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Triassic tectonics of the Southern margin of the South China Block

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ABSTRACT

Middle Triassic orogens are widespread around and inside the South China Block (SCB). The southern peripheral belts that develop from NW to SE, namely Jinshajiang, Ailaoshan, NW Vietnam, NE Vietnam, Yunkai and Hainan exhibit striking similarities, with Permian-Early Triassic magmatic arc, ophiolitic mélange, NE to N-directed synmetamorphic ductile nappes, and fold-and-thrust belt. These collisional belts result from oceanic, then continental subduction of the SCB below Indochina. Eastward of Hainan Island, a Triassic suture is hypothesized offshore of the SCB. Within the SCB, the Xuefengshan is a Middle Triassic intracontinental orogen with NW-directed folds and thrusts, and an intracrustal ductile decollement. This orogen accommodated the Middle Triassic continental subduction of the Western part of the SCB below the Eastern part. At variance to the generally accepted

models, the inter- and intra-continental Triassic orogens of the SCB are interpreted here as the result of South-directed subductions of the SCB.

Key words:

Triassic tectonics, Continental collision, Intracontinental subduction, South China Block, Indochina Block

1. Introduction

It is well acknowledged that the architecture of Asia results of the amalgamation of large continents such as Siberia, N. China, S. China, Tarim, Indochina, India, and several microcontinents: Lhasa, Qiangtang, Qaidam, etc... (e.g. Metcalfe, 2013; Fig. 1). The South China Block (SCB) is one of the most complex as it underwent a long Phanerozoic evolution after its Neoproterozoic formation before 850 Ma during a collisional event that welded the Yangtze and Cathaysia Blocks (e.g. Charvet et al., 1996; Li et al., 2007a; Fig 2). During the Early Paleozoic, the SCB was welded to the N. China block along the Qinling-Dabie belt (e.g. Mattauer et al., 1985; Li et al., 2007b; Faure et al., 2008; Dong et al., 2011; Liu et al., 2013). Between Late Ordovician and Early Silurian, the closure of a Neoproterozoic Nanhua rift was responsible for the building of an intracontinental belt (e.g. Wang and Li, 2003; Faure et al., 2009; Charvet et al., 2010; Wang et al. 2013). From Devonian to Early Triassic, during ca 170 my, the SCB behaved as a stable continent covered by a carbonate platform. However, in the Late Permian, the SW part of SCB, in Yunnan and Guangxi, experienced a huge intraplate magmatism coeval with rifting, known as the Emeishan Large Igneous Province (Ali et al., 2005; Fig. 2).

The Triassic appears as the most important period for the tectonic development of the SCB. Since the recognition of a Norian unconformity and the definition of "Indosinian" movements in Central Vietnam (Deprat, 1915; Fromaget, 1941), the term Indosinian has been ascribed to all Triassic tectonic and magmatic events throughout Asia, even if these features were geodynamically unrelated to Vietnamese ones. As numerous dates are now available, the Middle Triassic stratigraphic age will be preferred to "Indosinian".

Triassic events are widespread all around the SCB (Fig. 2). South of the Early Paleozoic Qinling belt, Triassic top-to-the-S ductile shearing, HP and UHP metamorphism, and plutonism are documented (e.g. Hacker et al., 1998; Lin et al., 2000; Ratschbascher et al. 2003; Li et al. 2007b; Faure et al., 2008; Liu et al., 2013). To the NW, in spite of an intense Cenozoic reworking, a SE-directed Triassic thrusting is recognized in the Longmenshan belt (e.g. Burchfiel et al., 1995; Roger et al. 2008; Robert et al., 2010). The Jinshajiang, Ailaoshan, and N. Vietnam belts represent the Western and Southwestern boundaries of the SCB. Furthermore, Middle Triassic events are responsible for the development of the Xuefengshan belt in the internal part of the SCB (Chu et al., 2012a,b; Wang et al., 2013; Fig. 2). The architecture and geodynamic evolution of these belts are still controversial, but it is widely accepted that the SCB belonged to the upper plate above a north (NE or NW)-dipping subduction zone (e.g. Wang et al., 2013; Li and Li, 2007).

The aim of this paper is to synthesize the Triassic tectonic features that develop along the southern margin of the SCB, and in its interior as well. Then a possible geodynamic interpretation, at variance to the present paradigm, will be discussed. The Triassic events of the northern part of the SCB, and the Jurassic and Cretaceous ones of the interior of SCB will not be addressed here.

2. Triassic orogens of N. Vietnam

It is sometimes proposed that the Red River Fault (RRF) is the boundary between SCB and Indochina. The RRF is a polyphase fault with Miocene sinistral ductile strike-slip (also referred to as the Ailaoshan-Red River shear zone), and a Plio-Quaternary dextral motion. The left-lateral ductile displacement developed in response to the Indian collision was variously estimated from a few tens to several hundred of km (e.g. Tapponnier et al., 1986; Leloup et al., 1995, 2006; Searle, 2006). The strike-slip faulting accounts for the Cenozoic tectonics, but when dealing with the Triassic events, the RRF cannot be considered as a plate boundary as ophiolites, subduction complexes, or HP metamorphic rocks are lacking. In contrast, two ophiolitic belts are recognized in NW and NE Vietnam on both sides of the RRF, along the Song Chay and Song Ma faults (Fig. 2; Lepvrier et al., 1997, 2008, 2011; Faure et al., 2014).

2.1. The NW Vietnam (Song Ma) belt

From SW to NE, several litho-tectonic zones are recognized (Figs. 2, 3A). 1) Permian-Early Triassic volcanic and sedimentary rocks of the *Sam Nua zone*, overlying an Early Paleozoic series, are interpreted as a magmatic arc (Tran et al., 2008a; Liu et al., 2012). 2) The *Song Ma zone* formed by ultramafic, mafic rocks and deep marine sediments represents an ophiolitic suture. 3) The *Nam Co metamorphic rocks*, developed at the expense of Neoproterozoic terrigenous series, and Paleozoic limestone and sandstone, correspond to the sedimentary cover of a continental basement ductilely deformed during the NE-ward thrusting of the Song Ma ophiolites. 4) Farther North, folded unmetamorphosed successions of Devonian to Carboniferous limestone, Permian volcanics, Early Triassic clastics, and Middle Triassic carbonates represent the outer zone (*Son La-Lai Chau zone*) of this belt. There, Late Permian alkaline basalts and volcanoclastites form the Song Da rift. Although sometimes considered as ophiolites, these rocks, emplaced in an intraplate setting, belong to

the Emeishan Large Igneous Province (Ali et al., 2005; Tran et al., 2008b; Tran and Vu, 2011). The Permian Tule acidic rocks are also relevant to this bimodal magmatism (Tran and Vu, 2011). 5) Lastly, the Proterozoic basement, stratigraphically overlain by a Paleozoic sedimentary cover, is called the *Posen-Hoabinh zone* that forms the deepest part of the NW Vietnam belt.

