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Structural evidence for the Permo-Triassic tectonic evolution of the Yidun Arc, eastern Tibetan Plateau

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Abstract

Deformation across the Yidun Arc occurred as a two-phase process; (i) Early Triassic deformation of Paleozoic sequences resulting from closure of the Jinsha Jiang Suture, and (ii) Late Triassic deformation of Middle to Late Triassic rocks as a result of final basin closure. Deformation in the western Yidun Arc is dominantly west-vergent. A north–south striking west-directed thrust, the Jinsha Thrust, forms the boundary between the western Yidun Arc and the eastern Qiangtang Block. The Jinsha Thrust incorporates within it ophiolitic material of the Jinsha Jiang Suture, and the structural geometry across the Jinsha Thrust suggests that Early Triassic subduction was east-dipping along the Jinsha Jiang Suture. Deformation within Middle to Late Triassic sequences of the eastern Yidun Arc, eastern Qiangtang Block and western Songpan Garzê Fold Belt is thin-skinned, being restricted largely to a single generation of upright folds and associated thrusts. Late Triassic westwards subduction underneath the combined western Yidun Arc–Qiangtang Block resulted in arc volcanism in the eastern Yidun Arc. Coeval arc volcanics in the northern margin of the Qiangtang Block suggest that the suture along the northern margin of the Qiangtang Block may be correlated with the Garzê–Litang Suture rather than the Jinsha Jiang Suture.

Keywords: Indosinian Orogeny; Yidun Arc; Suture; Tibet

1. Introduction

Many fold belts are dominated by marine sediments, which were accreted to the continents as a result of subduction processes. Ophiolites or ophiolitic fragments may be preserved in faults or shear zones interspersed with the deformed turbidite sequences in such fold belts. These fault-bound belts of mafic rock and associated melange may be associated with arc magmatism and separate distinct continental terranes, thereby defining a suture zone, such as the Yarlung–Tsangpo Suture in southern Tibet between the Indian continent and the Lhasa Terrane (Searle et al., 1987). The structural geometry of deformed rocks that host the ophiolite is important evidence that must be incorporated into models for the tectonic evolution of a given fold belt.

One prominent example of such a fold belt is the Songpan Garzê Fold Belt (Harrowfield and Wilson, 2004, this issue) in eastern Tibet, which is closely associated with a number of magmatic arc provinces in its southwestern region, including the Yidun Volcanic Arc (Fig. 1). Two zones of mafic melange in this region of eastern Tibet are both interpreted to be sutures; the Jinsha Jiang and the Garzê–Litang sutures (Fig. 1). These two sutures separate the Yidun Arc from the Songpan Garzê Fold Belt to the east and the Qiangtang Block to the west, respectively (Fig. 1). Few field structural studies have been reported from this region, largely due to the remote and mountainous nature of the terrain. However, the region is of particular importance in terms of the Mesozoic accretionary systematics of the Asian continent (e.g. Sengör, 1984; Sengör and Natal'in, 1996; Yin and Harrison, 2000; Roger et al., 2003). This contribution presents the results of structural investigations conducted along three transects across the Yidun Arc and surrounding areas. The results define the geometry of the principal deformation across the Yidun Arc on the basis of which a discussion of the tectonic evolution of the region is

