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Escape hypothesis for North and South China collision and tectonic evolution of the Qinling orogen, eastern Asia

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Key words: Qinling orogen, Tanlu fault zone, North China terrane, South China terrane, Qaidam terrane, Songpan-Ganzi terrane, South Korea, Emei basalt.

ABSTRACT

The E-W-trending Qinling Orogenic belt in central China marks the suture between the North China and South China terranes (the latter includes the whole of South Korea), two major microcontinental terranes of the Eurasian continent. Both middle Paleozoic and early Mesozoic collision zones within the Qinling orogenic belt, and the northward extension of the suture between the North and South China terranes that includes the Tanlu fault zone, have been recognized recently. The Songpan-Ganzi terrane proves to be a continental terrane underlain by Precambrian basement and is geographically very close to the Qaidam terrane. Permo-Triassic strike-slip faulting and rifting developed along the boundaries between the Qaidam and Songpan-Ganzi, the South China and Songpan-Ganzi, and the North and South China terranes. This suggests an escape hypothesis for a Central China terrane that was present between the North and South China terranes during the tectonic evolution of Qinling. In Paleozoic time, the linear fragments of a microcontinental plate between two sutures in the Qinling orogenic belt, and Qaidam and Songpan-Ganzi terranes, all bearing similar basement and early Paleozoic strata, could have belonged to an integrated triangular continental microplate, the Central China terrane, between North and South China. A stable triple junction could have existed around the Dabie Shan between the Central China, North China, and South China terranes. Central China first collided with North China and formed the northern suture of the Qinling orogenic belt in middle Paleozoic time and was gradually extruded westward from between North and South China and then split into the Qaidam and Songpan-Ganzi terranes in Permo-Triassic time, when South China collided diachronously from east to west with North China. The proposed model accommodates the abrupt bend between the Qinling-Dabie belt and the Tanlu belt, the two collisions along the Qinling orogenic belt, and the large-angular rotation of South China with respect to North China, and predicts the Permo-Triassic strike slip faulting and rifting along the Qinling orogenic belt, the western flank of South China, and the boundary between the Qaidam and Songpan-Ganzi terranes.

ZUSAMMENFASSUNG

Das E-W streichende Qinling Orogen in Zentralchina folgt der Sutur zwischen zwei eurasischen Mikrokontinenten, dem nordchinesischen und dem südchinesischen Terrane (letzteres umfasst auch ganz Südkorea). Mittelpaläozoische und frühmesozoische Kollisionszonen im Qinling Orogen und die nördliche Fortsetzung der Sutur zwischen dem nord- und dem südchinesischen Terrane, die auch die Tanlu-Störungszone umfasst, wurden vor kurzem entdeckt. Das Songpan-Ganzi Terrane erweist sich als kontinentales Terrane, unterlagert von einem präkambrischen Grundgebirge, es liegt geographisch ganz in der Nähe des Qaidam Terranes. Permotriassische strike-slip Verwerfungen und Rifting entwickelten sich an der Grenze zwischen Qaidam und Songpan-Ganzi, und zwischen nord- und südchinesischem Terrane. Das spricht für die Annahme eines zentralchinesischen Terranes, das während der tektonischen Entwicklung des Qinling zwischen nord- und südchinesischem Terrane lag. Schmale mikrokontinentale Fragmente zwischen den beiden Suturen des Qinling Orogens und den Qaidam und Songpan-Ganzi Terranes haben im Paläozoikum vielleicht zu einem zusammenhängenden dreieckigen Mikrokontinent zwischen Nord- und Südchina gehört, da alle ein sehr ähnliches Grundgebirge und frühes Paläozoikum besitzen. Beim Dhabi Shan könnte eine Triple Junction zwischen Nord-, Süd- und Zentralchina existiert haben. Zentralchina kollidierte zuerst mit Nordchina, so entstand die nördliche Sutur des Qinling Orogens im mittleren Paläozoikum. Zentralchina wurde allmählich zwischen Nord- und Südchina nach Westen ausgequetscht. Im Permo-Trias spaltete es sich in die Qaidam und Songpan-Ganzi Terranes auf, als Südchina diachron von Ost nach West mit Nordchina kollidierte.

Das vorgeschlagene Modell erklärt die scharfe Biegung zwischen der Qinling Dabie Zone und der Tanlu Zone, die beiden Kollisionen entlang des Qinling Orogens, und den grossen Winkel der Rotation von Südchina gegenüber Nordchina, und sagt die permotriassischen strike-slip Bewegungen und Rifting entlang des Qinling Orogens voraus, an der Westflanke von Südchina und an der Grenze zwischen Qaidam und Songpan-Ganzi Terranes.

Introduction

The E-W-trending Qinling Orogenic belt in central China marks the suture between the North China and South China terranes, two major microcontinental terranes of the Eurasian continent. A clear understanding of the North and South China collision zone and the evolution of the Qinling orogenic belt is important to elucidate the tectonic framework and evolution of the Eurasian continent. However, two main problems still remain regarding the nature of the collision of these two terranes and the evolution of Qinling orogenic belt. First, it has been intensely debated whether the

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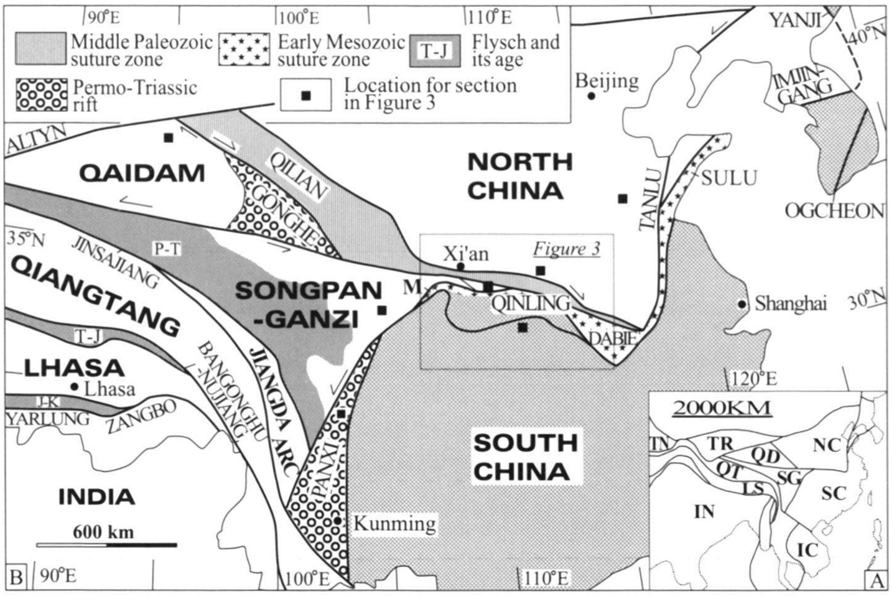