The NW Vietnam belt exhibits a structural and metamorphic polarity decreasing from SW to NE. Late Triassic sandstone and conglomerate unconformably cover deformed rocks. Biotite and muscovite $^{40}\text{Ar}/^{39}\text{Ar}$, zircon U/Pb, and monazite chemical U/Th/Pb ages around 245-230 Ma argue for a Middle Triassic age for the nappe architecture of the NW Vietnam belt (Lepvrier et al., 1997, 2008, Nakano et al., 2008, 2011).

2.2. The NE Vietnam (Song Chay) belt

NE of the RRF, another Triassic belt develops with the following SW to NE zonation (Lepvrier et al. 2011; Faure et al. 2014; Figs. 2, 3A). 1) The *Dai Nuy Con Voi* is a NW-SE striking Cenozoic HT antiform developed from grauwacke and pelite hosting granodiorite, diorite and gabbro plutons of Permian-Triassic age (Gilley et al., 2003; Zelazniewicz et al. 2013). This zone is interpreted as a magmatic arc. 2) The *Song Chay ophiolitic mélange* is composed of serpentinites, mafic rocks, limestone, and chert blocks included in a terrigenous matrix of Triassic age. 3) The *NE Vietnam nappe* consists of Cambrian-Ordovician terrigenous rocks, and Devonian to Permian carbonates. Ordovician porphyritic granites (e.g. the Song Chay massif) are now changed into augengneiss. N- to NE-verging folds and thrusts deform the entire lithological succession. Biotite-garnet-staurolite micaschist yields a monazite U-Th-Pb age at 246 ± 10 Ma (Faure et al., 2014). 4) The *outer zone* is a Paleozoic lithological succession similar to that of the NE Vietnam nappe covered by a thick Middle Triassic turbidite series with acidic lava flows and ashes. This formation includes olistoliths

of alkaline basalt, gabbro and limestone. Similar mafic rocks crop out in China where they intrude the late Paleozoic limestone platform. They have been ascribed to the "Babu ophiolites" (Fig. 2, Zhong 2000; Cai and Zhang, 2009), but their geological setting and geochemistry show that they are intraplate basalts corresponding to remote parts of the Emeishan Large Igneous Province (e.g. Zhou et al. 2006, see discussion in Faure et al., 2014). The NE Vietnam belt extends in China between Kunming and Nanning, the flat lying Late Paleozoic limestone platform is involved in N-directed folds and thrusts upon the Middle Triassic turbidite (Fig. 4C).

In summary, both the NW and SE Vietnam belts are collisional orogens formed by a SW-ward subduction of oceanic, then continental lithosphere. Due to their lithological, structural, and chronological similarities, the two belts have been interpreted as the result of a duplication of a single Triassic orogen by the Cenozoic left-lateral strike-slip shearing of the **Ailaoshan-Red River shear zone** (Faure et al., 2014).

3. The western extension of the N. Vietnam orogens

3.1. The Ailaoshan Belt

This NW-SE 500km-long belt (Fig. 2) is subdivided into several narrow stripes by belt-parallel strike-slip faults. In spite of the intense Cenozoic shearing (e.g. Leloup et al., 1995), the Ailaoshan is commonly acknowledged as a Triassic suture zone between the SCB and Indochina-Simao block but structural details and subduction polarity are disputed (e.g. Zhong 2000; Jian et al., 2009a,b; Fan et al., 2010; Lai et al., 2013a,b; Wang et al., 2013). From SW to NE, four litho-tectonic zones ascribed to the Triassic orogen are recognized (Fig. 2). 1) The *Western Ailaoshan*, characterized by volcanic and sedimentary rocks, is unconformably overlain by Late Triassic red conglomerate and sandstone. Basalt and andesite, dated between 287 and 265 Ma, were originated in a magmatic arc installed upon a

Silurian-Devonian terrigenous series (Jian et al., 2009a; Fan et al., 2010). 2) The *Central Ailaoshan* contains serpentinite, gabbro, dolerite, plagiogranite, basalt, chert, and limestone blocks enclosed into a terrigenous matrix (Lai et al., 2014b). Zircon from plagiogranite yields U-Pb ages at 383-376 Ma, 365 Ma, and 328 Ma interpreted crystallization age of ophiolitic protoliths (Jian et al., 2009b; Lai et al., 2014b). This domain represents an ophiolitic mélange but the age of the matrix is unknown. 3) The *Eastern Ailaoshan* consists of gneiss, micachists, amphibolites, marbles, and migmatites that form a Paleoproterozoic basement, partly reworked during the Cenozoic (Lin et al., 2012). Middle Triassic carbonate covers the crystalline basement. 4) The *Jinping area* exposes Late Permian mafic lava, pillow breccia, agglomerate, and volcanoclastites (Wang et al., 2007). Furthermore, felsic volcanites dated at ca 246 Ma result of syn- to late-collisional crustal melting (Lai et al., 2014a).

A steeply dipping foliation and a subhorizontal lineation are the main ductile structures developed during the Cenozoic shearing as they involve the Late Triassic rocks. Nevertheless, a steeply dipping stretching lineation with top-to-the NE sense of shear and NE verging folds are also observed (Fig 4B). These structures, incompatible with the strike-slip event, and not observed in the Late Triassic or younger rocks, are of Middle Triassic in age.

Thus in spite of the Tertiary overprint, the Ailaoshan belt is comparable with the N. Vietnam belts. Namely, the Western, Central, and Eastern Ailaoshan zones are equivalent to the Sam Nua, Song Ma, Posen-Hoabinh zones, respectively. The Sonla-Laichau zone pinches out in the Ailaoshan, except in the Jinping area where magmatic rocks are similar to the Song Da rift.

