cosmopolitan floral assemblage started to dilute the identity of the Cathaysian Realm. There were also Late Permian coals, interbedded with carbonates which included reefs, in South China (Shao et al., 2003), and a widespread carbonate platform in the Thai sector of Annamia (Ridd et al., 2011). Metcalfe (2006, p. 41) plotted the amphibian *Dicynodon* in the Late Permian in Annamia, which can only have occurred if there was some land connection with the mainland of Pangea at that time, but which sector of Pangea is uncertain.

Shi (2006) recognised four provinces in the Permian of east and northeast Asia based on marine benthos, particularly brachiopods: the Verkolyman, Sino-Mongolian-Japanese, Cathaysian and Panthalassan provinces. The latter province includes a number of Permian faunas which inhabited offshore oceanic environments and are mostly found within the accretionary prisms of terranes of Jurassic age, including the Mino Terrane of Japan, the Heilonjiang Terrane of northeast China and the Sikhote–Alin Terrane of Far East Russia. All the faunas must have originally inhabited seamounts or oceanic island arcs within the Panthalassic Ocean during the Palaeozoic. The Verkolyman Province occupied what we recognise as Siberia and peri-Siberia. The Cathaysian Province included both North and South China as well as Annamia, and the Himalayan Province those Gondwanan terranes which had left when the Neotethys Ocean opened, including Sibumasu and the Tibetan terranes.

Stevens et al. (2011) described the radiation and extinction patterns in the Permian floras of North China and also published facies maps for that continent which we have used here, as well as the data for southeast Asia of Li and Shen (1996). Liardin Stevens (personal communication, 2011) has helpfully reassessed and standardised the attribution of each flora over the entire area covered by this paper to its appropriate province through re-evaluation of all the original papers. Cai and Zhang (2009) published summary facies maps for South China in the Permian, which we have also used to create our maps. By the Early Permian at 280 Ma (Fig. 22), the Cathaysian Flora, characterised by plants such as *Cathaysiopteris*, had spread from North and South China to the northeastern margin of Gondwana, where it occurs in Sibumasu and the Tibetan terrane area; however, a Euramerian Province flora is also known in Sibumasu. In reality, the floral provinces were not so rigorously delimited as are shown on many maps (e.g. Metcalfe, 2011a, Fig. 15); for example, in today's western sector of North China, many plant localities have yielded a mixture of both Cathaysian and Euramerian genera. From the Khanka–Jiamusu–Bureya Terrane area, by that time united with North China, a mixture of Cathaysian and Angara Province floras have been found, even though most of the latter province occurs in the cooler-temperature belts of Siberia. In contrast, by the end of the Permian at 250 Ma (Fig. 24), only Cathaysian floras, including the distinctive *Gigantopteris*, are known from the region, apart from in a few places within South China where both Cathaysian and Euramerian plants occur together, and the erstwhile Hutag Uul–Songliao Terrane area, from which a mixture of Cathaysian and Angaran floras have been recovered from one locality.

14. Mesozoic to recent postscript

After the end of the Palaeozoic, there was the gradual break-up of Pangea, but that did not directly affect its eastern sector considered here. More important was the variable progress towards the unification of Eurasia, represented in the further widening and subsequently the closures of successively the Neotethys and Tethys oceans, which eventually resulted in the geography we know today.

In the region which is the subject of this paper, tectonic activity was substantial during the Triassic; for example, Annamia and North China became united during the Middle to Late Triassic and North China joined South China in the latest Triassic or early Jurassic. The Palaeotethys Ocean closed between Sibumasu and Annamia along the Inthanon Suture Zone at the end of the Trias (Sone and Metcalfe, 2008). The North China Terrane group and Siberia and its adjacent terranes in Laurasia finally united in the Late Jurassic or Early Cretaceous at about 150 Ma, marking the final closure of the Palaeoasian Ocean. The Tibet area of Gondwana divided into two separate terranes (Qiantang and Lhasa) which separated from each other in the Late Triassic, but which were reunited in the Early Cretaceous. The Neotethys Ocean closed at about 50 Ma (van Hinsbergen et al., 2011), which was followed by much tectonic shortening during the consequent and dramatic Himalayan Orogeny. To the east of the Himalayas, the cut and thrust tectonics and interactions of the relatively small oceanic plates, active in the Tertiary and still continuing, contributed to the construction of the complex East Indies region of today. Those tectonic and latitudinal changes were echoed by the interesting interactions of the Southeast Asian floras and faunas, some of which were described in the volume edited by Hall and Holloway (1998).

15. Discussion

15.1. The unity of South China and Annamia

One of the biggest unresolved problems of Palaeozoic palaeogeography in eastern Asia appears to be the status and successive situations of the substantial Annamia (Indochina) Terrane, which was large enough to be classified as a continent, and the surrounding sutures which were reviewed by Sone and Metcalfe (2008). As outlined in Section 2.1, Annamia includes the substantial Kontum Craton of Precambrian and Palaeozoic rocks, and, although there are no palaeomagnetic data from them, it was certainly a continental block throughout the Palaeozoic. The faunal evidence seems inconsistent: some of the Lower Palaeozoic faunas appear allied to South China, but most give no clear palaeobiogeographical signals. So was Annamia an independent continent? To make it so requires spreading centres and subduction zones which would make the tectonic scenarios accordingly more complex, although that appears to have been the situation from the Devonian up to past the end of the Palaeozoic. From the time of our original reconstructions (Cocks and Torsvik, 2002), we have maintained that Annamia is too substantial a continent to omit in palaeogeographical maps (as it has been by many authors, presumably chiefly through uncertainty of its Palaeozoic positions), and, if it was not allied with South China, where can it best be situated on our maps? The most parsimonious solution, which we have adopted, is to conclude that the South China and Annamia blocks together formed a single palaeocontinent from the Late Precambrian to some time in the Devonian. But along which parts of their continental margins were they joined? The current junction between the two along the Song Ma Line can be ruled out, since that suture zone contains the remnants of Cambrian and Ordovician island arcs (Findlay, 1998). Today's eastern margin of South China (the Cathaysian sector) can also be eliminated because of the accretionary prisms and island arcs now forming parts of Japan were being deposited there, at least during the Cambrian and Devonian (Isozaki et al., 2010). Comparably, Ridd et al. (2011) show that the western (Thai) margin of Annamia was oceanic in the Palaeozoic. Thus, by elimination, we rather arbitrarily show the two continents as united along today's southeastern margin of Annamia and the southwestern margin of South China, whilst stressing that that configuration is by no means proven.

Cai and Zhang (2009) also thought that South China and Annamia may have been together prior to the Silurian, and later drifted apart. However, they, like Metcalfe, concluded that South China and Annamia were integral parts of core Gondwana in the earlier parts of the Lower Palaeozoic, but that scenario cannot be reconciled with the palaeomagnetic data (reviewed by Torsvik and Cocks (2009) for Gondwana and here for South China), which shows that South China and Gondwana were not moving in the same ways as each other through the Palaeozoic. Because of the intervening South

China Sea and Gulf of Thailand today, it is uncertain whether or not East Malaya was a separate Palaeozoic microcontinent or whether it was a southern extension of Annamia as postulated by Metcalfe (2006), who concluded that it left Gondwana with Annamia in the opening of the Palaeotethys Ocean in the Lower Devonian and, because of that uncertainty, that relatively small area is not shown on