Fig. 1A. Sketch tectonic map of eastern Asia. Main terranes: IC-Indochina, IN-India, LS-Lhasa, NC-North China, QD-Qaidam, QT-Qiangtang, SC-South China, SG-Songpan-Ganzi, TN-Turan, TR-Tarim. Fig. 1B. Simplified geologic map of central China. Note that the Permian-Triassic flysch association in the Songpan-Ganzi terrane was thrust over the coastal sediments (blank).

collision between the North and South China terranes along the Qinling orogenic belt occurred during middle Paleozoic time (e.g., Huang 1977; Zhang, Z. M. et al. 1984; Mattauer et al. 1985; Liu & Hao 1989; Gao et al. 1995; Zhang, H. F. et al.

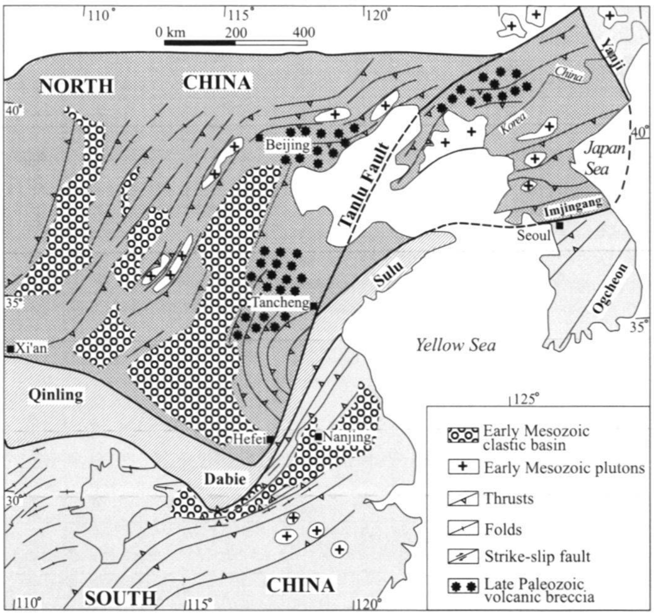

Fig. 2. Sketch tectonic map of eastern China, to show the structural relationships between the Qinling, Dabie, Imjingang, Yanji, and Ogcheon. Revised after Zhang, K. J. (1997, 1999) and many other data sources. Note that the existence of the Late Paleozoic calc-alkaline volcanism on the eastern margin of North China indicates a possible active continental margin there and that NNE-predominantly trending early Mesozoic contractional deformation in both the North and South China terranes marks a westward convergence and continental subduction between the North and South China terranes.

1997), or early Mesozoic time (e.g., Lin et al. 1985; Sengör 1990; Hsü et al. 1987; Zhao & Coe 1987; Ames et al. 1993; Okay et al. 1993; Yin & Nie 1993; Hacker at al. 1995; Gilder & Courtillot 1997). Second, the kinematic compatibility of the motion along the two perpendicular boundaries of the North China terrane, i.e., the southern one along the east-west trending Qinling orogenic belt and the eastern one along the north-south trending Tanlu fault zone (Zhang, K. J. 1997, 1999, 2000) (Figs. 1A, 1B, 2), remains an unsolved key question (e.g., Enkin et al. 1992).

In this paper, based upon the latest recognition of the northward extension of the suture between the North and South China terranes, including the Tanlu fault zone, the presence of both middle Paleozoic and early Mesozoic collision along the Qinling orogenic belt, and the continental basement of the Songpan-Ganzi terrane, an extrusion hypothesis is suggested for a region between the North and South China terranes in the evolution of the Qinling orogenic belt. First, I present evidence for the presence of both middle Paleozoic and Triassic collision zones and Permo-Triassic strike-slip faulting in the Qinling orogenic belt. I then review the geology of several Chinese terranes, including the Qaidam and Songpan-Ganzi terranes, to show the evidence for the presence of their continental basement and Permo-Triassic strike-slip faulting along the boundaries between these terranes. Finally, an escape model is proposed for the North and South China collision zone and the evolution of the Qinling orogenic belt, which hypothesizes that there could have existed a triangular microcontinent between the North and South China terranes, which first collided with the North China terrane and formed the northern Qinling collision zone during middle Paleozoic time, and later was extruded and split into the present Qaidam and Songpan-Ganzi terranes in western China, during formation of the southern Qinling zone during Permo-Triassic time when the South China terrane collided diachronously from east to west with the North China terrane.

2. Nature of the Tanlu fault zone and the geometry of the North and South China terranes

Tectonostratigraphic analysis (Zhang, K. J. 1997, 1999, 2000) supports the hypothesis of northward extension of the suture between the North and South China terranes into northeastern China along the Tanlu fault zone (e.g., Enkin et al. 1992; Ernst & Liou 1995) (Figs. 1A, 1B, 2).

A chain of late Paleozoic calc- alkaline volcanic rocks along the eastern flank of the North China terrane indicates a probable active margin (Zhang, K. J. 1997 and references therein; Fig. 2), similar to that along its southern margin, the northern Qinling zone (Hsü et al. 1987). The South China terrane possibly extends far to northeast, and includes southern Korea and southwestern Japan, according to paleobiographic data (e.g., Ernst & Liou 1995; Yin & Nie 1993, 1996; Zhang, K. J. 1997, 1999), and presents a NNE trend with regard to its present location (Fig. 2), paralleling the general NNE trend of the sedimentary facies through Paleozoic time (Zhang, K. J. 1997). In the eastern half of the North China terrane an eastern suture (Yanji suture; Fig. 2) containing lenses of Permo-Triassic ophiolites and blueschists has been discovered (Sao et al. 1995), and NNE-trending early Mesozoic contractional deformation and clastic molasse basins are present (e.g., Zhang, K. J. 1997; Fig. 2). Scattered blueschist and eclogite (e.g., Wang & Liou 1992; Li et al. 1993; Zhang, K. J. 1997, 1999), dominant contractional deformation of at least 220 km shortening (Zhang, K. J. 1997), and the Triassic foreland clastic basins on both sides of the Tanlu fault (Fig. 2), suggest it was originally part of an eastern suture belt (Zhang, K. J. 1997) (Figs. 1A, 1B, 2). The collision between the North and South China terranes along the eastern suture, from the Tanlu fault zone, via central Korea (Lee et al. 1996), to northeastern China (Zhang, K. J. 1997) (Fig. 2), immediately preceded the Mesozoic collision along the southern Qinling zone (Yin & Nie 1993, 1996; Zhang, K. J. 1997). The general NE trend of the Mesozoic fold and thrust belt in both the North and South China terranes intersecting the WNW trend of the Qinling-Dabie zone, indicates a right-lateral transpression along the Qinling-Dabie zone (Zhang, K. J. 1997) and the Qilian zone (Yin & Nie 1996) (Fig. 2) during the collision between North and South China.