3.2. The termination of the NE Vietnam Belt

The NE Vietnam Belt abruptly ends in China (Fig. 2). The Dai Nuy Con Voi metamorphics are surrounded by Permian-Early Triassic volcanites and grauwackes

corresponding to the magmatic arc, but ophiolites are not exposed. Folded and thrustured Paleozoic rocks are equivalent to the NE Vietnam nappe. To the north, Middle Triassic turbidites of the Youjiang basin involved in N-verging folds correlate with the outer zone of NE Vietnam.

3.3. The Jinshajiang Belt

At the edge of the Tibet plateau, the Triassic Jinshajiang orogen is documented by the Late Triassic unconformity overlying a folded Middle Triassic ophiolitic mélange with basalt, chert, and limestone blocks (Fig. 4A, Zhong 2000; Wang and Metcalfe, 2000). This mélange overthrusts to the East the Late Paleozoic-Triassic carbonate platform of the SCB. To the West, a Permian-Early Triassic magmatic arc argues for a west-directed subduction. The bimodal magmatism at 245-237 Ma is interpreted as syn- to post-collisional (Zi et al., 2012). The Jianshajiang Belt exhibits lithological and structural features similar to those of the Ailaoshan and N Vietnam orogens.

4. The eastern extension of the N. Vietnam orogens

4.1. The Yunkai Massif

In Guangxi, the Late Triassic-Jurassic red sandstone of the Shiwandashan basin (SB in Fig. 2) is a post-orogenic molasse with respect to the Triassic orogeny (e.g. Hu et al., 2014). The Yunkai massif consists of Early Paleozoic HT metamorphics, migmatites, and Triassic granites tectonically surrounded by weakly metamorphosed Devonian-Carboniferous sedimentary rocks (e.g. Wang et al., 2007; Lin et al., 2008). The metamorphic rocks belong to the Early Paleozoic orogen of SE China but were intensely reworked by the Triassic events. The flat-lying foliation and NE-SW stretching lineation, associated with a top-to-the-NE ductile shearing developed at ca 250-240 Ma. During this event, the Early Paleozoic granites

were changed to orthogneiss (Fig. 4D). The Yunkai massif is a 100km-scale basement nappe that overthrusts northward onto the Late Paleozoic sedimentary rocks of the SCB (Figs. 3C, 4E). As ophiolites are lacking there, the eastward extension of the Song Chay suture should be searched more to the South in Hainan Island (Fig.2).

4.2. Triassic tectonics in Hainan Island

The tectonic evolution of Hainan Island remains controversial. The Cretaceous and younger extensional events are not considered here. Late Triassic plutons seal the main ductile deformation (Fig. 3B). N-verging folds and thrusts deform the Early Paleozoic series and the underlying Proterozoic basement. Granodiorites and biotite granite with calcalkaline geochemical signatures, and yielding zircons SHRIMP U-Pb ages at 267 ± 3 Ma and 263 ± 3 Ma by SHRIMP method, are interpreted as the "Wuzishan magmatic arc" (Li et al., 2006). North of this arc, a Late Permian-Early Triassic terrigenous series including Carboniferous gabbro, basalt, siliceous rocks and limestone is interpreted as a mélangé (Fig. 4F; Li et al., 2002). This formation is ductilely deformed with top-to-the-N kinematics dated at ca 250-240 Ma by $^{40}\text{Ar}/^{39}\text{Ar}$ method on micas (Zhang et al., 2011). In spite of a still limited knowledge, the Hainan Island appears as a suitable site for the eastern extension of the Song Chay suture.

5. Triassic intracontinental tectonics in East SCB

5.1. The Xuefengshan Belt

Middle Triassic tectonics is not limited to the SCB margins. In central SCB (E. Hunan and Guangxi), the Xuefengshan Belt is a NNE-SSW striking 700 km long belt dominated by NW-directed thrusts and folds. SE-verging folds are interpreted as secondary back-folds (Chu et al., 2012a; Fig. 5). A ductile decollement layer, intruded by Late Triassic plutons dated at 225-215 Ma by SIMS U-Pb method on zircon (Chu et al., 2012c), exhibits a NW-SE striking

stretching lineation, and top-to-the-NW sense of shear (Chu et al., 2012b). This 500 km wide fold-and-thrust belt involves the entire Neoproterozoic to Early Triassic sedimentary pile to the west of the Chenzhou-Linwu fault (CLF in fig. 2). This fault, devoid of ophiolites and subduction mélange, is not a suture zone, but an intracontinental "scar". In order to balance the ca 300 km of shortening experienced by the sedimentary rocks overlying the decollement layer, a SE-ward continental subduction of the same amount must have taken place in the crystalline basement of the western part of SCB (Chu et al., 2012a).

5.2. Coastal and eastern SE China

E-W striking folds develop south of the Jiangshan-Shaoxing Fault (Fig. 2). The Late Triassic regional unconformity argues for a Middle Triassic event (Shu et al., 2008). As documented in the Jiuling area (Chu and Lin, 2014), upright folds are lateral ramps related to the Xuefengshan belt. The E-W elongated Wugongshan dome located immediately south of the Jiangshan-Shaoxing fault (Fig. 2; Faure et al., 1996) might be also developed during the reactivation of this Neoproterozoic suture. The Triassic ductile deformation is probably underestimated in the eastern part of SCB (Wang et al. 2014).

In the coastal area of SE China, widespread Jurassic and Cretaceous granites and volcanites hide older formations. West of Fuzhou, Middle Triassic rocks deformed by N-verging recumbent folds and covered by a Late Triassic unconformity indicate that the SE China coastal area also experienced a Middle Triassic deformation (Zhu et al., 1996).

6. Discussion of the Triassic orogens

A N-directed Triassic oceanic subduction, below the SCB, is often suggested (e.g. Zhou and Li, 2000; Li and Li, 2007). This view is based on the assumption that the active continental margin of SCB existed since the Middle Permian (Li et al., 2006, 2012). Indeed,

an active margin setting has been documented for the Cretaceous, but the geochemistry of the Jurassic magmatism supports rather an intraplate setting (Chen et al., 2008). As in Vietnam, in Hainan, the relative positions of the mélangé and arc argue for a South-directed subduction. In SE China, most of the Late Triassic plutons are S-type due to the melting of Proterozoic sediments, and a small amount of A-type plutons also exists (e.g. Li et al., 2006; Chen et al., 2011; Sun et al., 2011; Zhao et al., 2012; Wang et al. 2013). The tectonic setting of these plutons is not documented. Furthermore, their emplacement ages do not clearly show a NW-to-SE polarity that might be related to a N-directed subduction.