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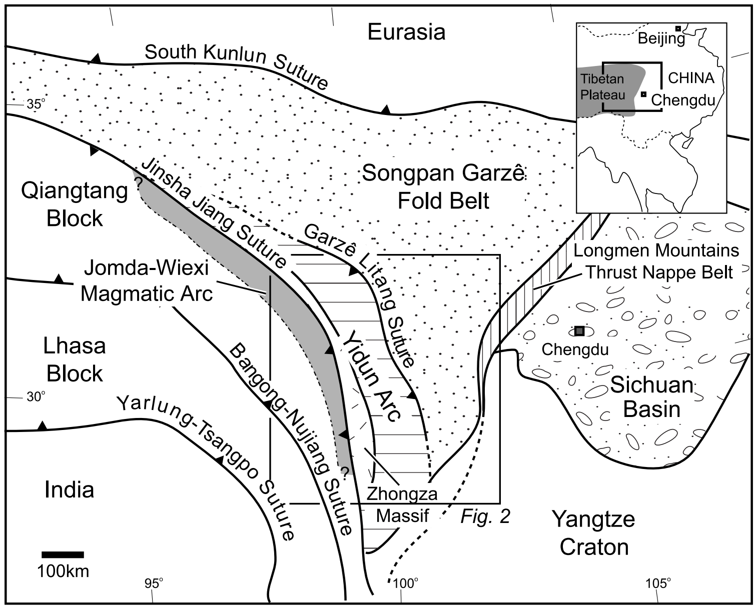

Fig. 1. Map of the principal tectonic framework of the eastern Tibetan Plateau, showing the location of major tectonic blocks and suture zones. Dip of suture zones after Chen et al. (1987) and Li et al. (1999).

presented, with particular emphasis on reconstructing the polarity of the paleo-subduction along the suture zones. This discussion highlights the importance of structural evidence in determining the dip of such ancient subduction zones.

2. Geological setting

Across the Yidun Arc region four structural domains are defined based on stratigraphic, lithological and structural criteria: the western Songpan Garzê Fold Belt, the eastern Yidun Arc, the western Yidun Arc, and the eastern Qiangtang Block (Fig. 2; Table 1). Although the Cenozoic collision of India with Asia has resulted in large-scale strike slip faulting (Wang and Burchfiel, 1997, 2000), the principle ductile deformation of the pre-Jurassic rocks in the region occurred during Triassic basin closure, an event sometimes referred to as the Indosinian Orogeny (e.g. Sengör, 1984).

Table 1
Stratigraphic column for the Yidun Arc, Qiangtang Block and western Songpan–Garzê Fold Belt, based on Chen et al. (1987)

	Eastern Qiangtang Block	Yidun Arc	Songpan Garze Fold Belt
Neogene	Intermontaine basin fill, coal, sandstone, gravel formations; intermediate to acid volcaniclastics	Intermontaine basin fill, minor alkali volcanics, coal	Intermontaine basin fill
Paleogene	Molasse, red beds	Molasse	Molasse
Cretaceous	Red beds intercalated with carbonates: acid volcanics	–	–
Jurassic	Red beds	–	–
Triassic	T_3: sandstone/shale, carbonate, with volcanics and red clastics. Local coal	T_3: flysch, calc-alkaline and rhyolitic volcanics, carbonates, coal	
	T_3: shale, sandstone		
	T_{1-2}: flysch, volcaniclastics and carbonates	T_{1-2}: flysch, carbonates, intermediate-mafic volcanics	T_{1-2}: shale, sandstone
Permian	Carbonates, clastics, volcanics and local coal bearing formations	P_2: sandstone, shale, acid volcanics	P_2: mafic volcanics, shale
		P_1: flysch, intermediate volcanics, carbonates, mafic volcanics, and interlayered chert	P_1: sandstone
Carboniferous	Carbonates, intermediate volcanics, sandstone, shale, with coal bearing formations	Mafic to intermediate-acid volcanics, carbonates, sandstone and shale	–
Devonian	Sandstone, shale, volcaniclastics, carbonates, interlayered with chert	Sandstone, shale, carbonates, intermediate-mafic volcanics	–
Silurian	–	Carbonates, sandstone, shale, intermediate-mafic volcanics	–
Ordovician	–	Carbonates, sandstone, shale	–
Cambrian	–	Carbonates, sandstone, shale	–