It has long been recognized that the Cambrian trilobites in most Chinese provinces of the South China terrane belong to North China types. Typical and native genera of the Cambrian trilobites in the North China terrane are present in every Chinese provinces of the Yangtze plate and several other Chinese provinces of the South China terrane, and include *Blackwelderia, Damesella, Dorypyge, Drepanura, Kaolishania, Liaoningaspis, Megapalaeolenus, Paleolenus, Redlichia chinensis, Shantungaspis* (see e.g., HBBGM 1988; SXBGM 1989; SCBGM 1991; Zhang, K. J. 1999 and references therein). In addition, Choi (1994) pointed out that the Cambrian trilobites in the Korean peninsula also belong to North China types. This conclusion is consistent with the data presented by Kobayashi (1966b) in his extensive studies on the Cambrian trilobites of eastern Asia (Zhang, K. J. 1999). Moreover, the Late Triassic timing (Cluzel, et al. 1991) and lack of high-pressure metamorphic rocks along the Ogcheon zone (Figs. 1B, 2) is not similar to the early Early Triassic timing (Zhang, K. J. 1997) and suture character (Zhang, K. J. 1997, 1999) of the Tanlu fault zone. Thus, there is no basis for a tectonic division in South Korea south of the Imjingang belt (Figs. 1B, 2) as initially proposed by Cluzel et al. (1990, 1991) and then followed by Yin & Nie (1993, 1996). The Cambrian trilobites can not be used as a basis for distinguishing between the North and South China terranes. All of south Korea is considered to be part of the South China terrane (Figs. 1B, 2), because the Paleozoic strata in south Korea are similar to those in south China (Kobayashi 1966a, 1966b), and because the Imjingang belt forms a major boundary and correlates with the Sulu-Tanlu-Dabie belt (Hsü et al. 1987; Yin & Nie 1993, 1996; Lee et al. 1996; Zhang, K. J. 1997, 1999). The change of the Cambrian lithologies across the Ogcheon belt is best explained as a natural lateral continuation of lithofacies (Kobayashi 1966a).

3. Qinling orogen

Various opinions exist about the tectonic subdivisions of the Qinling orogenic belt (e.g., Mattauer et al. 1985; Tao et al. 1993; Gao et al. 1995; Zhang, K. J. 1997). Here it is divided into two main zones, the northern and southern Qinling zones (NQZ and SQZ in Fig. 3a), by the Danfeng fault (DFF in Fig. 3a). Very detailed geologic maps and stratigraphic columns and descriptions of Archean and post-Archean rocks for the whole Qinling orogenic belt and its adjacent regions have been presented by HBBGM (1988), SXBGM (1989), SCBGM (1991), Tao et al. (1993), and Ji et al. (1997).

3.1 Northern Qinling

It is commonly agreed that the northern Qinling zone contains the southern margin of the North China terrane (Huang & Wu 1992; Tao et al. 1993; Gao et al. 1995; Zhang, K. J. 1997; Zhang, H. F. et al. 1997; Meng & Zhang 1999), and records a middle Paleozoic collision event (Mattauer et al. 1985; Gao et al. 1995; Zhang, K. J. 1997; Zhang, H. F. et al. 1997; Meng & Zhang 1999). The evidence for this collision is briefly summarized as follows.

(1) Bands or lenses of coesite-bearing eclogite within granoblastic quartzofeldspathic gneiss (Fig. 3a) (e.g., Hu et al. 1994; Liu & Zhou 1994) dated at 400 ± 30 Ma (Sm-Nd, $^{40}Ar/^{39}Ar$. e.g., Zhang, Z. Q. et al. 1994) in the Early Proterozoic Qinling Complex and the Middle-Late Proterozoic Kuanpin Complex, extend over 50 km E-W in the northern