Therefore, an alternative interpretation is tentatively proposed here. The NW-directed shearing and 300 km shortening recorded by the sedimentary series of the Xuefengshan Belt are balanced by the same amount of continental subduction. This means that during the Triassic, the SE China lithosphere was underlain by a slab corresponding to the SE-ward subducted lithosphere of the Western part of SCB (Figs. 6,7).

Along the SE China coast, evidence for a Triassic subduction is not documented. Assuming an eastward extension of the Jinshajiang-Ailaoshan-N Vietnam-Hainan belt would imply that the SCB represents the lower plate. Such a polarity may account for the thrusting sense observed in Yunkai, Hainan, and SE China. The Triassic peraluminous plutons (e.g. Darongshan granite, DS in Fig. 2) emplaced in the footwall of the major thrust zones during deep-seated thrusting coeval with melting. Moreover, Permian arc magmatism is documented in Mindoro Island of W. Philippines (Fig. 1; Knittel et al., 2010). Considering the Cenozoic opening of the S. China sea, this arc represents the eastern extension of the Wuzishan arc of Hainan. Triassic ophiolites and tectonics are unknown in the Philippines, but the Tailuko belt of Taiwan that exposes the deepest rocks of the island yields garnet-chloritoid-kyanite-staurolite micaschist with metamorphic zircon dated at 200 ± 22 Ma (Yui et al., 2009; Fig. 2). Furthermore, HP metamorphic rocks crop out in the S. Ryukyu Islands (Fig.2). In these

mafic schists, phengite and barroisite are dated at 225 ± 5 Ma and 237 ± 6 Ma, respectively (Faure et al., 1988). One possibility is to relate these features to the Triassic orogeny of SCB.

In conclusion, the Triassic belts that wrap around the SCB southern margin from SW to SE exhibit lithostratigraphic, structural and chronological resemblances that allow us to infer that a single belt developed in response to the subduction and collision of the SCB below the Qiangtang-Indochina block. Such a S-directed subduction was coeval with the intra-continental subduction responsible for the development of the structures in SE China. Work in progress aims at testing this new interpretation.

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Figure Captions

Fig. 1. Schematic map of Central-Eastern Asia showing the main continental blocks, ophiolitic sutures and faults. SCB: South China Block, D: Dabieshan, XFS: Xuefengshan, RRF: Red River Fault, LMS: Longmenshan. Pink lines denote the Triassic belts discussed in this paper. Diamond in Mindoro Island locates the Permian magmatic arc.

Fig. 2. Tectonic map of the South China Block with emphasis of the Triassic events. The light pink area represents the Xuefengshan belt. RRF: Red River Fault, SCS: Song Chay suture, SMS: Song Ma suture, CLF: Chenzhou-Linwu fault, MXT: Main Xuefeng Thrust, JSF: Jiangshan-Shaoxing fault, DBF: Dien Bien Fu fault. NEV: NE Vietnam belt, DNCV: Day Nui Con Voi Triassic arc, DS: Darongshan pluton, SB: Shiwandashan Mesozoic basin. The cross sections (Fig. 2A, B, C) are located.

Fig. 3. Crustal scale cross sections of the Triassic belts
A: NW Vietnam-S China profile (simplified from Faure et al., 2014). B: Hainan profile. C: Yunkai profile.

Fig. 4. Field pictures of the Triassic belts. A: Late Triassic red beds unconformably overlying subvertical Middle Triassic turbidite (Jinshajiang, E. of Dexing). B: Bedding (S0) and cleavage (S1) relationships in Middle Triassic limestone indicate a NE-verging fold. A down-dip stretching lineation is observed in the S1 surface (Ailaoshan). C: Permian limestone overthrusting Middle Triassic turbidite (S. Guangxi). D: Early Paleozoic porphyritic granite deformed as orthogneiss with top-to-the-N shearing (Yunkai massif). E: N-verging fold in Devonian sandstone, in the footwall of the Yunkai thrust (Luoding). F: Carboniferous limestone olistolith in a Permian-Triassic siltite matrix (Hainan).

Fig. 5. Crustal scale cross section of the intracontinental Xuefengshan belt (modified from Chu et al. 2012a). Folding and shearing, pre-dated by the emplacement of Late Triassic plutons accommodated the SE-ward underthrusting of the Western part of the SCB below its Eastern part. S1, S2, S3 are the cleavage planes related to the Triassic deformation phases (cf Chu et al., 2012a for detail).

614

615 Fig. 6. Lithosphere scale interpretative cross section from the Xuefengshan to the SE coast of
 616 SCB depicting the Triassic deformation. The Early Paleozoic and Cretaceous events have
 617 been omitted for clarity. The Triassic geodynamics of the S. part of the SCB are interpreted as
 618 the consequence of intracontinental subduction in the Xuefengshan and collision of the SCB
 619 with a continental block equivalent to Indochina presently hidden below the S. China Sea.
 620 Evidence for a magmatic arc is documented in Hainan Island and in W. Philippines.

621

622 Fig. 7. Schematic map showing the main Triassic tectonic features of the South margin of the
 623 SCB. At variance with the previous interpretations, this cartoon emphasizes the southward
 624 continental subduction of the SCB below the Indochina Block and its eastward extension in
 625 W. Philippines that was located South of the SCB before the opening of the South China Sea.
 626 Collision was preceded by oceanic subduction that gave rise to several magmatic arcs,
 627 namely: W. Ailaoshan, Sam Nua, Dai Nuy Con Voi, Wuzishan, Mindoro. JSJ: Jinshajiang
 628 suture, AS: Ailaoshan suture, SMS: Song Ma suture, SCS: Song Chay suture, HS: Hainan
 629 suture. Terrigenous deposits of the Shiwandashan basin (SB) unconformably cover the folds
 630 and thrusts of the Middle Triassic Youjiang basin. The intracontinental Xuefengshan Belt
 631 developed in response to the SE-ward continental subduction of the basement of the SCB.
 632 MXT: Main Xuefengshan Thrust. Dotted lines represent the fold axes. The Triassic E-W to
 633 NE-SW striking folding developed in the Neoproterozoic Jiuling Massif corresponds to a
 634 dextral ramp of the Xuefengshan belt. The Triassic plutons have been omitted for clarity.