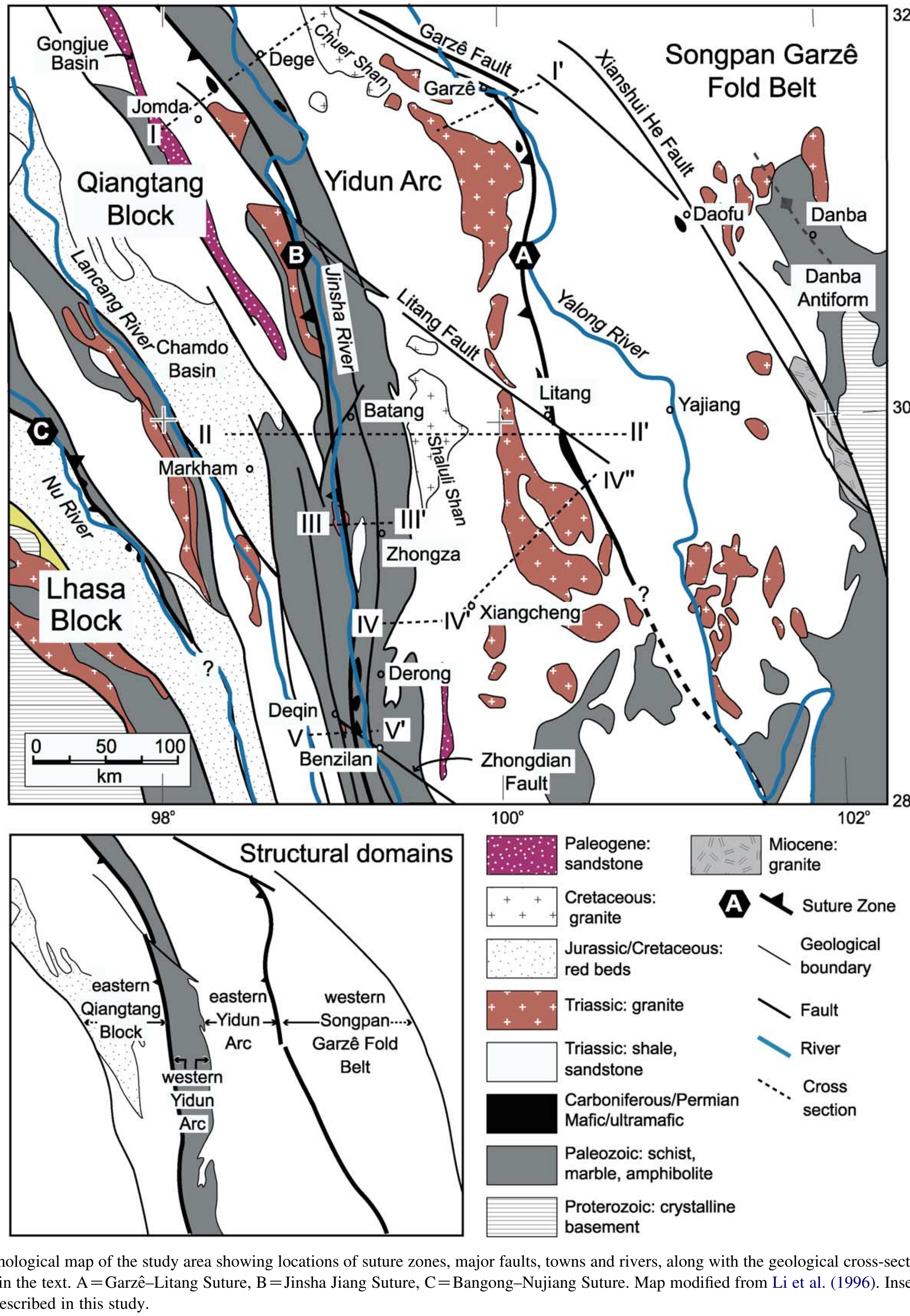

Fig. 2. Lithological map of the study area showing locations of suture zones, major faults, towns and rivers, along with the geological cross-sections that are described in the text. A = Garzê–Litang Suture, B = Jinsha Jiang Suture, C = Bangong–Nujiang Suture. Map modified from Li et al. (1996). Inset: Structural domains described in this study.