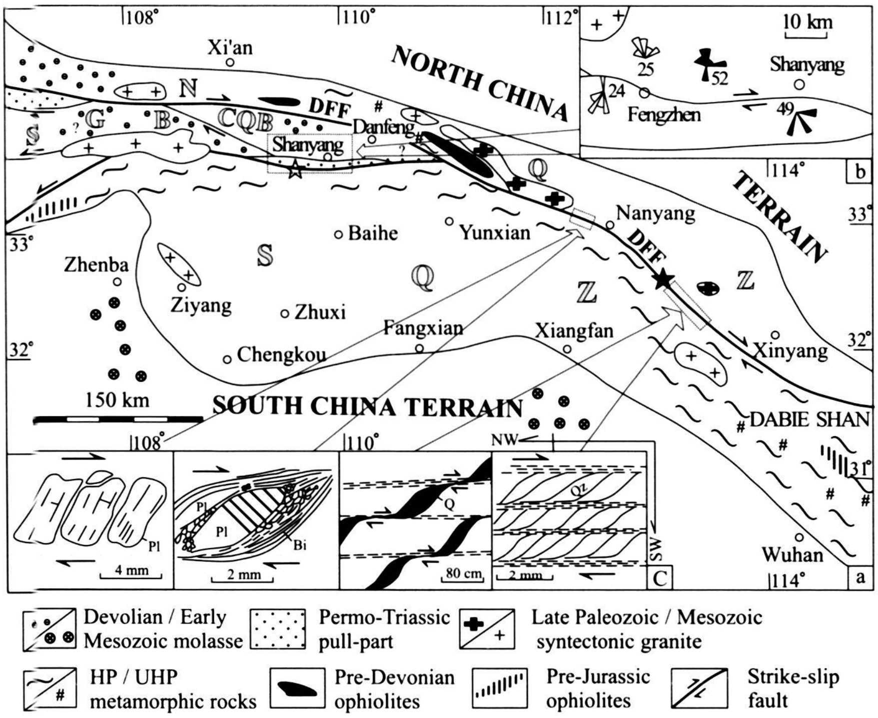

Fig. 3a. Simplified geologic map of the Qinling Orogenic belt, revised after Mattauer et al. (1985), HBBGM (1988), Zhang, S. Y. & Kang (1989), SXBGM (1989), SCBGM (1991), Tao et al. (1993), and Ji et al. (1997). The blank asterisk denotes the location where marginal sea-type thin-bedded and turbidity limestones were discovered by Jiang et al. (1963), Yin et al. (1992) and Ji et al. (1997), and the filled asterisk denotes the location where Triassic abyssal radiolarians were discovered by Feng et al. (1994). CQB, NQZ, SQZ- central, northern, southern Qinling zone, respectively; SGB-Songpan-Ganzi terrane; DFF-Danfeng fault. See Fig. 1b for the location. Fig. 3b. Clastic orientations of the Devonian molasse basins in both sides of the Shanyang fault, from Meng et al. (1995). The filled flowers denote those of the Middle Devonian, and the blank ones denotes those of the Upper Devonian. Note their distinct contrary orientations, which indicates a continent between these two basins could have been lost. Fig. 3c. Microstructures (plan view) showing right-lateral motion along the Danfeng fault, associated with Wei (1993) and Ji et al. (1997). Bi-biotite; pl-plagioclase; Q-quartzous vein; Qz-quartz.

Qinling zone near Danfeng (Fig. 3a) (e.g., Liu & Zhou 1994; Hu et al. 1996;). In addition, middle Paleozoic UHP eclogite (722 ± 123°C, 2200 MPa) has been documented in quartzofeldspathic gneiss in the middle segment (ca. 38°00', 95°00') of the Qilian suture (Fig. 1) (Yang et al. 1998). The Qilian suture is a well-known middle Paleozoic suture between the North China and Qaidam terranes (Zhang, Z. M. et al. 1984; Yin & Nie 1996), and there has been no evidence found for a Triassic metamorphic event (Chen 1994). This is also true in the northernmost flank of the Dabie Shan, where Middle Paleozoic eclogites were also reported (e.g., about 401 Ma, ^{40}Ar / ^{39}Ar. Liu et al. 1993). The dominance of acidic gneiss in the northern Qinling and Qilian UHP complex suggests that it represents a Precambrian continental basement deeply subducted during middle Paleozoic time. Therefore, an event of middle Paleozoic continental subduction in and around the southern margin of North China appears likely (e.g., Hu et al. 1993; Kroner et al. 1993; Gao et al. 1995; Zhang, H. F. et al. 1997; Zhai et al. 1998; Meng & Zhang 1999).

(2) A >150-km-wide middle Paleozoic north-verging foreland fold-and-thrust zone involving Sinian and early Paleozoic marine strata of the North China terrane is present in the southern margin of the North China terrane north of the Qinling orogenic belt (e.g., Zhang, J. et al. 1998). This deformational zone is unconformably overlain by terrigenous strata of late Paleozoic and Mesozoic age (e.g., SXBGM 1989), and is well documented on seismic profiles (Zhang, J. et al. 1998).

(3) Termination of marine sedimentation in the North China terrane through Mesoproterozoic to early Paleozoic, and the unconformable relationship between the lower Paleozoic marine deposits and Devonian alluvial-fluvial units in both the southern flank of the North China terrane and the northern and central Qinling zones indicates the existence of a pre-Devonian deformation (Fig. 4) (e.g., Huang 1977; Mattauer et al. 1985; Chen 1994; Ji et al. 1997).

(4) The extensive collision-type granites in the northern Qinling zone with the ages that range from 323-262 Ma (Fig. 3a) (U-Pb, Rb-Sr. e.g., Zhang, B. R. 1994) supports a middle Paleozoic deformation. Pb isotopes of Paleozoic collision-related granitoids along the Danfeng fault zone indicate these granitoids could result from the underthrusting of continental crust beneath the northern Qinling in Devonian time (Zhang, H. F. et al. 1997).

(5) Floral and paleogeographic data suggest the North China terrane must have been adjacent to a terrane with South China affinity during Carboniferous time (Enkin et al. 1992; Chen 1994). Similar Carboniferous floras and warm-water limestones in both the North and South China terranes, belonging to the Euramerican type in Early to Middle Carboniferous time and to the Cathaysian type in Late Carboniferous time (e.g., Chen 1994), and plant migration routes were present from the Chinese terranes to Europe in Late Carboniferous time (Laveine et al. 1989).