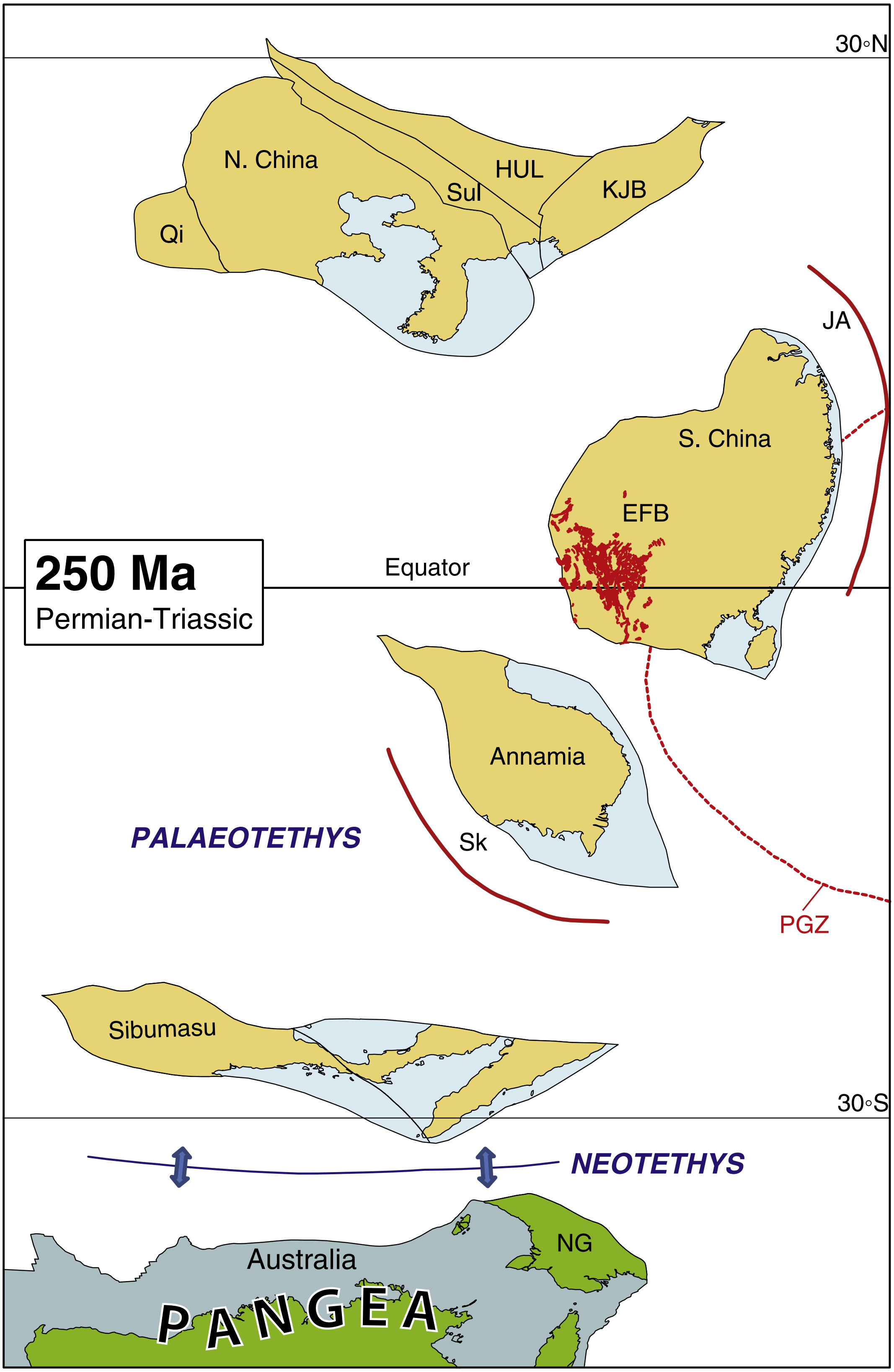

Fig. 23. Distribution of major tectonic units at Permian–Triassic boundary time at 250 Ma. EFB, Emeishan flood basalts (LIP); HUL, Hutag Uul–Songliao; JA, Japanese arcs; KJB, Khanka–Jiamusu–Bureya; NG, New Guinea; Qi, Qaidam–Qilian Terrane; Sk, Sukothai and related island arcs; Sul, Sulinheer. Thinner red lines and PGZ, plume generation zones, thicker red lines are subduction zones.

our reconstructions. Despite having been united during the Lower Palaeozoic, subsequent ocean floor spreading may be demonstrated between Annamia and South China by the presence of Mid Ocean Ridge Basalts (MORB) of Devonian to Early Permian age, some dated at 329 Ma (Visean), as reviewed by Cai and Zhang (2009). However, the Late Permian calc-alkaline granitoids indicate that, at some time before 260 Ma, the sea-floor spreading regime had changed to one of subduction.

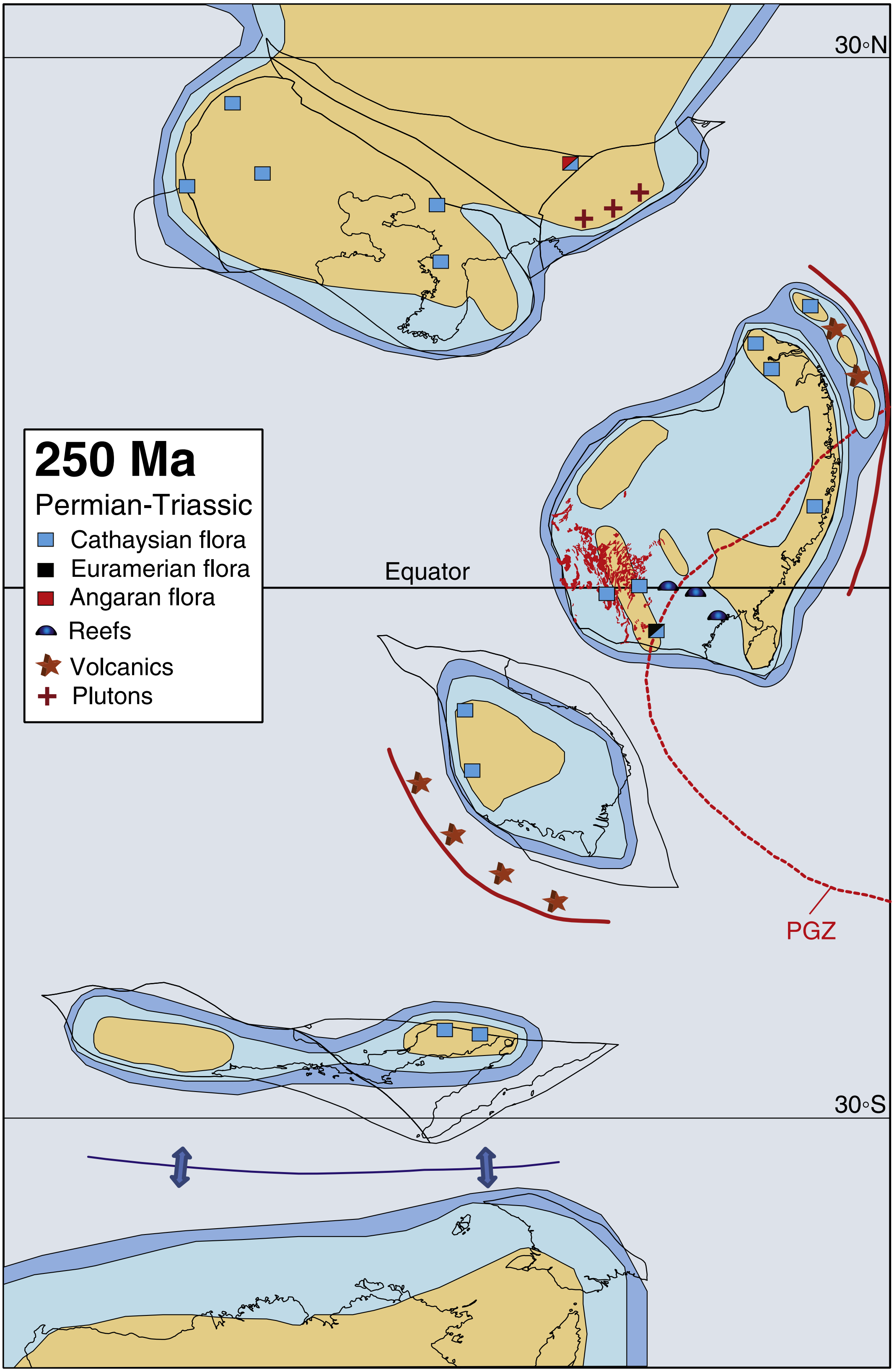

Fig. 24. Palaeogeography at Permian–Triassic boundary time at 250 Ma. Thinner red lines and PGZ, plume generation zones, thicker red lines are subduction zones. Floral provinces are shown from newly-reviewed data: the sites where a combination of two provinces is found show the mix in two colours.

15.2. The palaeogeographical positions of South China–Annamia and North China

What have been major points of discussion for many authors is whether or not South China was an integral part of Gondwana during the Palaeozoic, and, whether integral or not with the main bulk of the supercontinent, where both South China and North China were situated in relation to the rest of Gondwana? Metcalfe, in a series of papers partly summarised in 2006 and 2011b, mapped South China and North China, together with Tarim and Annamia, as parts of core Gondwana immediately offboard of Australia throughout the Lower Palaeozoic, and shows those four regions as leaving Gondwana together in a group when the Palaeotethys Ocean opened in the Early Devonian, and that view was echoed by Barber et al. (2011). In Torsvik and Cocks (2009, Figs. 3 to 5), South China was shown as a separate continent straddling the Equator offshore of, and independent from, the Australian and Sibumasu sector of Gondwana and remaining in a similar position throughout the Lower Palaeozoic. We were then uncertain where Annamia (Indochina) lay in the Lower Palaeozoic, and so it was not shown on that map, but, after a review of the faunas, Fortey and Cocks (2003, p. 275) had concluded that it was not far from Gondwana but situated relatively further to today's west than at present; for example, the trilobites *Nesuretinus* and *Vietnamia* are most closely related to higher-latitude Mediterranean Province Middle to Later Ordovician faunas from Sardinia and elsewhere. However, in Torsvik et al. (2009), which was written more than a year later than Torsvik and Cocks (2009) and in the light of new data, chiefly on the occurrences of Cambrian trilobites listed in Section 8.2, South China was shown outboard of the Afghan terranes at a slightly higher palaeolatitude during the Cambrian and at about 30° further south than the equatorial position near Australia shown by Torsvik and Cocks (2009, Fig. 3). That more southwesterly position helps to explain the distribution (Fig. 6) of the large and distinctive pentamerid brachiopod *Yangzteella*, which was previously known only in South China and Turkey in the Early Ordovician (Cocks and Fortey, 1988) but which was later found in Iran (L.E. Popov, personal communication, 2011) and Karakorum (Zhan et al., 2011). It also helps to explain why some marine benthic faunas, such as the brachiopod *Spanodonta* (also shown on Fig. 6), occur and are abundant in some tropical shallow-water rocks at the Gondwanan margin in Australia, Sibumasu and Tibet (Harper et al., 2011), but are absent from South China and Annamia.