2.1. The western Songpan Garzê Fold Belt

This domain is composed of monotonous Late Triassic mudstone and shale (Fig. 2; Table 1). The greater Songpan Garzê Fold Belt preserves some 220,000 km^2 of Middle to Late Triassic turbidites shed from the evolving Qinling Orogen to the east (Fig. 3), and deposited within the relict Paleotethys Ocean (Zhou and Graham, 1996). These turbidites were accreted to the southern margin of Asia as a result of the northwards migration of the Qiangtang (North Tibetan) Block and consumption of Paleotethyan oceanic crust along the South Kunlun Suture (Figs. 1 and 3). In the western Songpan Garzê Fold Belt Permian mafic volcanogenic sediments, limestone and shale are exposed only locally. Jurassic and Cretaceous sediments are absent from the Songpan Garzê Fold Belt, and Late Triassic/Early Jurassic granitic plutons intrude the Triassic sequences. Tertiary and Quaternary intracontinental sediment is present in localized basins associated with Cenozoic strike-slip faults (Wang et al., 1998).

2.2. The eastern Yidun Arc

This is dominated by weakly metamorphosed Triassic mudstone and shale that are indistinguishable in hand specimen from those of the western Songpan Garzê Fold Belt (Fig. 2; Table 1; Zhang et al., 1994; Chen and Lou, 1999). Late Triassic 'arc-type' rhyolitic and calc–alkaline volcanics are also present (Hou, 1993), which are the defining feature of the Yidun Arc. These volcanics are generally interpreted to be the result of the westwards subduction of the so-called Garzê–Litang Ocean (Hou and Mo, 1991; Hou, 1993), the remnants of which are now apparently exposed as mafic/ultramafic rocks, limestone and chert olistosomes within the melange of the Garzê–Litang Suture. Coarse clastic sediments and coal-bearing units occur towards the top of the Late Triassic and suggest a shallowing of the depocentre before final basin closure. Late Triassic and Cretaceous granite–granodiorite plutons intrude the deformed Triassic sequences (Reid et al., 2004), thus providing a minimum age for the timing of deformation in this domain. Early Tertiary and Quaternary intracontinental basins are locally developed and are typically associated with one of the numerous Cenozoic strike-slip faults of the region (Wang and Burchfiel, 2000).

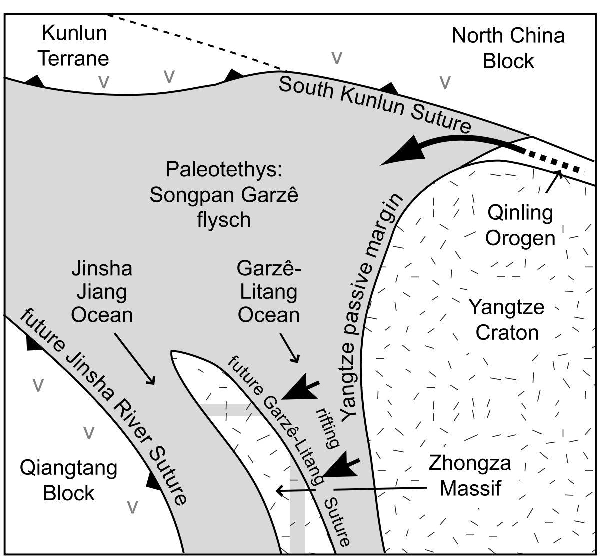

Fig. 3. Reconstruction of late Paleozoic continental geometry and subduction polarity in the region of what is now eastern Tibet, after Li et al. (1999). Active margin volcanism is shown as light coloured 'v's. The western Yidun Arc (=Zhongza Massif) is shown as a continental sliver that rifted from the Yangtze Craton. Late Triassic subduction of the Garzê–Litang Ocean resulted in the formation of the 'Yidun Arc'. The collision between the Yangtze Craton and the North China Block formed the Qinling Orogen, which provided the source material for the flysch of the Songpan–Garzê Fold Belt (Zhou and Graham, 1996).