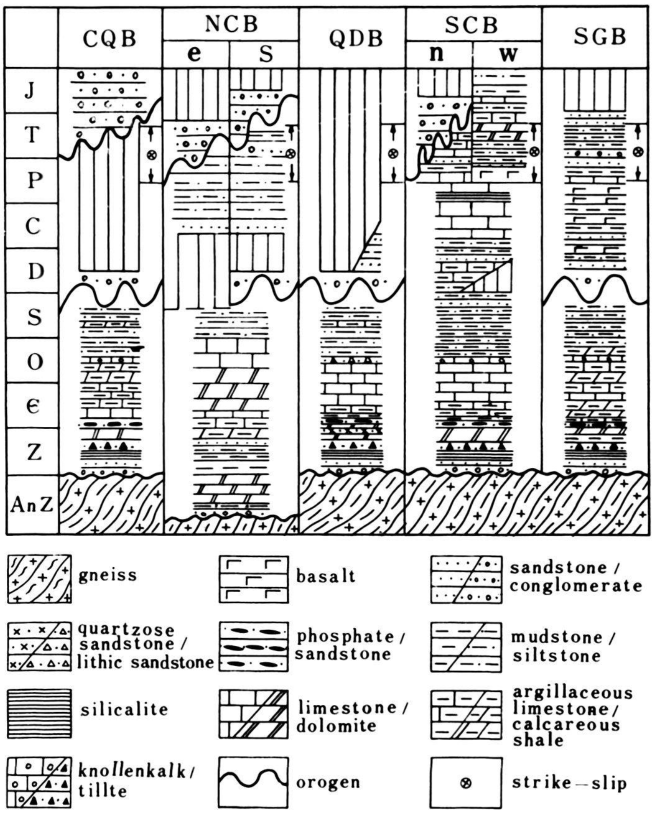

Fig. 4. Tectonostratigraphic correlations among central Qinling (CQB, i.e. fragments of the continental terrane in Fig. 3a between two suture zones in eastern Qinling), the North China terrane (NCB), the Qaidam terrane (QDB), the South China terrane (SCB), and the Songpan-Ganzi terrane (SGB), after Tao et al. (1993); Chen (1994), and Ji et al. (1997). e, n, s, and w denote eastern, northern, southern, and western margin, respectively. See Fig. 1b for the locations of the sections. AnZ-Presinian; Z-lower, upper Lower Sinian; Є-Cambrian; O-Ordovician; S-Silurian; D-Devonian; C-Carboniferous; P-Permian; T-Triassic; J-Jurassic.

3.2 Southern Qinling

The southern Qinling zone contains the northern margin of the South China terrane and records an early Mesozoic tectonic event along its northern fringe (Figs. 1 and 3a). Generally, it is believed that the southern Qinling zone contains the South China terrane-type Precambrian basement and experienced a continuous passive-margin sedimentation during Paleozoic to Middle Triassic time, similar to the South China terrane (e.g., Hsü et al. 1987; Huang & Wu 1992; Tao et al. 1993; Gao et al. 1995; Ji et al. 1997). Although it underwent passive continental margin-type volcanism during early Paleozoic time (e.g., Huang & Wu 1992; Ji et al. 1997), the sedimentary facies of the southern Qinling zone was the oceanic extension of the South China terrane (HBBGM 1988; SXBGM 1989; SCBGM 1991; Zhang, K. J. 1997); locally pelagic deposits defines its northernmost rim. For example, in Jinjiling hill (blank asterisk in Fig. 3a, ca. 33°15', 119°20') of Zhen'an county (Shaanxi province), marginal sea-type thin-bedded and turbidity limestones up to 2254.4 m thick have been discovered (Jiang et al. 1963; Yin et al. 1992; Ji et al. 1997); in the Guimei village (filled asterisk in Fig. 3a, ca. 32°25', 113°20') in Tongbai county (Henan province), and many Triassic radiolarians have been reported in the deep sea sedimentary deposits of coeval ophiolites (e.g., Feng et al. 1994). According to Feng et al. (1994), these deep marine rocks contain *Archaeospongoprunum compactum* Nakaseko and Nishimura, *Cenoshaera* sp., *Shengia yini* (Feng), *Triassocampe* sp., *Triassomitra zhangi* n. gen. et sp., *Yangia chinensis* Feng of Triassic age. No distinct tectonic divide, not to mention a suture, exists between southern Qinling and the main body of South China. Therefore, southern Qinling does not constitute an independent terrane or plate as proposed by Meng & Zhang (1999).

Mesozoic suturing, which is locally marked by high-pressure metamorphism, only occurred and was localized along the northern fringe of southern Qinling (see Zhang, S. Y. & Kang 1989; Fig. 3a). The southern Qinling zone suffered more intense intracontinental subduction and subsequent thrusting than any other part of the South China terrane (HBBGM 1988; SXGBM 1989; SCBGM 1991). Several main lines of evidence for the Mesozoic North and South China collision include:

(1) Ultrahigh- to high- pressure metamorphic rocks dated at 230 ± 30 Ma are present in the Dabie Shan (e.g., Zhang, S. Y. & Kang 1989; Wang & Liou 1992; Ames et al. 1993; Li et al. 1993; Okay et al. 1993; Hacker et al. 1995). The high-pressure metamorphic rocks in the southern Qinling zone are mainly localized along its northern fringe (Zhang, S. Y. & Kang 1989) (Fig. 3a).
(2) A <50-km-wide zone with lenses of ophiolites is present along the suture and in the western southern Qinling zone the ophiolites are dated at 242 ± 21 and 221 ± 13 Ma (Sm-Nd. Li et al. 1996) (Fig. 3a).
(3) A >200-km-wide Late Triassic to Middle Jurassic south-verging foreland fold-and-thrust zone involving Paleozoic and early Mesozoic marine strata of passive margin of the South China terrane including the southern Qinling zone (HBBGM 1988; SCBGM 1991) is related to the North China-South China collision.
(4) Continuous Sinian to Middle Triassic marine record of the entire South China terrane including the southern Qinling and Late Triassic and Jurassic molasses in southern Qinling and the South China terrane (Figs. 3a and 4) (HBBGM 1988; SXBGM 1989; SCBGM 1991; Chen 1994) indicates that only an early Mesozoic deformation occurred in the South Qinling.
(5) Abundant paleomagnetic data indicate that the North and South China terranes did not make contact until early Mesozoic time (e.g., Lin et al. 1985; Zhao & Coe 1987; Enkin et al. 1992; Gilder & Courtillot 1997).
(6) Extensive Mesozoic collision-type granites in the Qinling orogenic belt are evidence for an early Mesozoic collision (Reischman et al. 1990; Chen 1994) (Fig. 3a).

4. Songpan-Ganzi and Qaidam terranes

Although the triangular Songpan-Ganzi terrane in central China has long been believed underlain by oceanic crust (e.g., Sengör 1990; Yin & Nie 1993, 1996), recently several deep seismic lines traversing the terrane reveal that it is underlain by continental crust (e.g., Cui et al. 1996). The upper sialic crust of the terrane has a P-wave velocity less than 6.35 km / s and is about 29-32 km thick. This could be made up of folded and thrust Mesozoic and Paleozoic sediments and Precambrian basement (Cui et al. 1996; Zhang, K. J. 2001). Additional several lines of evidence support the inference of the continental basement: (1) South China-type Precambrian basement is exposed all along the periphery of the Songpan-Ganzi terrane (e.g., Yin et al. 1988; QHBGM 1991; SCBGM 1991; Cui et al. 1996; Yang et al. 1994), (2) Mesoproterozoic granites with an age of about 1585 Ma (Xu et al. 1996) have been reported along the margin of the Songpan-Ganzi terrane (ca. 30°50', 101°50'), and (3) Early Paleozoic strata in the surroundings of the Songpan-Ganzi terrane commonly contain voluminous boulders from the Proterozoic granitic basement as indicated by sediment transport direction (e.g., Yang et al. 1994). Therefore, the flysch succession of the Songpan-Ganzi terrane has been interpreted as allochthonous tectonic flakes above a continental crust (Fig. 1B. Zhang, K. J. 2001).