Figure 1
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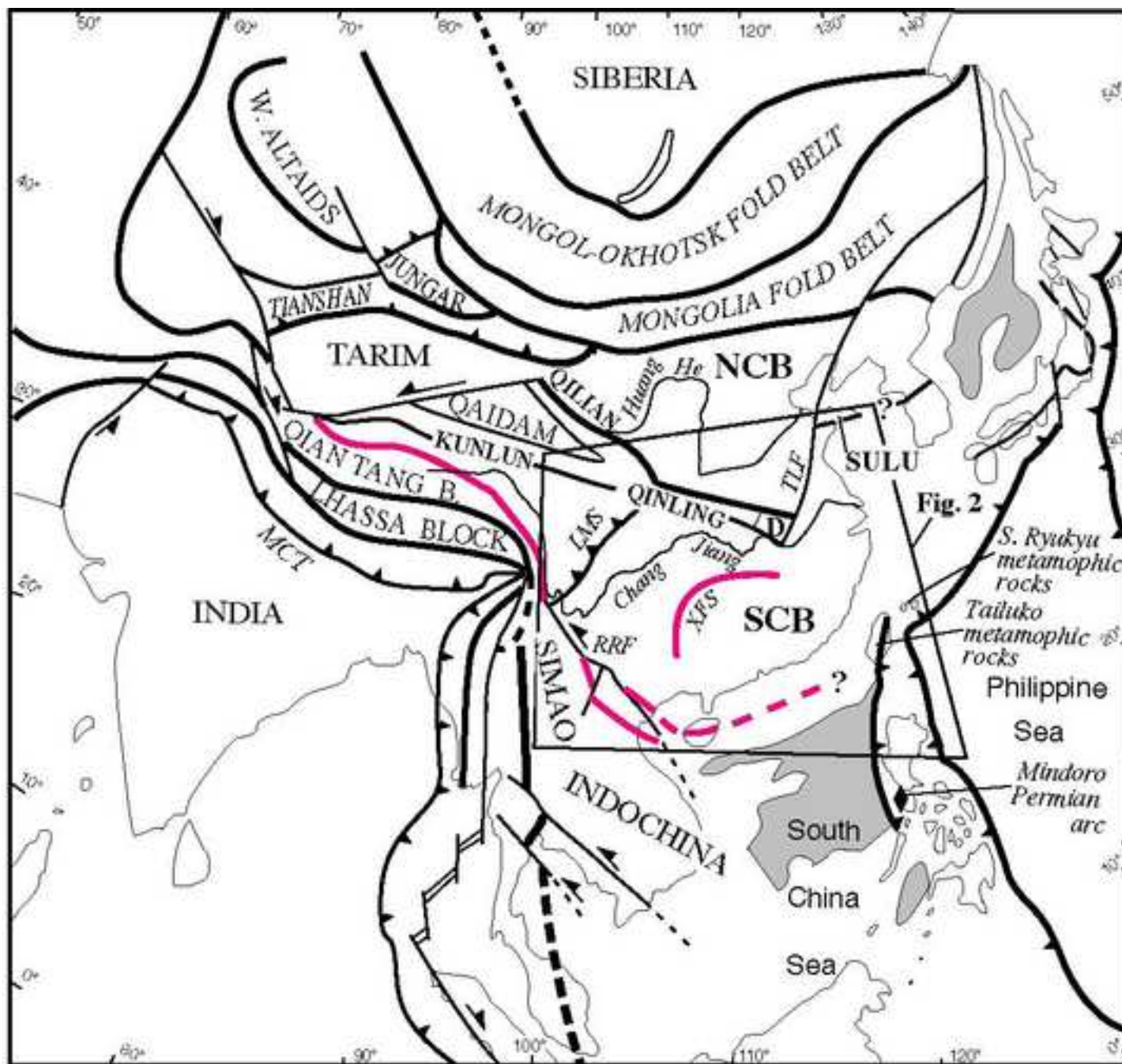


Fig. 1

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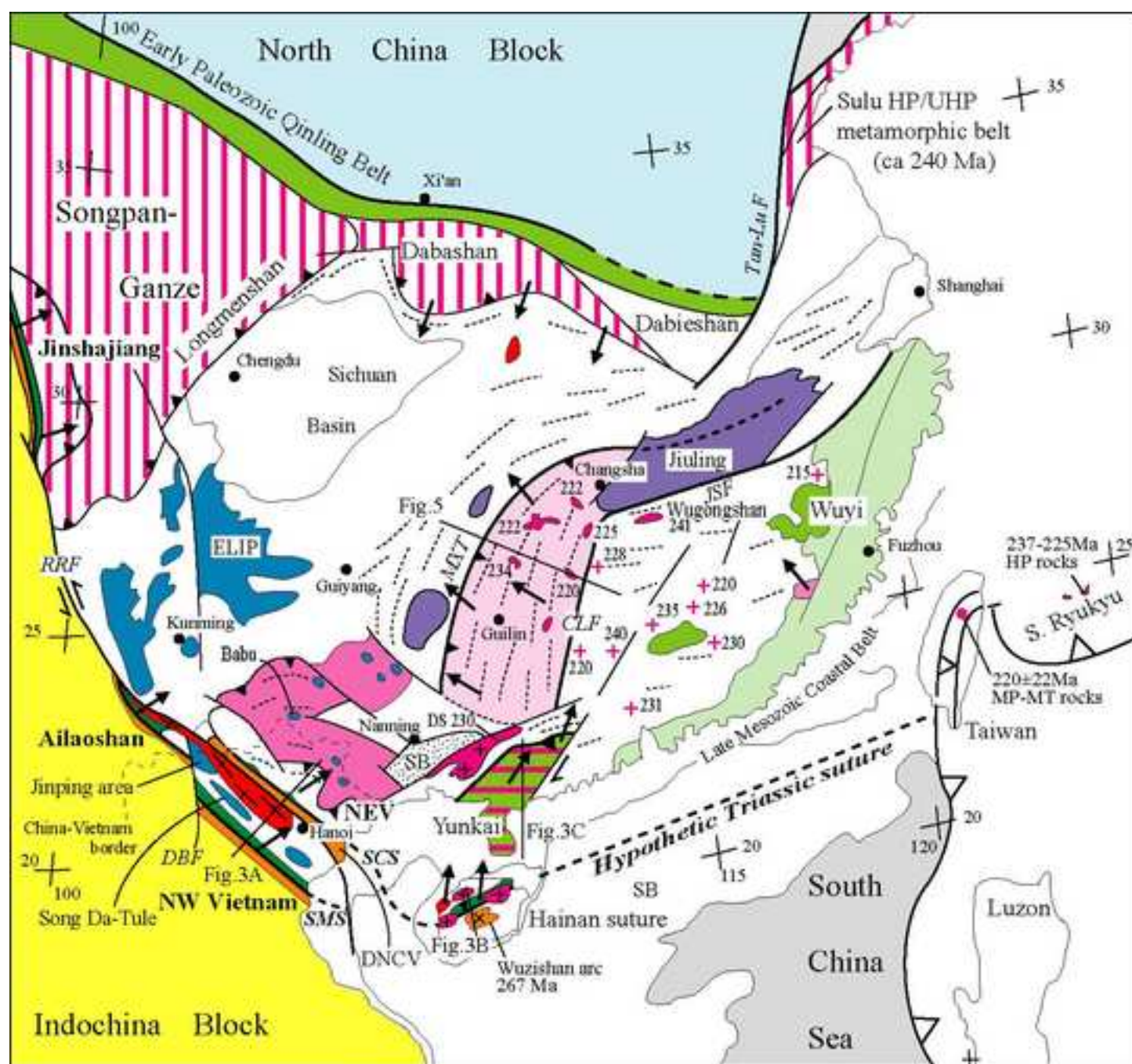