Thus we largely follow the Torsvik et al. (2009) higher-latitude positioning of South China here, with the important difference that we now think that South China and Annamia (the latter not shown on the Torsvik et al., 2009 maps) were united as a single continent, as discussed above. That combined continent moved northeastwards along a substantial strike-slip fault from near India to near Australia through much of the Lower Palaeozoic, which explains why the South China trilobites were essentially identical to those in Sibumasu in the Early Late Ordovician (Sandbian) at about 460 Ma (Fortey, 1997). The strike-slip movement continued until Early Devonian times at about 400 Ma, when the strike slip faulting changed to rifting. Annamia and South China separated in the Devonian at some undetermined time, but probably either at the same time as the Palaeotethys Ocean opened or very soon after that, since the subsequent successions of Palaeozoic faunas clearly show that the two continents remained not very far separate from each other for the rest of the Palaeozoic. The 'final' reunion of Annamia and South China did not take place until they became united along the Song Ma Suture during the Middle Triassic, at about 220 Ma, although there were also some minor tectonic adjustments later in the general area of that line.

Presumably as a result of their separation, it is notable that the distinctive and endemic Early Carboniferous (Tournaisian) brachiopod *Chuiella* is restricted to South China and Tarim, but does not occur in Annamia (for example, Metcalfe, 2011a). It is worth stressing again that the configurations and outlines of Annamia in particular, and also to a lesser extent South China, are quite unrealistic on our reconstructions, particularly during the Lower Palaeozoic, since they are based largely on the outlines of the areas occupied by their terranes today; for example, there are no proven rocks older than Late Silurian in the western (Thai) sector of Annamia (Ridd et al., 2011).

Some other studies have also indicated that, during the Ordovican, South China drifted slowly into lower and therefore warmer palaeolatitudes. For example, Zhan et al. analysed the brachiopods from successive Ordovician horizons in South China and concluded (2011, p. 276) that the continent moved from temperate into tropical latitudes as the period progressed. However, since the Ordovician was a period of increasing and substantial diversification for many faunal groups, for example the brachiopods (Harper et al., 2004), it is thus difficult to disentangle the effects of that increased diversification from other effects, such as changes in palaeolatitude.

But what were the relationships between the combined South China–Annamia continent and North China over the Palaeozoic, and how did those two continents relate to northeastern Gondwana? McKenzie et al. (2011) analysed the distributions of Late Cambrian (Furongian) trilobites and zircons in North China, South China and two sectors of northeastern Gondwana (Sibumasu and Australia). They concluded that at that time North China was situated within the Gondwanan margin adjacent to the northeastern Himalaya between South China and Australia, and they particularly noted that the Precambrian and Early Cambrian zircon profiles were similar between the Bhutan sector of the Himalaya (Hughes et al., 2010) and parts of North China (Darby and Gehrels, 2006). However, Darby and Gehrels (2006) also reviewed zircons from other parts of North China which show quite different patterns, although their complexity clearly indicates provenance from a large continent, probably Gondwana, at some time in the Precambrian.

In contrast, the Early Ordovician trilobites reviewed by, for example, Zhou and Zhen (2008), appear to indicate that North China was not close to South China and Annamia. Thus, because it would require much tectonic juggling, including a major rifting event from Gondwana, to reposition North China from the Gondwanan margin between South China–Annamia and Australia in the Cambrian into its positions later in the Palaeozoic, we have placed North China well away from Gondwana. In addition, there also appears to be significant Lower Palaeozoic palaeomagnetic differences between Gondwana and North China, although there is little Cambrian data. All that, together with the probable longitudinal indications from the kimberlites contained within North China, the large space required to accommodate our united Annamia–South China continent (the substantial Annamia was not shown by McKenzie et al.), and the Ordovician and later faunal differences, combine to make the Cambrian position suggested by McKenzie et al. (2011) for North China appear as a less likely alternative.

Some authors, reviewed by Wilhem et al. (2012), have postulated that North China and Tarim, together with the intervening Dunhuang microcontinent (reviewed here with Ala Shan in Section 3.5) were united along their northern margins during much of the Palaeozoic. It is suggested that this formed an elongate passive margin in the Cambrian to early Ordovician but that margin became active in the Middle Ordovician after the accretion of the Tulinkai Arc to the North China continent. However, although the palaeomagnetic evidence for the separation and relative movements and rotations of Tarim and North China is not as strong as we would wish, we think that it is most parsimonious to show the two as independent before the Late Palaeozoic.

15.3. The relationship between the northern blocks and Siberia

We have also had a substantial problem in siting the Nuhetdavaa and Hutag Uul–Songliao terranes and the Khanka–Jiamusu–Bureya microcontinent on our reconstructions, and those units and their now-vanished extensions may well have occupied substantially larger areas in the north of the areas of our reconstructions than we have shown. What were their relationships to each other, and with Siberia and peri-Siberia, particularly in the Early Palaeozoic? Wu et al. (2011) concluded that the Hutag Uul–Songliao Terrane was itself divided into two between a more northerly Songliao Terrane (as they defined it) and a more southerly Liaoyuan Terrane, between which was a Permian ocean which only closed at about 250 Ma, which, if correct, would help to explain the space problem. Parfenov et al. (2009), summarising some previous papers, postulated what they termed the ‘Solon Collage’ consisting of several small Palaeozoic terranes which had originally been fragments of a ‘Solon Ocean plate’. That plate was thought to have been subducted to form many of the southern Mongolian arcs and some of the rocks in the Korean sector of North China. However, although we have not explicitly recognised the Solon Plate on our reconstructions here; if it existed, some parts of it might have provided the land which probably stretched between North China and Siberia at the end of the Palaeozoic (Fig. 24).

No useful palaeomagnetic data have been gathered from any of those units. The Solonker Suture Zone between the Sulinheer sector of North China and the Hutag Uul–Songliao Terrane closed obliquely between the Late Carboniferous and the Earliest Permian, and we have shown a steadily decreasing ocean prior to that closure back to our Late Silurian maps. Comparably, Dacheng et al. (2004) concluded that the Khanka sector of the Khanka–Jiamusu–Bureya microcontinent accreted to North China during the Late Permian to Early Triassic. However, the date of suturing between Hutag Uul–Songliao and the Nuhetdavaa Terrane to its north is not well constrained. Wilhem et al. (2012, p. 312) show a long ribbon in the Late Cambrian as part of peri-Siberia stretching from the Altai–Mongol area eastwards to include Nuhetdavaa–Enshoo, Songliao and Jiamusu, with an ocean separating that ribbon from the rest of the Mongolian terranes and the Siberian Craton, but our maps do not include these areas until the Late Silurian.

Thus we have put Nuhetdavaa near peri-Siberia (off our palaeogeographical maps) and the combined Hutag Uul–Songliao and Khanka–Jiamusu–Bureya units near North China only on the Late Silurian and Upper Palaeozoic reconstructions (Figs. 11–24). In addition, although Hutag Uul–Songliao and Khanka–Jiamusu–Bureya may have been separate in the Palaeozoic, we have kept them together on our maps through lack of definitive palaeogeographical data for them. However, there remain space problems in the latest Palaeozoic in that large area.

It is clear from good palaeomagnetic data that the cores of Siberia and North China were at a considerable distance from each other during most of the Palaeozoic, and the bulk of those continents did not unite until the Late Jurassic or Early Cretaceous. But between the two continents today lie several terranes which have not yet yielded useful palaeomagnetic data, but whose sutures appear to suggest that they all came together both with each other and with Siberia and the rest of Pangea at approximately similar times near the end of the Permian. Clearly, in reality one of those sutures must have been much later than previously deduced, and thus we have had to make somewhat arbitrary decisions in placing the Gurvansayhan Terrane within the Palaeoasian Ocean near Ala Shan and the Nuhetdavaa Terrane near Siberia.

Various authors, for example Shi (2006, Fig. 5) in a Middle Permian reconstruction, show continuous land between 20° and 40° N consisting of, from west to east, united Siberia, Kazakhstania, Tarim, Qaidam–Qilian, Khanka–Jiamusu–Bureya and North China. However, we are yet to review central Asia, including Kazakhstania and Tarim in the Late Palaeozoic, and thus do not have original opinions on the topic. Thus, although it reasonable to assume that a wide Palaeoasian Ocean lay to the north of Hutag Uul–Songliao, Khanka–Jiamusu–Bureya and North China during all of the Devonian and Early Carboniferous, the progressive geography of that ocean's subsequent narrowing and even closure during the Permian is unresolved.

16. Conclusions

The Asia of today has become unified only since the Cretaceous, and during the Palaeozoic its modern components were a disparate selection of continents and smaller terranes; however, many of those units formed integral parts of the superterrane of Gondwana or peri-Gondwana during the Lower Palaeozoic. From the Cambrian onwards the region was bounded to the south and southeast by Gondwana, and continued to be so until after Gondwana's union with Laurussia in the Carboniferous to form Pangea, after which the bulk of the new and enlarged supercontinent lay largely to the west of the area considered here. We have created new reconstructions to show how the eastern Asia region changed during the Palaeozoic, but have deliberately simplified some areas; for example, we have not shown as separate some of the many and varied smaller terranes, many of which were themselves composite.