The Qaidam and Songpan-Ganzi terranes converge toward and extend eastwards into the western Qinling (Figs. 1B and 3a). The Qaidam terrane was partly covered by early Paleozoic stable marine sediments; its northern flank was covered by Devonian molasse (QHBGM 1991; Chen 1994). The eastern Songpan-Ganzi terrane is successively covered by stable marine sediments through early Paleozoic time, partly by Devonian molasse in its eastern part (Fig. 3a), and by an association of near-shore clastics and limestones of Carboniferous to Triassic age (Figs. 1B and 4) (SCBGM 1991; Zhang, K. J. et al. 2002). The boundary between the Songpan-Ganzi and South China terranes is marked by early Mesozoic blueschist (Zhang, S. Y. & Kang 1989), ophiolitic rocks (Chen 1994), and extensive thrusting and strike slip deformation (Zhang, K. J. 2001). The early Paleozoic strata in the Qaidam and Songpan-Ganzi terranes (Fig. 4) contain rich floras and faunas of South China affinity (Chen 1994; Yang et al. 1994). However, they have been apparently mixed with the North Cathaysian floras and faunas since Early Carboniferous time, especially in the Qaidam terrane, which reveals their possible amalgamation to the North China terrane in middle Paleozoic time (Chen 1994).

Notably, the faunas in the Paleozoic strata in the Songpan-Ganzi terrane bear much closer affinity to the Qaidam terrane than to any other Chinese terrane (Chen 1994), which implies, comparing their similar basement and geologic evolution (Fig. 4), that the Songpan-Ganzi and Qaidam terranes could have evolved in very close geographical proximity. The western end of the Songpan-Ganzi terrane immediately adjacent to the Qaidam terrane contains evidence of intense rifting during Permo-Triassic time (Chen 1994) (Fig. 1B). Different from the general trend of northward motion of nearly all other terranes in eastern Asia (e.g., Enkin et al. 1992), paleomagnetic study has documented a distinct southward motion on the order of several hundreds of kilometers for the southeasternmost tip of the Songpan-Ganzi terrane from Late Permian to Triassic time (Zhu et al. 1988).

5. Permo-Triassic strike-slip faulting and rifting among the Chinese terranes

5.1. Central Qinling

The central Qinling, lying between the northern and southern Qinling zones, comprises 0-20-km-wide linear fragments of a paleo-continental plate (CQB in Fig. 3a) in the east, and the eastward extension of the Qaidam and Songpan-Ganzi terranes in the west (Figs. 1B and 3a). Like the Qaidam and Songpan-Ganzi terranes, the central Qinling is made up of the South China-type basement and early Paleozoic marine strata of a passive margin of South China affinity (Figs. 1B and 4) (e.g., SCBGM 1991; Chen 1994; Ji et al. 1997), and is partly covered by the Devonian foreland molasse (Tao et al. 1993; Meng et al. 1995; Ji et al. 1997) (Figs. 3a and 4). Many approximately E-W-striking vertical faults cut the Qinling orogenic belt, and all appear to be strike-slip faults (Figs. 1B and 3a) with probable large offsets. (e.g., Mattauer et al. 1985). Further, mapping at 1:50,000 scale in the Qinling belt (e.g., Wei 1993) has documented complicated strike-slip faults, of late Paleozoic, Mesozoic, and Cenozoic age, with left- and right- lateral displacement (Zheng 1990; Suo et al. 1992; Tao et al. 1993; Wei 1993; Tang & Liu 1995; Ji et al. 1997), rather than consistent left-lateral strike-slip as suggested by Mattauer et al. (1985). The important faults of this group correspond to boundaries between the northern and southern zones.

From regional geology and tectonics, the Danfeng fault (DFF in Fig. 3a) appears to be the most important fault (Mattauer et al. 1985). Microstructure studies conducted in northwestern Tongbai Shan, Dabie Shan-Tongbai Shan (Suo et al. 1992), central Qinling (Tao et al. 1993), Tongbai Shan (Fig. 3c. Wei 1993), western Dabie Shan (Tang & Liu 1995), and the Danfeng area (Ji et al. 1997) (Fig. 3a), as well as the shape of Permo-Triassic pull-aparts along the Danfeng fault in the western Qinling (Fig. 3a), indicate that the Danfeng fault could have been mainly a right-lateral strike-slip fault during Permo-Triassic time. However, other important faults, appear to be dominated by left-lateral strike-slip (Fig. 3a).

The Permo-Triassic rifting was developed along, and limited to, central Qinling (Tao et al. 1993) (Fig. 1B). The rifting resulted in a series of basins (Fig. 3a). These basins are deep, rhomb-shaped, and bounded on their sides by main subparallel, overlapping strike-slip faults (e.g., Tao et al. 1993; Yang et al. 1994; Ji et al. 1997) (Fig. 3a). These basins can be interpreted to be syntectonic pull-aparts related to the right-lateral strike-slip faulting during Permo-Triassic time.