2.3. The western Yidun Arc

This domain is also referred to as the Zhongza Massif (Fig. 1; Chen et al., 1987) and is composed of Paleozoic carbonates and intercalated mafic volcanogenics that define a passive margin-type stratigraphic sequence (Table 1). Although no Proterozoic basement is exposed within the western Yidun Arc, a Proterozoic continental sliver or 'microcontinent' is considered to underlie the region (e.g. Chang, 1997). This inference is based largely on the geochemistry of Triassic volcanic rocks of the eastern Yidun Arc, which suggests volcanism developed above a thinned continental crust (Hou, 1993). Furthermore, the apparent fossil and lithological similarity between Paleozoic rocks of the Yidun Arc and those of the Yangtze Craton—exposed in the eastern Songpan Garzê Fold Belt (Figs. 1 and 2)—provide the basis for the suggestion that the western Yidun Arc rifted from the eastern margin of the Yangtze Craton during the upper Paleozoic in response to the formation of the so-called Garzê–Litang Ocean (Figs. 1 and 3; Chen et al., 1987; Zhang et al., 1994; Zhang et al., 1998).

2.4. The eastern Qiangtang Block

The eastern portion of the Qiangtang Block is composed of weakly metamorphosed Paleozoic carbonates and clastics overlain by Permian and Triassic shale, sandstone and volcanics, and roughly corresponds to the 'Chamdo Block' of Chang et al. (1989) (Fig. 2; Table 1). Triassic volcanic rocks of the eastern Qiangtang Block have been considered to define a second volcanic arc, the so-called Jomda–Weixi Magmatic Arc, which resulted from the southwestward subduction of the Jinsha Jiang Ocean (Figs. 1 and 3; Mo et al., 1994; Shen et al., 1995; Du et al., 1998; Wang et al., 1999). Localized Late Triassic intra-plate volcanism is documented within the eastern Qiangtang Block, which is interpreted to have developed due to post-collisional extension in the region (Hou et al., 2003). Jurassic–Cretaceous red bed sediments are present within the Chamdo Basin on the eastern Qiangtang Block (Fig. 2; Table 1). Localized intracontinental sedimentation also occurred within the eastern Qiangtang Block during the Tertiary and Quaternary (Horton et al., 2002).

The Jinsha Jiang Suture that separates the eastern Qiangtang Block from the western Yidun Arc is interpreted to extend to the northwest beyond the northern extent of the Yidun Arc, where it separates the Qiangtang Block from the Songpan Garzê Fold Belt (Fig. 1). The southern extension of the Jinsha Jiang Suture into southeast Asia is the subject of considerable debate (e.g. Metcalfe, 1996; Roger et al., 2003). In the vicinity of the eastern Qiangtang Block and western Yidun Arc, the suture is considered to have closed during the mid-Permian (Chang, 1997) and certainly by the Early–Middle Triassic at the latest (Dewey et al., 1988; Mo et al., 1994; Sengör and Natal'in, 1996; Sun et al., 1997; Li et al., 1999; Wang et al., 2000; Zhong, 2000; Reid et al., 2004).

The Yidun and the Jomda–Weixi volcanic arcs together with the ophiolite complexes of the Garzê–Litang and Jinsha Jiang sutures are generally considered to represent 'coupled' systems of arc volcanism related to west-dipping subduction (Fig. 3; Mo et al., 1994). An alternative interpretation considers subduction across the Jinsha Jiang Suture to have been east-dipping (Calassou, 1994; Chang, 1997; Harrowfield, 2001). In such an interpretation, the Garzê–Litang Suture is regarded as the remnants of a collapsed back-arc that developed behind an east-dipping subduction zone—the Jinsha Jiang Suture. Further discussion of the Mesozoic accretionary systematics of this region is presented following description of structural evidence from the Yidun Arc.