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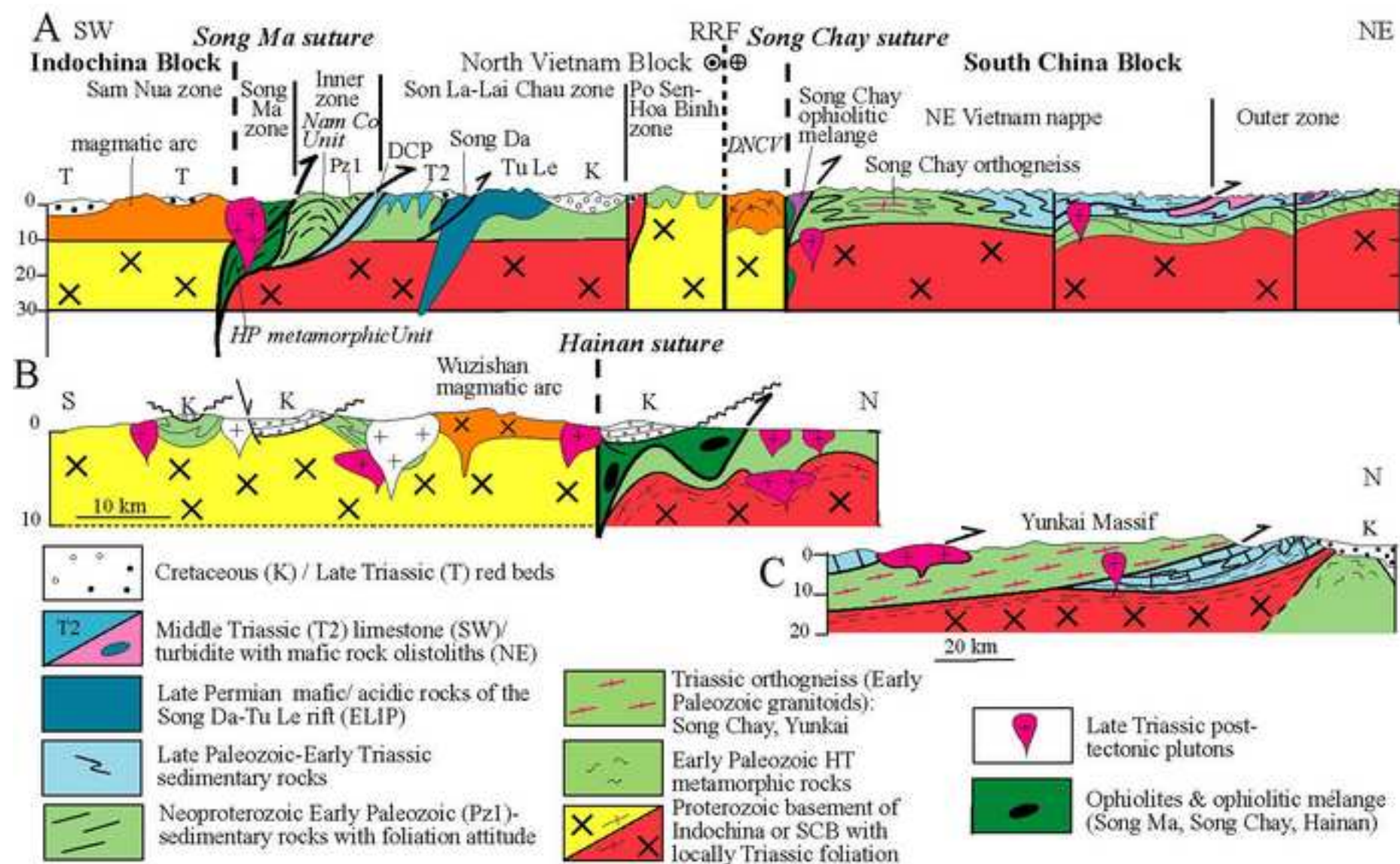