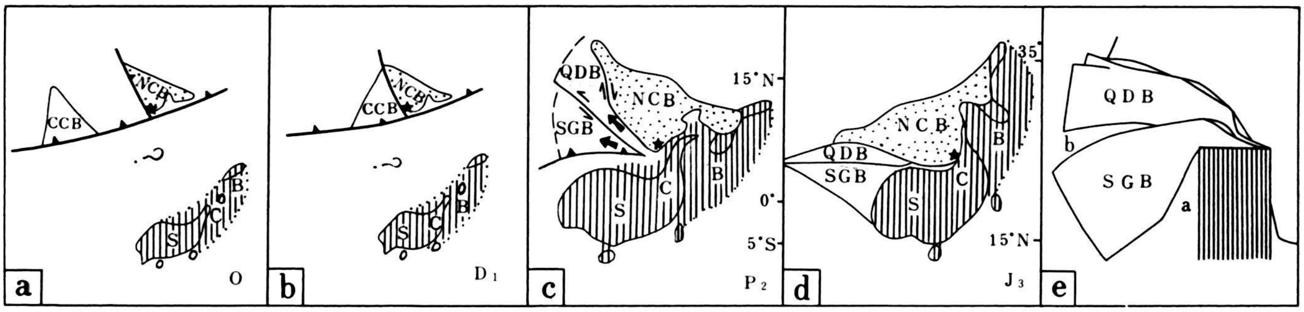

Fig. 5. Paleozoic and Mesozoic reconstructions of central China. CCB - assumed Central China terrane; other abbreviations as in Fig. 4. The asterisk denotes the Dabie Shan. O-Ordovician, D_1-Early Devonian, P_2-Late Permian, J_3-Late Jurassic. Paleolatitude data after Lin et al. (1985), Zhao & Coe (1987), and Enkin et al. (1992). Fig. 5e is after Tapponnier et al. (1982), and a and b correspond respectively to the Panxi rift in the western margin of the South China terrane (Fig. 1B), and the westernmost rift between the Qaidam and Songpan-Ganzi terranes.

Lithofacies analysis of two different Devonian molasse basins on both sides of Shanyang show they have distinctly different sediment transport directions (Meng et al. 1995) (Fig. 3b), and their similar clastic components could have come from the same continent composed of metamorphic rocks, which can be traced into the eastern part of the Songpan-Ganzi terrane (Meng et al. 1995) just west of Fig. 3a. Therefore, it appears plausible to infer a paleo-continental terrane, possibly containing the Songpan-Ganzi terrane, could have been removed and transported westward, leaving the fragments in the central Qinling as the relics of the continental plate.

5.2. Gonghe rift

The Gonghe rift lies among the Qilian suture, the Qaidam and Songpan-Ganzi terranes (Fig. 1). Although it has been considered by many authors as the northern extension of the Songpan-Ganzi terrane (e.g., Sengör 1990), I here propose that it is a Permo-Triassic rift based on following evidence. The Permo-Triassic volcanics and ophiolites in its southern end have been suggested to have formed in a continental rift environment (Pearce & Deng 1988; Pearce & Mei 1988). In addition, according to known geologic data, Triassic flysch association in the rift is obviously separated from the southern main body in Songpan-Ganzi by Paleozoic and Precambrian rocks (Fig. 1B. QHBGM 1991; SCBGM 1991; Zhang, K. J. 2001). The Triassic strata are mainly composed of continental-neritic facies, and the Triassic flysch is only localized in the middle of the rift (QHBGM 1991; Zhang, K. J. 2001). Therefore, this triangular rift could be the result of strike slip movement among Chinese terranes during Permo-Triassic time.

5.3. Panxi rift

The Panxi rift (a in Fig. 5e) in the western margin of the South China terrane (Fig. 1B) represents a famous and typical intracontinental rift, which developed on the passive margin from Late Sinian to Early Jurassic time (e.g., Kie 1987). This rift was active during Late Permian to Triassic time, during the formation of Late Permian intracontinental Emei basalt, up to 2-3 km thick, and Triassic turbidites and alkaline volcanic rocks of continental rift character (SCBGM 1991; Chen 1994; Yang et al. 1994). Because of the well-defined Permo-Triassic left-lateral strike-slip displacement between the Songpan-Ganzi and South China terranes (Zhu et al. 1988; Enkin et al. 1992), these features are alternatively interpreted to have been related to coeval left-lateral strike-slip displacement along the western margin of the South China terrane (Figs. 1B and 5e)

6. Tectonic model

Two active margins flanked both the eastern and southern margins of the North China terrane, and they joined at the abrupt tectonic bend in Dabie Shan (Figs. 1A, B). The South China terrane could have contained a west-facing passive continental margin that lasted into Triassic time, extends far into northeastern Asia, and includes South Korea. The southern suture, or the Qinling orogenic belt, including Dabie Shan, suffered both middle Paleozoic and early Mesozoic collisions. The eastern suture, including the Tanlu zone, suffered only early Mesozoic collision. The continental fragments in central Qinling, the Qaidam terrane, and the Songpan-Ganzi terrane possess similar Precambrian basement and early Paleozoic tectonic and paleogeographic characteristics. Permo-Triassic strike-slip faulting and rifting developed along the boundaries between the North and South China, Qaidam and Songpan-Ganzi, and South China and Songpan-Ganzi terranes.

The middle Paleozoic collision in the northern Qinling zone occurred between the North China terrane and another large continental plate that could not be the South China terrane, because its northern margin contains a continuous Sinian to Middle Triassic marine record (Yin & Nie 1993, 1996; Zhang, K. J. 1997). Moreover, this large continental plate, now largely missing, is not the southern Qinling zone (i.e. the Qinling terrane of Meng & Zhang 1999), because the southern

Qinling contains the northern margin of the South China terrane and does not constitute an independent plate. There is no evidence to support the eastward extension of the "Mianlue suture" of Meng & Zhang (1999) between southern Qinling and South China. An alternative, and better, explanation for the "Mianlue suture" (M in Fig. 1B), the basis of Meng and Zhang's Qinling terrane, can be that it converges into the boundary between the South China and Songpan-Ganzi terranes (Fig. 1B).

On the basis of these geologic relationships and constraints, an escape model is proposed for the collision of the North and South China terranes and the evolution of the Qinling orogenic belt. The abrupt bend in the orogenic belt at the Dabie Shan implies there could have existed a stable triple junction during the long-term subduction through Paleozoic time along the present eastern and southern active margins of the North China terrane. At present, these two subduction-related boundaries are assumed to be two trench-type boundaries, and it is suggested here that a third trench-type boundary could have extended southwards perhaps originally in alignment with Tanlu fault zone. The third trench and the present southern margin of the North China terrane (i.e. the northern Qinling zone) could have bounded a triangular-shaped opening between the North and South China terranes (Figs. 5a, b), as indicated by abundant paleomagnetic data (its central angle = 67° from Late Permian to Early Triassic time [Zhao & Coe 1987], and not ceasing until Middle Jurassic time [Gilder & Courtillot 1997]). Within the triangular-shaped space there could have existed a triangular microcontinental plate from Paleozoic through early Mesozoic time (Figs. 5a, b), most of which is now preserved as linear continental fragments along the central Qinling, the Qaidam and Songpan-Ganzi terranes (Figs. 5c, d), which have similar South China-type basement, early Paleozoic strata, and a similar tectonic evolution (Fig. 4). Here, the assumed paleo-plate is named the Central China terrane, which was separated from the South China terrane by the third trench-type boundary, or a possible southward extension of the present eastern active margin of the North China terrane (Zhang, K. J. 1997) through Paleozoic time (Figs. 5a, b).