There are many unresolved issues. For example, which of the peri-Siberian terranes occupied the area between North China (and Hutag Uul Songliao and Khanka–Jiamusu–Bureya) and core Siberia near the end of the Palaeozoic? Perhaps there was land between the two, perhaps an open ocean, or perhaps, more probably, an archipelago.

Another issue is what were the relationships of the South China and Annamia (Indochina) continents, both to each other and also with the rest of the region, most particularly Gondwana and North China? Some authors have considered South China and Annamia as completely independent of each other during the Lower Palaeozoic, other authors saw them as together within core Gondwana until the Palaeotethys Ocean opened in the Early Devonian; and yet others concluded that the two were joined to each other in the Lower Palaeozoic but were independent from Gondwana, although not too far away from it. After review in Section 15, we favour the third alternative, and conclude also that South China–Annamia moved northeastwards as a single united continent from a position outboard of the Afghan Terranes in the Cambrian to a position off Australia just before the Palaeotethys opened in the Devonian. The progressive change of their palaeolatitudes from between about 30° S in the Cambrian to north of the palaeoequator in the Devonian also explains the initially increased and then approximately stable diversities of the many benthic faunas known from South China during those times. However, that combined Annamia–South China continent broke into its two major component parts during the Devonian, possibly coincidentally with the opening of the Palaeotethys Ocean, but long prior to their eventual reunification during the Triassic. But, although we consider that North China was independent from South China–Annamia, their relationships, and also with the Tarim continent remain topics not yet finally resolved.

Acknowledgments

We have much appreciated discussions with Rob Van der Voo, Douwe van Hinsbergen, Richard Fortey, Ian Metcalfe, Mike Ridd, Rong Jiayu, Zhou Zhiyi, Shen Shuzhong, and many other colleagues. Nigel Hughes has also provided valuable data as well as constructive comments on the manuscript. We are also very grateful to Lil Stevens for reinterpreting and replotting Late Palaeozoic palaeofloral data, to the European Research Council under the European Union's Seventh Framework Programme (FP7/2007–2013)/ERC Advanced Grant Agreement Number 267631 (Beyond Plate Tectonics) for funding, and to The Natural History Museum, London, for the provision of facilities.

References

Asama, K., Iwai, J., Veeraburus, M., Hongnusonthi, A., 1968. Permian plants from Loei, Thailand. Geology and Palaeontology of Southeast Asia 4, 82–99.
Astashkin, V.A., Pegel, T.V., Repina, L.N., Belyaeva, G.Y., Esakova, N.V., Rozanov, A.Y., Zhuravlev, A.Y., Osadchaya, D.V., Pakhomov, N.N., 1995. The Cambrian system of

the foldbelts of Russia and Mongolia. International Union of Geological Sciences Publication 32, 1–132.

Badarch, G., Cunningham, W.D., Windley, B.F., 2002. A new terrane subdivision for Mongolia: implications for the Phanerozoic crustal growth of Central Asia. Journal of Asian Earth Sciences 21, 87–110.

Barber, A.J., Ridd, M.F., Crow, M.J., 2011. The origin, movement and assembly of the pre-Tertiary units of Thailand. In: Ridd, M.F., Barber, A.J., Crow, M.J. (Eds.), The Geology of Thailand. The Geological Society, London, pp. 507–538.

Batkhishig, B., Noriyoshi, T., Greg, B., 2010. Magmatism of the Shuteen Complex and Carboniferous subduction of the Gurvansaikhan terrane, South Mongolia. Journal of Asian Earth Sciences 37, 399–411.

Biske, Y.S., Dzhenchuraeva, A.V., Neevin, A.V., Vorobev, T.Y., 2003. The Middle–Upper Paleozoic stratigraphy and paleogeography of the transitional area between the Turkestan Ocean and Tarim continent (Tien Shan). Stratigraphy and Geological Correlation 6, 573–584.

Blight, J.H.S., Petterson, M.G., Crowley, Q.G., Cunningham, D., 2010. The Oyut Ulaan Volcanic group: stratigraphy, magmatic evolution and timing of Carboniferous arc development in Mongolia. Journal of the Geological Society of London 167, 491–509.

Boucot, A.J., Blodgett, R.B., 2001. Silurian–Devonian biogeography. In: Brunton, C.H.C., Cocks, L.R.M., Long, S.L. (Eds.), Brachiopods Past and Present. Taylor and Francis, London and New York, pp. 335–344.

Boucot, A.J., Cocks, L.R.M., Racheboeuf, P.R., 1999. Early Devonian brachiopods from Satun Province, southern Thailand. Journal of Paleontology 73, 850–859.

Buckman, S., Aitchison, J.C., 2004. Tectonic evolution of Palaeozoic terranes in West Junggar, Xinjiang, NW China. Geological Society, London, Special Publication 226, 101–129.

Burtman, V.S., 2008. Nappes of the southern Tien Shan. Russian Journal of Earth Sciences 10 (ES1006), 1–35.

Cai, J.X., Zhang, K.J., 2009. A new model for the Indochina and South China collision during the Late Permian to the Middle Triassic. Tectonophysics 467, 35–43.

Carroll, A.R., Graham Stephen, A., Chang, E.Z., McKnight, C., 2001. Sinian through Permian tectonostratigraphic evolution of the northwestern Tarim basin, China. Geological Society of America Memoir 194, 47–69.

Carter, A., Roques, D., Bristow, C., Kinny, P., 2001. Understanding Mesozoic accretion in Southeast Asia: significance of Triassic thermotectonism (Indosinian orogeny) in Vietnam. Geology 29, 211–214.

Cawood, P.A., Johnson, M.R.W., Nemchin, A.A., 2007. Early Palaeozoic orogenesis along the Indian margin of Gondwana: tectonic response to Gondwana assembly. Earth and Planetary Science Letters 255, 70–84.

Charvet, J., Shu, L., Laurent-Charvet, S., 2007. Paleozoic structural and geodynamic evolution of eastern Tianshan (NW China): welding of the Tarim and Junggar plates. Episodes 30, 162–186.

Chen, X., Zhou, Z.-y, Fan, J.-x, 2010. Ordovician paleogeography and tectonics of the major paleoplates of China. Geological Society of America Special Paper 466, 85–104.

Chen, Z.Q., Shi, G.R., Zhan, L.P., 2003. Early Carboniferous athyridid brachiopods from the Qaidam Basin, northwest China. Journal of Paleontology 77, 84–862.

Choi, D.K., Kim, D.H., Sohn, J.W., Lee, S.B., 2003. Trilobite faunal successions across the Cambrian–Ordovician boundary intervals in Korea and their correlation with China and Australia. Journal of Asian Earth Sciences 21, 781–793.

Cocks, L.R.M., Fortey, R.A., 1988. Lower Palaeozoic facies and faunas around Gondwana. Geological Society, London, Special Publications 37, 183–200.

Cocks, L.R.M., Torsvik, T.H., 2002. Earth geography from 500 to 400 million years ago: a faunal and palaeomagnetic review. Journal of the Geological Society of London 159, 631–644.

Cocks, L.R.M., Torsvik, T.H., 2007. Siberia, the wandering northern terrane, and its changing geography through the Palaeozoic. Earth-Science Reviews 82, 29–74.

Cocks, L.R.M., Torsvik, T.H., 2011. The Palaeozoic geography of Laurentia and western Laurussia: a stable craton with mobile margins. Earth-Science Reviews 106, 1–51.

Cocks, L.R.M., Zhan, R.B., 1998. Caradoc brachiopods from the Shan States, Burma (Myanmar). Bulletin of the British Museum (Natural History). Geology 54, 109–130.

Cocks, L.R.M., Fortey, R.A., Lee, C.P., 2005. A review of Lower and Middle Palaeozoic biostratigraphy in west peninsular Malaya and southern Thailand in its context within the Sibumasu Terrane. Journal of Asian Earth Sciences 24, 703–717.

Cocks, L.R.M., Fortey, R.A., Rushton, A.W.A., 2010. Correlation for the Lower Palaeozoic. Geological Magazine 147, 171–180.

Compston, W., Zhang, Z., Cooper, J.A., Ma, G., Jenkins, R.J.F., 2008. Further SHRIMP geochronology on the Early Cambrian of South China. American Journal of Science 308, 399–420.

Cope, T., Ritts, B.D., Darby, B.J., Fildani, A., Graham, S.A., 2005. Late Paleozoic sedimentation on the northern margin of the North China Block: implications for regional tectonics and climate change. International Geology Review 47, 270–296.

Copper, P., 2002. Silurian and Devonian reefs: 80 million years of global greenhouse between two ice ages. SEPM Special Publication 72, 181–238.

Dacheng, J., Ruizhong, H., Yan, L., Xuelin, Q., 2004. Collision belt between the Khanka block and the North China block in the Yanbian Region, Northeast China. Journal of Asian Earth Sciences 23, 211–219.

Darby, B.J., Gehrels, G., 2006. Detrital zircon reference for the north China block. Journal of Asian Earth Sciences 26, 637–648.