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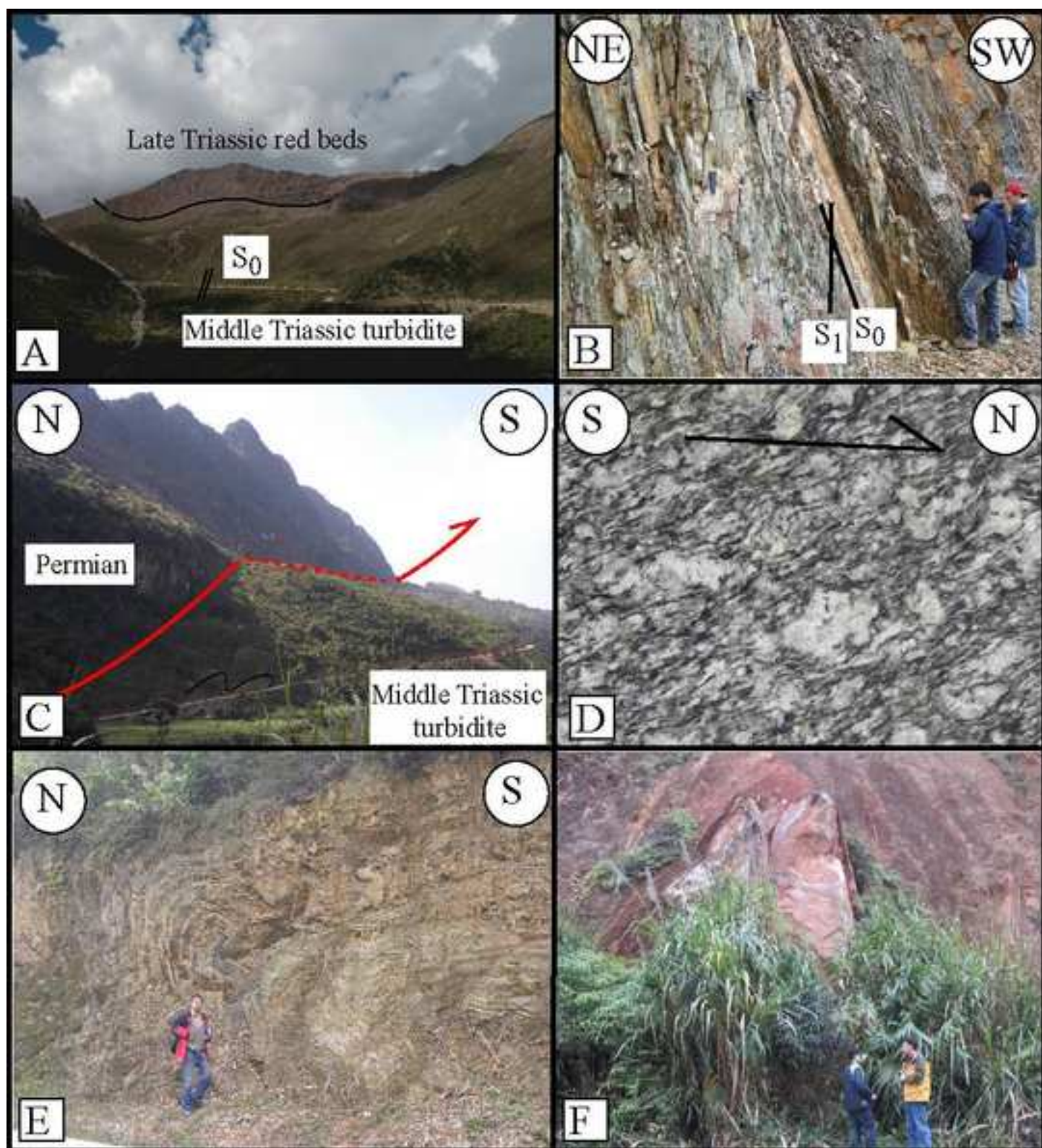


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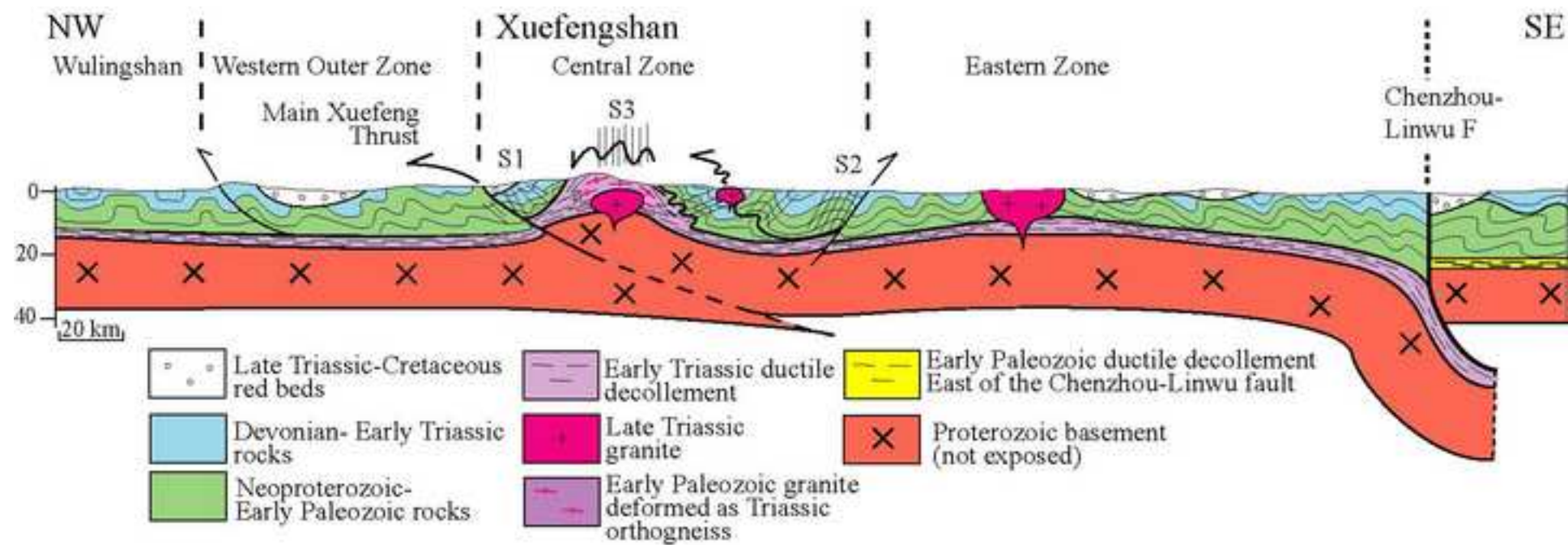