3. Structure of the Yidun Arc region

Structural investigations were conducted along northern, central and southern transects across the Yidun Arc (see Fig. 2 for location of cross-sections I–V). In the following descriptions, standard structural terminology, S_1, S_2, D_1, D_2, is utilized to identify successive phases of structural development. The definition of S_1, S_2, etc., varies between the structural domains and the observation of one generation of any structural element in a given area does not necessarily imply synchroneity with a fabric designated the same generation elsewhere.

3.1. Northern transect: Daofu to Jomda (section I–I′)

Some of the few outcrops of Permian rocks in the western Songpan Garzê Fold Belt are exposed west of Daofu Here, Permian slate and interleaved basic volcanics preserve an east dipping chlorite/mica-defined foliation, a down-dip mineral stretching lineation and abundant west-vergent thrusts (Fig. 4a). The strongly flattened and sheared volcanogenic units are tectonically interleaved with kilometre-scale limestone blocks and basalt. This set of Permian outcrops is designated a 'melange' in Sichuan Bureau of Geology and Mineral Resources mapping (SBGMR, 1981). The lithological and structural similarity between this melange and the melange of the Garzê–Litang Suture is notable.

To the northwest of Daofu, away from the Xianshui He Fault, Late Triassic flysch of the western Songpan Garzê Fold Belt is deformed with metre-scale tight, upright, F_1 folds that are associated with bedding parallel thrusts and show no consistent fold asymmetry (section I–I′, Fig. 5). These structures are typical of the first generation structures identified in the Songpan Garzê Fold Belt elsewhere in the region (Burchfiel et al., 1995; Harrowfield and Wilson, 2004, this issue).

To the immediate south of Garzê, ultramafics, mafic volcanics, limestone and micaceous schist outcrop representing the northern extension of the Garzê–Litang Suture Zone. Here, massive mafic lithologies are relatively undeformed in contrast to multiply deformed meta-volcanics and micaceous units. The latter show a mica-defined foliation, S_1, subparallel to primary compositional layering, which is overprinted by an upright, northwest-trending S_2 foliation (Fig. 4b). In places, these micaceous units show an *S*–*C* fabric with top-to-the-southwest kinematics (section I–I′, Fig. 5). Southwest-vergent duplexes were observed in massive limestones some 20 km west of the main outcrop of the Garzê–Litang melange. Mica-schist in the vicinity of these limestones preserves a strong muscovite/biotite defined spaced cleavage (S_1) yet lacks any overprinting cleavage, suggesting that post-D_1 strain was localized within the Garzê–Litang melange.

West of the unfoliated granite–granodiorite body at the core of the Chuer Shan lies the western Yidun Arc (section I–I′, Fig. 5). Around Dege, F_1 folds are typically tight to isoclinal, with primary compositional layering (S_0) generally parallel to a muscovite and rare biotite defined S_1 foliation (Fig. 4c and d). These folds are refolded by open to tight F_2 folds at a variety of scales (Fig. 4e). Superimposed upon these second generation structures are a series of upright, west-vergent, asymmetric kink folds, accompanied by discrete southwest-dipping axial planar thrusts (Fig. 4f). Micaceous schists around Dege also preserve west-dipping D_3 shear band foliations that overprint the steep, S_2 cleavage (Fig. 4g). The west-over-east kinematics of these shear bands is antithetic to the vergence trends observed to the east.

To the immediate west of the Jinsha River lies a high-strain zone composed of Silurian marbles and intercalated mica-schists in which layer parallel boudinage and isoclinal F_1 folds are refolded by open F_2 folds (Fig. 4h). Little outcrop was observed on the eastern side of the 4245 m Nge–La Pass; however, float material contained abundant mafic, ultramafic and chert lithologies, many of which appeared brecciated and/or highly strained, and which