Daukeev, S.Z., Uzhkenov, B.S., Miletenko, N.V., et al. (Eds.), 2002. Atlas of the Lithology–Paleogeographical, Structural, Palinspastic and Geoenvironmental Maps of Central Eurasia. Scientific Research Institute of Natural Resources, Almaty.

de Jong, K., Xiao, W., Windley, B.F., Masago, H., Lo, C.H., 2006. Ordovician ^{40}Ar/^{39}Ar phengite ages from the blueschist-facies Ondor Sum subduction–accretion complex (Inner Mongolia) and implications for the Early Paleozoic history of continental blocks in China and adjacent areas. American Journal of Science 306, 799–845.

Dobbs, P.N., Duncan, D.J., Hu, S., Shee, S.R., Colgan, E., Brown, M.A., Smith, C.B., Allsopp, H.L., 1994. The geology of the Mengyin kimberlites, Shandong, China. In: Meyer, H.O.A., Leonardos, O.H. (Eds.), Proceedings of 5th International Kimberlite Conference 1. Diamonds: Characterization. Genesis and Exploration. CPRM, Brasilia, pp. 106–115.

Dong, Y., Zhang, G., Neubauer, F., Liu, X., Genser, J., Hauzenberger, C., 2011. Tectonic evolution of the Qinling orogen, China: review and synthesis. Journal of Asian Earth Sciences 41, 213–237.

Ehiro, M., Kanisawa, S., 1999. Origin and evolution of the South Kitakami Microcontinent during the Early–Middle Palaeozoic. In: Metcalfe, I. (Ed.), Gondwana Dispersion and Accretion. Balkema, Rotterdam, pp. 283–295.

Embleton, B.J.J., McElhinny, M.W., Ma, X., Zhang, Z., Li, Z.X., 1996. Permo-Triassic magnetostratigraphy in China: the type section near Taiyuan, Shanxi Province, China. Geophysical Journal International 126, 382–388.

Fang, W., Van der Voo, R., 1990. Ordovician paleomagnetism of eastern Yunnan, China. Geophysical Research Letters 17, 953–956.

Fang, W., Van der Voo, R., Liang, Q., 1989. Devonian paleomagnetism of Yunnan Province across the Shan–Thai–South China suture. Tectonics 8, 939–952.

Fang, Z., Cope, J.C.W., 2004. Early Ordovician bivalves from Dali, West Yunnan, China. Palaeontology 47, 1121–1158.

Findlay, R.H., 1998. The Song Ma Anticinorium, northern Vietnam: the structure of an allochthonous terrane containing an early Palaeozoic island arc sequence. Journal of Asian Earth Sciences 15, 453–464.

Fortey, R.A., 1997. Late Ordovician trilobites from southern Thailand. Palaeontology 40, 397–450.

Fortey, R.A., Cocks, L.R.M., 2003. Palaeontological evidence bearing on global Ordovician–Silurian continental reconstructions. Earth-Science Reviews 61, 245–307.

Gonez, P., Huu, H.N., Hoa, P.T., Clément, G., Janvier, P., 2012. The oldest flora of the South China Block, and the stratigraphic bearings of the plant remains from the Ngoc Vung Series, north Vietnam. Journal of Asian Earth Sciences 43, 51–63.

Hacker, B.R., Ratschbacher, L., Liou, J.G., 2004. Subduction, collision and exhumation in the ultrahigh-pressure Qinling–Dabie orogen. Geological Society, London, Special Publications 226, 157–175.

Hall, R., Holloway, J.D. (Eds.), 1998. Biogeography and Geological Evolution of SE Asia. Backhuys, Leiden (417 pp.).

Hamada, T., 1971. Early Devonian brachiopods from the Lesser Khingan district of northern China. Paleontological Society of Japan Special Paper 15, 1–98 (pls 1–30).

Han, G., Liu, Y., Neubauer, F., Genser, J., Li, W., Zhao, Y., Liang, C., 2011. Origin of terranes in the eastern Central Asian Orogenic Belt, NE China: U–Pb ages of detrital zircons from Ordovician–Devonian sandstones, North Da Xing'an Mts. Tectonophysics 511, 109–124.

Harper, D.A.T., Cocks, L.R.M., Popov, L.E., Sheehan, P.M., Bassett, M.G., Copper, P., Holmer, L.E., Jin, J., Rong, J.Y., 2004. Brachiopods. In: Webby, B.D., Paris, F., Droser, M.L., Percival, I.G. (Eds.), The Great Ordovician Biodiversification Event. ColumbiaUniversity Press, New York, pp. 157–178.

Harper, D.A.T., Zhan, R., Stemmerick, L., Liu, J., Donovan, S.K., Stouge, S., 2011. Ordovician on the roof of the world: macro- and microfaunas from tropical carbonates in Tibet. Cuardernos del Museo Geominero, Madrid 14, 215–220.

Holland, C.H., Bassett, M.G. (Eds.), 2002. Telychian rocks of the British Isles and China (Silurian, Llandovery Series). National Museums and Galleries of Wales Geological Series 21, 1–220.

Holmer, L.E., Popov, L.E., Koneva, S.P., Bassett, M.G., 2001. Cambrian–early Ordovician brachiopods from Malyi Karatau, the western Balkash Region, and Tien Shan, Central Asia. Special Papers in Palaeontology 65, 1–180.

Huang, B., Yang, Z., Otofuji, Y., Zhu, R., 1999. Early Palaeozoic paleomagnetic poles from the western part of the North China Block and their implications. Tectonophysics 308, 377–402.

Huang, K., Opdyke, N.D., 1998. Magnetostratigraphic investigations on an Emeishan basalt section in western Guizhou Province, China. Earth and Planetary Science Letters 163, 1–14.

Huang, B., Shi, R., Wang, Y., Zhu, R., 2005. Palaeomagnetic investigation on Early–Middle Triassic sediments of the North China block: a new Early Triassic palaeopole and its tectonic implications. Geophys. Journal International 160, 101–113.

Huang, K., Opdyke, N.D., Zhu, R., 2000. Further paleomagnetic results from the Silurian of the Yangtze Block and their implications. Earth and Planetary Science Letters 175, 191–202.

Hughes, N.C., Myrow, P.M., McKenzie, N.R., Harper, D.A.T., Bhargava, O.N., Tangri, S.K., Ghalley, K.S., Fanning, C.M., 2010. Cambrian rocks and faunas of the Wachi La, Black Mountains. Bhutan. Geological Magazine. http://dx.doi.org/10.1017/S0016756810000750.

Hutchison, C.S., 1996. Geological Evolution of South-east Asia. Geological Society of Malaysia, Kuala Lumpur. (368 pp.).

Isozaki, Y., 2011. Ordovician rocks in Japan. In: Gutierrez-Marco, J.C., Rabano, I., Garcia-Bollido (Eds.), Ordovician of the World. Instituto Geologico y Minero de Espana, Madrid, pp. 251–252.

Isozaki, Y., Aoki, K., Nakama, T., Yanai, S., 2010. New insight into a subduction-related orogen: a reappraisal of the geotectonic framwork and evolution of the Japanese islands. Gondwana Research 18, 82–105.

Jeong, H., Lee, Y.I., 2000. Late Cambrian biogeography: conodont bioprovinces from Korea. Palaeogeography, Palaeoclimatology, Palaeoecology 162, 119–136.

Jian, P., Liu, D., Kröner, A., Windley, B.F., Shi, Y., Zhang, F., Shi, G., Miao, L., Zhang, W., Zhang, Q., Zhang, L., Ren, J., 2008. Time scale of an early to mid-Palaeozoic orogenic cycle of the long-lived Central Asian Orogenic Belt, Inner Mongolia of China: implications for continental growth. Lithos 101, 233–259.

Jian, P., Liu, D., Kröner, A., Windley, B.F., Shi, Y., Zhang, W., Zhang, F., Miao, L., Zhang, L., Tomurhuu, D., 2010. Evolution of a Permian intraoceanic arc–trench system in the Solonker suture zone, Central Asian Orogenic Belt, China and Mongolia. Lithos 118, 169–190.

Kim, D.H., Choi, D.K., 2000. *Jujuyaspis* and associated trilobites from the Mungok Formation (Lower Ordovician), Yongwol, Korea. Journal of Paleontology 74, 1031–1042.

Kröner, A., Windley, B.F., Badarch, G., Tomurtogoo, O., Hegner, E., Jahn, B.M., Grushka, S., Khain, E.V., Demoux, A., Wingate, M.T.D., 2007. Accretionary growth and crust formation in the Central Asian Or orogenic belt and comparison with the Arabian–Nubian shield. Geological Society of America Memoir 200, 181–209.

Lee, S., Choi, D.K., Shi, G.R., 2010. Pennsylvanian brachiopods from the Geumcheon–Jangseong Formation, Pyeongan Supergroup, Taebaeksan Basin, Korea. Journal of Paleontology 84, 417–443.

Lepvrier, C., Maluski, H., Van Tich, V., Leyreloup, A., Thi, P.T., Van Vuong, N., 2004. The Early Triassic Indosinian orogeny in Vietnam (Truong Son Belt and Kontum Massif); implications for the geodynamic evolution of Indochina. Tectonophysics 393, 87–118.

Lethiers, F., Crasquin-Soleau, S., 1995. Distribution des ostracodes et paléocourantologie au Carbonifère terminal-Permien. Geobios 18, 257–272.