Fig 5

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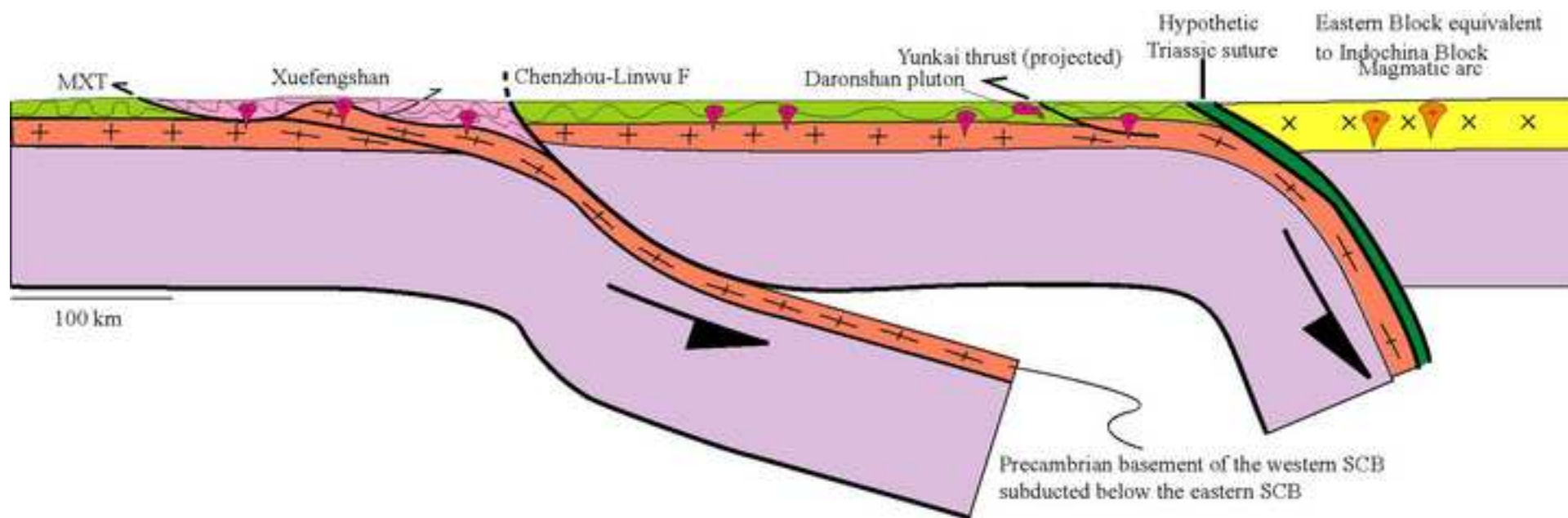


Fig. 6

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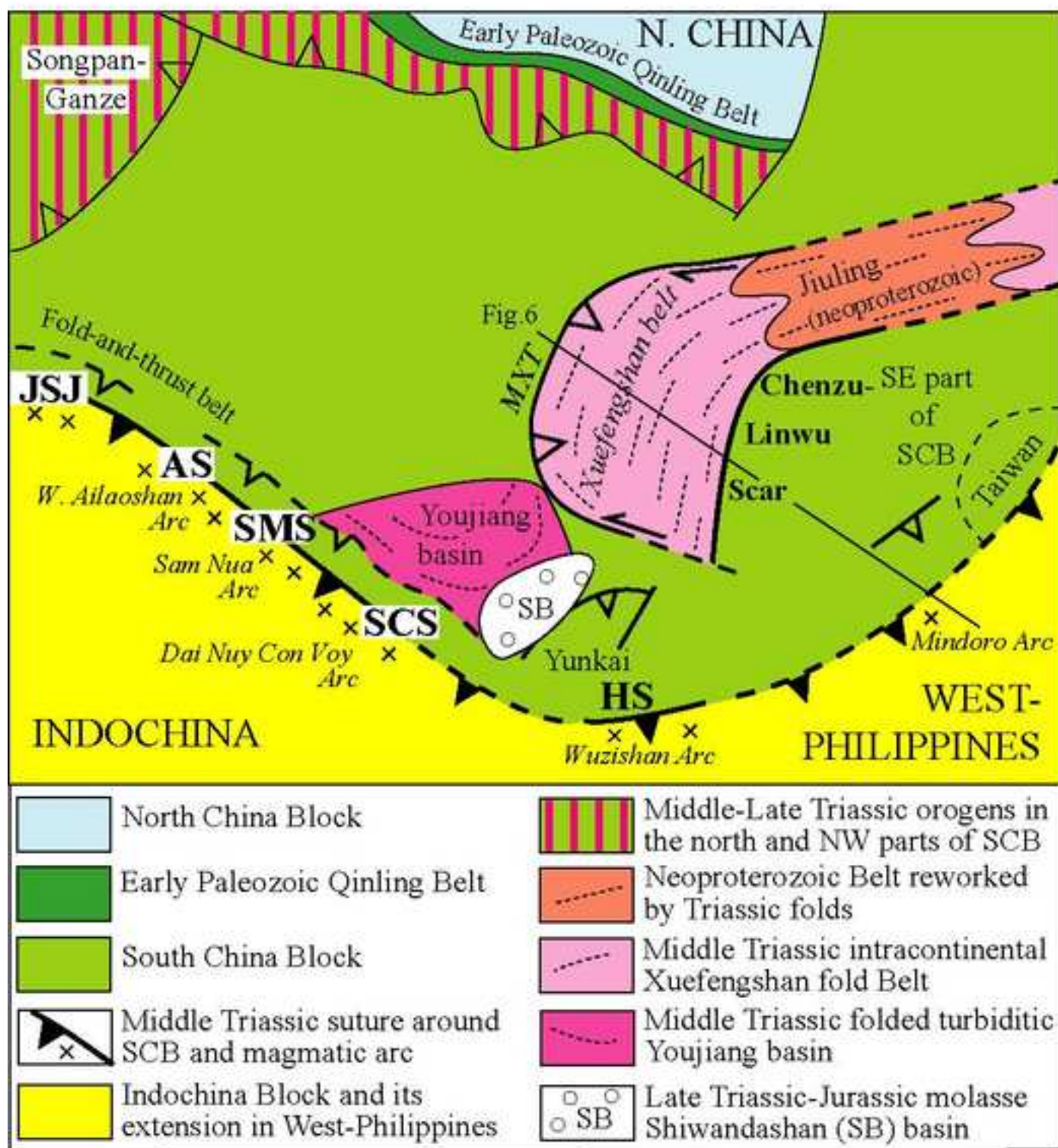


Fig.7