In middle Paleozoic time, when the assumed ocean between the Central China terrane and the North China terrane was consumed, the Central China terrane collided with the North China terrane along the southern active margin of the North China terrane, forming the suture in the northern Qinling zone (Fig. 5b). Meanwhile, the ocean between the Central China terrane, the North and South China terranes could have been subducting towards the Central China terrane and the North China terrane. In latest Early Permian time, the North and South China terranes made initial contact along the eastern margin of the North China terrane, according to geological and paleomagnetic data (e.g., Zhao & Coe 1987; Yin & Nie 1993, 1996; Zhang, K. J. 1997). The emergence of the northward subduction and rotation of the South China terrane toward the North China terrane initiated westward removal (or extrusion) of the Central China terrane, which resulted in the intense Permo-Triassic rifting and development of pull-aparts along the central Qinling, and the boundary faults along the Qaidam and Songpan-Ganzi terranes (Fig. 5c). Meanwhile, the ocean between the Central China terrane and the South China terrane could have been subducting towards the Central China terrane in view of the stable marine sedimentation on the northern flank of the South China terrane that lasted into early Mesozoic time (e.g., Zhang, K. J. 1997) (Fig. 5d). Intracontinental subduction between the North and South China terranes developed along the eastern and southern margin of the North China terrane. During Late Triassic time the entire Central China terrane could have been extruded from between the North and South China terranes when the South China terrane collided with the North China terrane.

A subduction zone, probably along the Jinsajiang belt (Fig. 1B; Zhang, K. J. et al. 2002), to the west of the South China terrane could have acted as the free lateral boundary for the deformation (Tapponnier et al. 1982). Strike-slip faults could have originated at the easternmost tip of the Central China terrane (the assumed triple junction), and developed preferentially along preexisting fault zones, including the northern Qinling middle Paleozoic suture and the northwestward subduction zone between the Central China terrane and the South China terrane (Fig. 5c). I speculate that the strike-slip fault between the Qaidam terrane and the Songpan-Ganzi terrane could have initiated at the same time or later than the initiation of strike-slip faults along the Qinling belt and the subduction zone between the Central China terrane and the South China terrane. These faults split the Central China terrane into the Qaidam terrane and the Songpan-Ganzi terrane, and guided their progressive extrusion and rotation while the South China terrane gradually approached the North China terrane. Finally, as the South China terrane collided with the North China terrane, the entire Central China terrane was extruded beyond the suture between the North and South China terranes. Numerous pull-aparts and rifts opened along the boundary faults with the largest ones formed along the boundary faults near the free edge. Particularly spectacular gaps (rifts) were produced between the Qaidam terrane and the Songpan-Ganzi terrane (b in Fig. 5e), and between the Songpan-Ganzi terrane and the western side of the South China terrane (a in Fig. 5e). The western flank of the South China terrane could have been modified during this deformation.

A critical aspect of this extrusion tectonic model for the North and South China collision is that it accommodates the abrupt bend between the Qinling orogenic belt, including the Dabie Shan, and the Tanlu belt, and the two various collisions along the Qinling orogenic belt, and predicts the Permo-Triassic rifting along the Qinling belt, the western flank of South China, and the boundary between the Qaidam and Songpan-Ganzi terrane. This model also is well compatible with the Permo-Jurassic clockwise rotation of the South China terrane with respect to the North China terrane, well documented by numerous paleomagnetic studies (e.g., Lin et al. 1985; Zhao &

Coe 1987; Enkin et al. 1992; Gilder & Courtillot 1997). Liu (1999) considered the incompatibility with the large-angular rotation as fatal weakness of the models of Yin & Nie (1993, 1996). The present model also explains the paradox of the mixed assemblage of the North and South Cathaysian floras and faunas along the southern flank of the North China terrane during late Paleozoic time (e.g., Enkin et al. 1992; Chen 1994) prior to contact between the North and South China terranes, which could be the result of the middle Paleozoic amalgamation of the North China terrane and the Central China terrane bearing floras and faunas of the South China terrane affinity during early Paleozoic time.

7. Summary

Although it has been intensely debated whether the collision between the North and the South China terranes occurred during middle Paleozoic or early Mesozoic time along the Qinling Orogenic belt, voluminous data reveal that both of these two collision events are present, and recently there seems another more general trend among Qinling geologists to admit two collision zones across the Qinling orogenic belt (e.g., Yin & Nie 1996; Zhang, K. J. 1997; Zhai et al. 1998; Meng & Zhang 1999). From north to south across the Qinling orogenic belt, there could exist both middle Paleozoic and Mesozoic collisional zones, between which were spread linear fragments of a microcontinental plate. The suture belt between the North and South China terranes possibly extends far into northeastern China along the eastern margin of the North China terrane. The whole of South Korea tectonically belongs to the South China terrane. The Songpan-Ganzi terrane is a proven continental terrane underlain by a South China-type Precambrian basement. An integrated continental terrane consisting of Qaidam, Songpan-Ganzi, and central Qinling, could be parts of a continental plate which collided with the North China terrane during middle Paleozoic time, in view of their Paleozoic tectonostratigraphic similarity. Permo-Triassic strike-slip faulting and rifting was intensely developed along the boundaries of these belts and terranes.

An alternative escape model for the North and South China collision and the evolution of the Qinling orogenic belt is suggested. The model proposes that a triangular microplate existed between the North and South China terranes through Paleozoic time, and that in middle Paleozoic time it collided with the North China terrane and formed the northern Qinling collision zone. In Permo-Triassic time it was extruded westward and split into the present Qaidam and Songpan-Ganzi terranes in central western China. The Permo-Triassic rifting in Qinling, the western margin of South China, and the boundary between the Qaidam and Songpan-Ganzi terranes, has been associated with the escape of a Central China terrane. Not only was the extrusion tectonic framework modified, but also the consequent rifts were closed during the Mesozoic amalgamation of the Tibetan terranes (Zhang, K. J. et al. 2002) and the Cenozoic Himalayan tectonism.

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