Li, J.-y., 2006. Permian geodynamic setting of Northeast China and adjacent regions: closure of the Paleo-Asian Ocean and subduction of the Paleo-Pacific Plate. Journal of Asian Earth Sciences 26, 207–224.

Li, X., Shen, G., 1996. A brief review of the Permian macrofloras in southeast Asia and their phytogeographical delimitation. Journal of Southeast Asian Earth Sciences 13, 161–170.

Li, Z.X., Powell, C. McA, 2001. An outline of the palaeogeographic evolution of the Australasian region since the beginning of the Neoproterozoic. Earth-Science Reviews 53, 237–277.

Li, Y., Zhou, H., Brouwer, F.M., Wijbrans, J.R., Zhong, Z., Liu, H., 2011. Tectonic significance of the Xilin Gol Complex, Inner Mongolia, China: petrological, geochemical and U–Pb zircon age constraints. Journal of Asian Earth Sciences 43, 1018–1029.

Liu, J., Sun, Y., Tong, L., Sun, W., 2009. Emplacement age of the Songshugou ultramafic massif in the Qinling orogenic belt, and geological implications. International Geology Review 51, 58–76.

Lu, S., Zhao, G., Wang, H., Hao, G., 2008. Precambrian metamorphic basement and sedimentary cover of the North China Craton: a review. Precambrian Research 160, 77–93.

Manankov, I.N., Shi, G.R., Shen, S., 2006. An overview of Permian marine stratigraphy and biostratigraphy of Mongolia. Journal of Asian Earth Sciences 26, 294–303.

McKenzie, P.M., Hughes, N.C., Myrow, P.M., Choi, D.K., Part, T.Y., 2011. Trilobites and zircons link north China with the eastern Himalaya during the Cambrian. Geology 39, 591–594.

Metcalfe, I., 1988. Origin and assembly of south-east Asian continental terranes. Geological Society, London, Special Publications 37, 101–118.

Metcalfe, I., 2006. Palaeozoic and Mesozoic tectonic evolution and palaeogeography of East Asian crustal fragments: the Korean Peninsula in context. Gondwana Research 9, 24–46.

Metcalfe, I., 2011a. Tectonic framework and Phanerozoic evolution of Sundaland. Gondwana Research 19, 3–21.

Metcalfe, I., 2011b. Palaeozoic–Mesozoic history of SE Asia. Geological Society, London, Special Publications 355, 7–35.

Metcalfe, I., Sone, M., 2008. Biostratigraphy and palaeobiogeography of Lower Permian (Lower Kungurian) conodonts from the Tak Fa Formation (Saraburi Limestone), Thailand. Palaeogeography, Palaeoclimatology, Palaeoecology 257, 139–151.

Myrow, P.M., Hughes, N.C., Searle, M.P., Fanning, C.M., Peng, S., Parcha, S.K., 2008. Stratigraphic correlation of Cambrian–Ordovician deposits along the Himalaya: implications for the age and nature of rocks in the Mount Everest region. Geological Society of America Bulletin 120, 323–332.

Nikitin, I.F., Popov, L.E., Bassett, M.G., 2006. Late Ordovician rhynchonelliformean brachiopods of north-eastern Kazakhstan. National Museum of Wales Geological Series 25, 223–294.

Opdyke, N.D., Huang, K., Xu, W., Zhang, W.Y., Kent, D.V., 1987. Paleomagnetic results from the Silurian of the Yangtze paraplatform. Tectonophysics 139, 123–132.

Otoh, S., Tsukada, K., Sano, K., Nomura, R., Jwa, Y.J., Yanai, S., 1999. Triassic to Jurassic dextral ductile shearing along the eastern margin of Asia: a synthesis. In: Metcalfe, I. (Ed.), Gondwana dispersion and accretion. Balkema, Rotterdam, pp. 89–113.

Parfenov, L.M., Badarch, G., Berzin, N.A., Khanchuk, A.I., Kuzmin, M.I., Nokleberg, W.J., Prokopiev, A.V., Ogadawara, M., Yan, H., 2009. Summary of Northeast Asia geodynamics and tectonics. European Geosciences Union Stephan Mueller Special Publication Series 4, 11–33.

Patte, E., 1926. Études paléontologiques relatives à la géologie de l'est du Tonkin (Paléozoïque et Trias). Bulletin du Service géologique de l'Indochine 15 (1), 1–240 (pls 1–12).

Pavlova, E.E., Manankov, I.N., Morozova, I.P., Solovjeva, M.N., Suetenko, O.D., Bogoslovskaya, M.F., 1991. Permian invertebrates of southern Mongolia. Trudy Sovnestnaya Sovetsko-Mongolskii Paleontologeskii Exspeditiya 40, 1–173 (In Russian).

Peng, S., Hughes, N.C., Helm, N.A., Sell, B.K., Xhu, X., Myrow, P.M., Parcha, S.K., 2009. Cambrian trilobites from the Parahio and Zanskar Valleys, Indian Himalaya. Paleontological Society Memoirs (Jounal of Paleontology Supplement) 71, 1–95.

Percival, I.G., Glen, R.A., 2007. Ordovician to earliest Silurian history of the Macquarie Arc, Lachlan Orogen, New South Wales. Australian Journal of Earth Sciences 54, 143–165.

Pirajno, F., Mao, J., Zhang, Z., Zhang, Z., Chai, F., 2008. The association of mafic–ultramafic intrusions and A-type magmatism in the Tian Shan and Altay orogens, NW China: implications for geodynamic evolution and potential for the discovery of new ore deposits. Journal of Asian Earth Sciences 32, 165–183.

Qian, Q., Gao, J., Klemd, R., He, G., Song, B., Liu, D., Su, R., 2009. Early Paleozoic tectonic evolution of the Chinese South Tianshan Orogen: constraints from SHRIMP zircon U–Pb geochronology and geochemistry of basaltic and dioritic rocks from Xiate, NW China. International Journal of Earth Sciences 98, 551–569.

Ren, J.S., Wang, Z.X., Chen, B.W., Jiang, C.F., Niu, B.G., Li, J.Y., Xie, G.L., He, Z.J., Liu, Z.G., 1999. The tectonics of China from a global view — a guide to the Tectonic Map of China and adjacent regions. Geological Publishing House, Beijing. (32 pp.).

Ridd, M.F., 2009. The Phuket Terrane: a Late Palaeozoic rift at the margin of Sibumasu. Journal of Asian Earth Sciences 36, 238–251.

Ridd, M.F., Barber, A.J., Crow, M.J. (Eds.), 2011. The Geology of Thailand. The Geological Society, London.

Rojas-Agramonte, Y., Kröner, A., Demoux, A., Xia, X., Wang, W., Donskaya, T., Liu, D., Sun, M., 2011. Detrital and xenocrystic zircon ages from Neoproterozoic to Palaeozoic arc terranes of Mongolia: significance for the origin of crustal fragements in the Central Asian Orogenic belt. Gondwana Research 19, 751–763.

Rong, J.Y., Zhang, Y., 1994. Rariellidae, a new family of Rhynchoporoidea (Brachiopoda) with a restudy of the type genus *Rariella* Zhang, 1981, from the Emsian (Early Devonian) of Inner Mongolia, north China. Alcheringa 18, 135–146.

Rong, J.Y., Boucot, A.J., Su, Y.Z., Strusz, D.L., 1995. Biogeographical analysis of Late Silurian brachiopod faunas, chiefly from Asia and Australia. Lethaia 28, 39–60.

Rong, J.Y., Chen, X., Su, Y.Z., Ni, Y.N., Zhan, R.B., Chen, T.E., Fu, L.P., Li, R.Y., Fan, J.X., 2003. Silurian paleogeography of China. New York State Museum Bulletin 493, 243–298.

Sengor, A.M.C., Natalin, B.A., 1996. Palaeotectonics of Asia: fragments of a synthesis. In: Yin, A., Harrison, T.M. (Eds.), The Tectonic Evolution of Asia. Cambridge University Press, Cambridge, pp. 486–640.

Shao, L., Zhang, P., Gayer, R.A., Chen, J., Dai, S., 2003. Coal in a carbonate sequence stratigraphic framework: the Upper Permian Heshan Formation in central Guangxi, southern China. Journal of the Geological Society of London 160, 285–298.

Shen, X., Zhang, H., Wang, Q., Wyman, D.A., Yang, Y., 2011. Late Devonian–early Permian A-type granites in the southern Altay Range, Northwest China: petrogenesis and implications for tectonic setting of "A2-type" granites. Journal of Asian Earth Sciences 43, 986–1007.

Shi, G.R., 2006. The marine Permian of east and northeast Asia: an overview of biostratigraphy, palaeobiogeography and palaeogeographical implications. Journal of Asian Earth Sciences 26, 175–206.

Sone, M., Metcalfe, I., 2008. Parallel Tethyan sutures in mainland Southeast Asia: new insights for Palaeo-Tethys closure and implications for the Indosinian orogeny. Comptes Rendus Geoscience 340, 166–179.

Song, S., Niu, Y., Zhang, L., Wei, C., Liou, J.G., Su, L., 2009a. Two types of peridotite in North Qaidam UHPM belt and their tectonic implications for oceanic and continental subduction: a review. Journal of Asian Earth Sciences 35, 285–297.

Song, S., Su, L., Niu, Y., Zhang, G., Zhang, L., 2009b. Tectonic evolution of early Paleozoic HP metamorphic rocks in the North Qilian Mountains, NW China: new perspectives. Journal of Asian Earth Sciences 35, 334–353.

Stevens, L.G., Hilton, J., Bond, D.P.G., Glasspool, I.J., Jardine, P.E., 2011. Radiation and extinction patterns in Permian floras from North China as indicators for environmental and climate change. Journal of the Geological Society of London 168, 607–619.

Su, Y., 1988. Devonian paleogeography of northeastern China. Canadian Society of Petroleum Geologists Memoir 14 (2), 608–618.

Suess, E., 1901. Das Antlitz der Erde, vol. 3, part 1. F. Tempsky, Vienna.

Talent, J.A., 2000. Brachiopoda. Association of Australasian Palaeontologists Memoir 23, 182–194.

Tashi, S.M., Burago, V.I., 1974. Lithologo-paleoflora characteristics of the Permian deposits of South Primor'e. Sovetskaya Geologiya 1974 (9), 40–48 (In Russian).

Tazawa, J., 2001. A Permian Boreal brachiopod fauna from Okutadami, central Japan, and its tectonic implication. In: Brunton, C.H.C., Cocks, L.R.M., Long, S.L. (Eds.), Brachiopods Past and Present. Taylor and Francis, London, pp. 373–383.

Tazawa, J., 2005. Japan. In: Selley, R.C., Cocks, L.R.M., Plimer, I.R. (Eds.), Encyclopedia of Geology. Vol. 3. Elsevier, Amsterdam, pp. 297–305.

Tong-Dzuy, T., Boucot, A.J., Rong, J.Y., Fang, Z.J., 2001. Late Silurian marine shelly fauna of central and northern Vietnam. Geobios 34, 315–338.

Torsvik, T.H., 2003. The Rodinia jigsaw puzzle. Science 300, 1379–1381.

Torsvik, T.H., Cocks, L.R.M., 2004. Earth geography from 400 to 250 million years: a palaeomagnetic, faunal and facies review. Journal Geol. Soc. Lond. 161, 555–572.

Torsvik, T.H., Cocks, L.R.M., 2009. The Lower Palaeozoic palaeogeographical evolution of the northeastern and eastern peri-Gondwanan margin from Turkey to New Zealand. Geological Society, London, Special Publications 325, 3–21.

Torsvik, T.H., Cocks, L.R.M., 2011. The Palaeozoic palaeogeography of central Gondwana. Geological Society, London, Special Publications 357, 137–166.

Torsvik, T.H., Cocks, L.R.M., in press. New global palaeogeographical reconstructions for the Lower Palaeozoic and their generation. Geological Society, London, Memoirs.

Torsvik, T.H., Smethurst, M.A., Meert, J.G., Van der Voo, R., McKerrow, W.S., Brasier, M.D., Sturt, B.A., Walderhaug, H.J., 1996. Continental break-up and collision in the Neoproterozoic and Palaeozoic: a tale of Baltica and Laurentia. Earth-Science Reviews 40, 229–258.

Torsvik, T.H., Steinberger, B., Cocks, L.R.M., Burke, K., 2008. Longitude: linking Earth's ancient surface to its deep interior. Earth and Planetary Science Letters 276, 273–282.

Torsvik, T.H., Paulsen, T.S., Hughes, N.C., Myrow, P.M., Ganerød, M., 2009. The Tethyan Himalaya: palaeogeographical and tectonic constraints from Ordovician palaeomagnetic data. Journal of the Geological Society of London 166, 679–687.

Torsvik, T.H., Burke, K., Steinberger, B., Webb, S.C., Ashwal, L.D., 2010. Diamonds sourced by plumes from the core mantle boundary. Nature 466. http://dx.doi.org/10.1038/nature09216352.

Torsvik, T.H., Van der Voo, R., Preeden, U., Mac Niocaill, C., Steinberger, B., Doubrovine, P.V., van Hinsbergen, J.J., Domeier, M., Gaina, C., Tohver, E., Meert, J.G., McCausland, P.J.A., Cocks, L.R.M., 2012. Phanerozoic Polar Wander, palaeogeography and dynamics. Earth-Science Reviews 114, 325–368.

Tsukada, K., Koike, T., 1997. Ordovician conodonts from the Hitoegane area, Kamitakara Village, Gigu Prefecture. Journal of the Geological Society of Japan 103, 171–174 (In Japanese).

Ueno, K., 2003. The Permian fusulinoidean faunas of the Sibumasu and Baoshan blocks: their implications for the paleogeographic and paleocimatologic reconstruction of the Cimmerian Continent. Palaeogeography, Palaeoclimatology, Palaeoecology 193, 1–24.

van Hinsbergen, D.J.J., Kapp, P., Dupont-Nivet, G., Lippert, P.C., DeCelles, P.G., Torsvik, T.H., 2011. Restoration of Cenozoic deformation in Asia and the size of Greater India. Tectonics 30, 1–31.

Veevers, J.J., 2004. Gondwanaland from 650–500 Ma assembly through 320 Ma merger in Pangea to 185–100 Ma breakup: supercontinental tectonics via stratigraphy and radiometric dating. Earth-Science Reviews 68, 1–132.

Wan, B., Xiao, W., Zhang, L., Windley, B.F., Han, C., Quinn, C.D., 2011. Contrasting styles of mineralization in the Chinese Altai and East Junggar, NW China: implications for the accretionary history of the southern Altaids. Journal of the Geological Society of London 168, 1311–1321.

Wang, B., Chen, Y., Zhan, S., Shu, L., Faure, M., Cluzel, D., Charvet, J., Laurent-Charvet, L., 2007. Primary Carboniferous and Permian paleomagnetic results from the Yili Block (NW China) and their implications on the geodynamic evolution of Chinese Tianshan Belt. Earth and Planetary Science Letters 263, 288–308.

Wang, X.D., Ueno, K., Mizuno, Y., Sugiyama, T., 2001. Late Paleozoic faunal, climatic, and geographic changes in the Baoshan block as a Gondwana-derived continental fragment in southwest China. Palaeogeography, Palaeoclimatology, Palaeogeography 170, 197–218.

Wang, Y., Rong, J., 1986. Yukiangian (Early Emsian, Devonian) brachiopods of the Nanning-Liujing District, central Guangxi, southern China. Palaeontologica Sinica 172, 1–282 (pls 1–46. (In Chinese)).

Wang, Y., Zhou, L., Zhao, L., Ji, M., Gao, H., 2010. Palaeozoic uplands and unconformity in the North China Block: constraints from zircon LA–ICP–MS dating and geochemical analysis of bauxite. Terra Nova 22, 264–273.

Wartes, M.A., Carroll, A.R., Greene, T.J., 2002. Permian sedimentary record of the Turpan-Hami basin and adjacent regions, northwest China: constraints on postamalgamation tectonic evolution. Gological Society of America Bulletin 114, 131–152.

Wilde, S.A., Wu, F.Y., Zhang, X., 2003. Late Pan-African magmatism in northeastern China: SHRIMP U–Pb zircon evidence from granitoids in the Jiamusi Massif. Precambrian Research 122, 311–327.

Wilde, S.A., Wu, F.Y., Zhao, G., 2010. The Khanka Block, NE China, and its significance for the evolution of the Central Asian Orogenic Belt and continental accretion. Geological Society, London, Special Publications 338, 117–137.

Wilhem, C., Windley, B.F., Stampfli, G.M., 2012. The Altaids of Central Asia: a preliminary innovative review. Earth-Science Reviews 113, 303–341.

Windley, B.F., Alexeiev, D., Xiao, W., Kröner, A., Badarch, G., 2007. Tectonic models for accretion of the Central Asian Orogenic Belt. Journal of the Geological Society of London 164, 31–47.

Wu, F.Y., Sun, D.Y., Ge, W.C., Zhang, Y.B., Grant, M.L., Wilde, S.A., Jahn, B.M., 2011. Geochronology of the Phanerozoic granitoids in northeastern China. Journal of Asian Earth Sciences 41, 1–30.

Xiang, H., Zhang, L., Zhong, Z.Q., Santosh, M., Zhou, H.W., Zhang, H.F., Zheng, J.P., Zheng, S., 2012. Ultrahigh-temperature metamorphism and anticlockwise *P-T-t* path of Paleozoic granulites from north Qinling–Tongbai orogen, Central China. Gondwana Research 21, 559–576.

Xiao, W., Han, C., Yuan, C., Sun, M., Lin, S., Chen, H., Li, Z., Li, J., Sun, S., 2008. Middle Cambrian to Permian subduction-related accretionary orogenesis of Northern Xinjiang, NW China: implications for the tectonic evolution of central Asia. Journal of Asian Earth Sciences 32, 102–117.

Xiao, W., Huang, B., Han, C., Sun, S., Li, J., 2010a. A review of the western part of the Altaids: a key to understanding the architecture of accretionary orogens. Gondwana Research 18, 253–273.

Xiao, W., Mao, Q., Windley, B.F., Han, C., Qu, J., Zhang, J., Ao, S.J., Guo, Q., Cleven, N.B., Lin, S.F., Shan, Y., Li, J., 2010b. Paleozoic multiple accretionary and collisional processes of the Beishan orogenic collage. American Journal of Science 310, 1553–1594.

Xiao, W., Windley, B.F., Hao, J., Li, J., 2002. Arc-ophiolite obduction in the Western Kunlun Range (China): implications for the Palaeozoic evolution of central Asia. Journal of the Geological Society of London 159, 517–528.

Xiao, W., Windley, B.F., Yong, Y., Yan, Z., Yuan, C., Liu, C., Li, J., 2009a. Early Palaeozoic to Devonian multiple-accretionary model for the Qilian Shan, NW China. Journal of Asian Earth Sciences 35, 323–333.

Xiao, W., Windley, B.F., Yuan, C., Sun, M., Han, C.M., Lin, S.F., et al., 2009b. Paleozoic multiple subduction–accretion processes of the southern Altaids. American Journal of Science 309, 221–270.

Xu, H.K., Liu, D.Y., 1984. Late early Ordovician brachiopods of southwestern China. Nanjing Institute of Geology and Palaeontology Bulletin 8, 149–235.

Yan, Z., Xiao, W.J., Windley, B.F., Wang, Z.Q., Li, J.L., 2010. Silurian clastic sediments in the North Qilian Shan, NW China: chemical and isotopic constraints on their forearc provenance with implications for the Paleozoic evolution of the Tibetan Plateau. Sedimentary Geology 231, 98–114.

Yang, J., Xu, Z., Zhang, J., Chu, C.Y., Zhang, R., Liou, J.G., 2001. Tectonic significance of early Paleozoic high-pressure rocks in Altun–Qaidam–Qilian Mountains, northwest China. Geological Society of America Memoir 194, 151–170.

Yang, Z., Sun, Z., Yang, T., Pei, J., 2004. A long connection (750–380 Ma) between South China and Australia: paleomagnetic constraints. Earth and Planetary Science Letters 220, 423–434.

Yin, A., 2006. Cenozoic tectonic evolution of the Himalayan orogeny as constrained by along-strike variation of structural geometry, exhumation history, and foreland sedimentation. Earth-Science Reviews 76, 1–131.

Yin, A., Manning, C.E., Lovera, O., Menold, C.A., Chen, X., Gehrels, G.E., 2007. Early Paleozoic tectonic and thermomechanical evolution of ultrahigh-pressure (UHP) metamorphic rocks in the northern Tibetan Plateau, northwest China. International Geology Review 49, 681–716.

Young, G.C., Janvier, P., 1999. Early-Middle Palaeozoic vertebrate faunas in relation to Gondwana dispersion and Asian accretion. In: Metcalfe, I. (Ed.), Gondwana Dispersion and Accretion. Balkema, Rotterdam, pp. 115–140.

Yue, Y., Liou, J.G., Graham, S.A., 2001. Tectonic correlation of Beishan and Inner Mongolia orogens and its implications for the palinspastic reconconstruction of north China. Geological Society of America Memoir 194, 101–116.

Zhan, R.B., Cocks, L.R.M., 1998. Late Ordovician brachiopods from the South China plate and their palaeogeographical significance. Special Papers in Palaeontology 59, 1–70.

Zhan, R.B., Rong, Y.L., Percival, I.G., Liang, Y., 2011. Brachiopod biogeographic change during the Early to Middle Ordovician in South China. Memoirs of the Association of Australasian Palaeontologists 41, 273–287.

Zhang, H.-F., Sun, M., Lu, F.-X., Zhou, X.-H., Zhou, M.-F., Liu, Y.-S., Zhang, G.-H., 2001. Geochemical significance of a garnet lherzolite from the Dahongshan kimberlite, Yangtze Craton, southern China. Geochemical Journal 35, 315–331.

Zhang, H.-F., Zhou, M.-F., Sun, M., Zhou, X.-H., 2010. The origin of Mengyin and Fuxian diamondiferous kimberlites from the North China Craton: implication for Palaeozoic subducted oceanic slab–mantle interaction. Journal of Asian Earth Sciences 37, 425–437.

Zhang, J., Li, J., Liu, J., Feng, Q., 2011a. Detrital zircon U–Pb ages of Middle Ordovician flysch sandstones in the western Ordos margin: new constraints on their provenances, and tectonic implications. Journal of Asian Earth Sciences 43, 1030–1047.

Zhang, J.X., Mattinson, C.G., Meng, F.C., Yang, H.J., Wan, Y.S., 2009. U–Pb geochronology of paragneisses and metabasite in the Xitieshan area, north Qaidam Mountains, western China: constraints on the exhumation of HP/UHP metamorphic rocks. Journal of Asian Earth Sciences 35, 245–258.

Zhang, L., Qin, K., Xiao, W., 2008. Multiple mineralization events in the eastern Tianshan district, NW China: isotopic geochronology and geological significance. Journal of Asian Earth Sciences 32, 236–246.

Zhang, S.H., Zhao, Y., Sung, B., Yang, Z., Hu, J.M., Wu, H., 2007. Carboniferous granitic plutons from the northern margin of the North China Block: implications for a Late Palaeozoic active continental margin. Journal of the Geological Society of London 164, 451–463.

Zhang, W., Chen, P., Palmer, A.R. (Eds.), 2003. Biostratigraphy of China. Science Press, Beijing (599 pp.).

Zhang, X., Wilde, S.A., Zhang, H., Zhai, M., 2011b. Early Permian high-K calc-alkaline volcanic rocks from NW Inner Mongolia, North China: geochemistry, origin and tectonic implications. Journal of the Geological Society of London 168, 525–543.

Zhao, X., Coe, R.S., Liu, C., Zhou, Y., 1992. New Cambrian and Ordovician paleomagnetic poles for the North China Block and their paleogeographic implications. Journal of Geophysical Research 97, 1767–1788.

Zhou, D., Graham, S.A., Chang, E.Z., Wang, B., Hacker, B., 2001a. Paleozoic tectonic amalgamation of the Chinese Tian Shan: evidence from a transect along the Dushanzi–Kuqa Highway. Geological Society of America Memoir 194, 23–46.

Zhou, Z.-y, Zhou, Z.-q, Zhang, J.-l, 1989. Ordovician trilobite biofacies of North China platform and its western marginal area. Acta Palaeontologica Sinica 28, 296–313.

Zhou, J.B., Wilde, S.A., Zhao, G.C., Zhang, X.Z., Wang, H., Zeng, W.S., 2010. Was the easternmost segment of the Central Asian Orogenic Belt derived from Gondwana or Siberia: an intriguing dilemma? Journal of Geodynamics 50, 300–317.

Zhou, Z.-y, Bergström, J., Zhou, Z.Q., Yuan, W.W., Zhang, Y.B., 2011. Trilobite biofacies and palaeogeographic development in the Arenig (Ordovician) of the Yangtze Block, China. Palaeoworld 20, 15–45.

Zhou, Z.-y, Zhen, Y., 2008. Trilobite-constrained Ordovician biogeography of China with reference to faunal connections with Australia. Proceedings of the Linnean Society of New South Wales, 129, pp. 183–195.

Zhou, Z.-y, Zhen, Y., Zhou, Z.-q, Yuan, W., 2007. A new approach to the division of Ordovician geographic units of China. Acta Palaeontologica Sinica 46 (Supplement), 558–563.

Zhou, Z.-y, Dean, W.T., Luo, H., 1998a. Early Ordovician trilobites from Dali, West Yunnan, China, and their palaeogeographical significance. Palaeontology 41, 429–460.

Zhou, Z.-y, Dean, W.T., Yuan, Y., Zhou, T., 1998b. Ordovician trilobites from the Dawangou Formation, Kalpin, Xinjiang, north-west China. Palaeontology 41, 693–735.

Zhou, Z.-y, Luo, H.-l, Zhou, Z.-q, Yuan, W.W., 2001b. Palaeontological constraints on the extent of the Ordovician Indo-China terrane in Western Yunnan. Acata Palaeontologica Sinica 40, 310–317 (pls 1, 2. (In Chinese)).

Zhou, Z.-y, Chen, P. (Eds.), 1992. Biostratigraphy and Geological Evolution of Tarim. Science Press, Beijing (399 pp.).

Zhou, Z.-y., Dean, W.T. (Eds.), 1996. Phanerozoic geology of northwest China. Science Press, Beijing (316 pp.).

Zhu, Y., Guo, X., Song, B., Zhang, L., Gu, L., 2009. Petrology, Sr–Nd–Hf isotopic geochemistry and zircon chronology of the Late Palaeozoic volcanic rocks in the southwestern Tianshan Mountains, Xinjiang, NW China. Journal of the Geological Society of London 166, 1085–1099.

Ziegler, A.M., Hulver, M.L., Rowley, D.B., 1997. Permian world topography and climate. In: Martini, I.P. (Ed.), Late glacial and Postglacial Environmental Changes. Oxford University Press, New York, pp. 111–146.

Zimina, V.G., 1977. Flora of Early to early Late Permian of Southern Primor'ya. Dafnevost Scientific Publishing House, Moscow. (127 pp. (In Russian)).

Zonenshain, L.P., Kuzmin, M.I., Natapov, L.M., 1990. Geology of the USSR: a plate-tectonic synthesis. American Geophysical Union Geodynamics Series 21, 1–242.