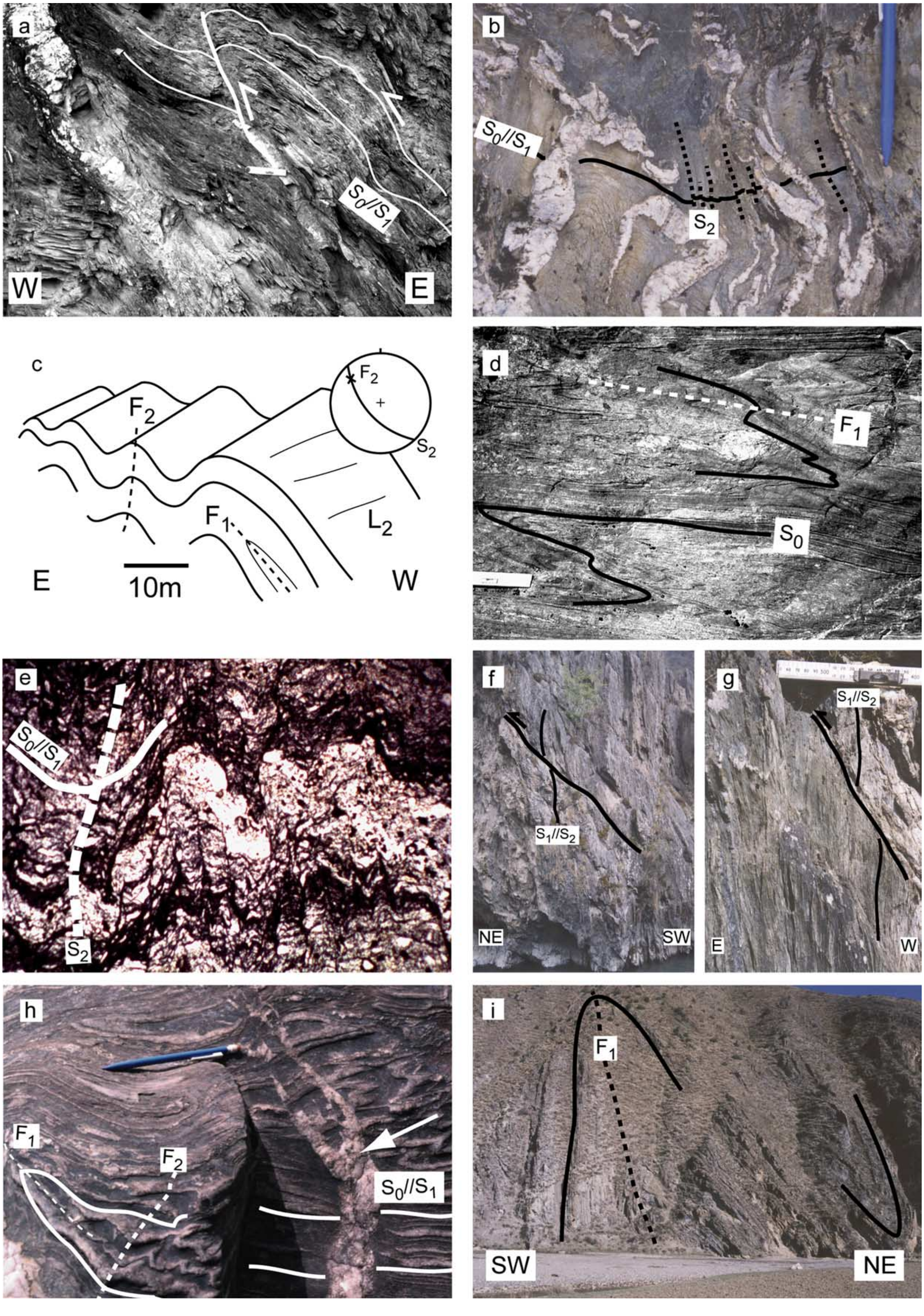

Fig. 4. Field photographs and sketches from the northern transect. (a) West-vergent thrust within Permo-Triassic phyllites, Daofu. Ruler is 30 cm long. (b) Crenulated mica-schist, within the Garzê–Litang Melange near Garzê, showing F_2 crenulations and associated axial planar quartz–carbonate veins overprinting

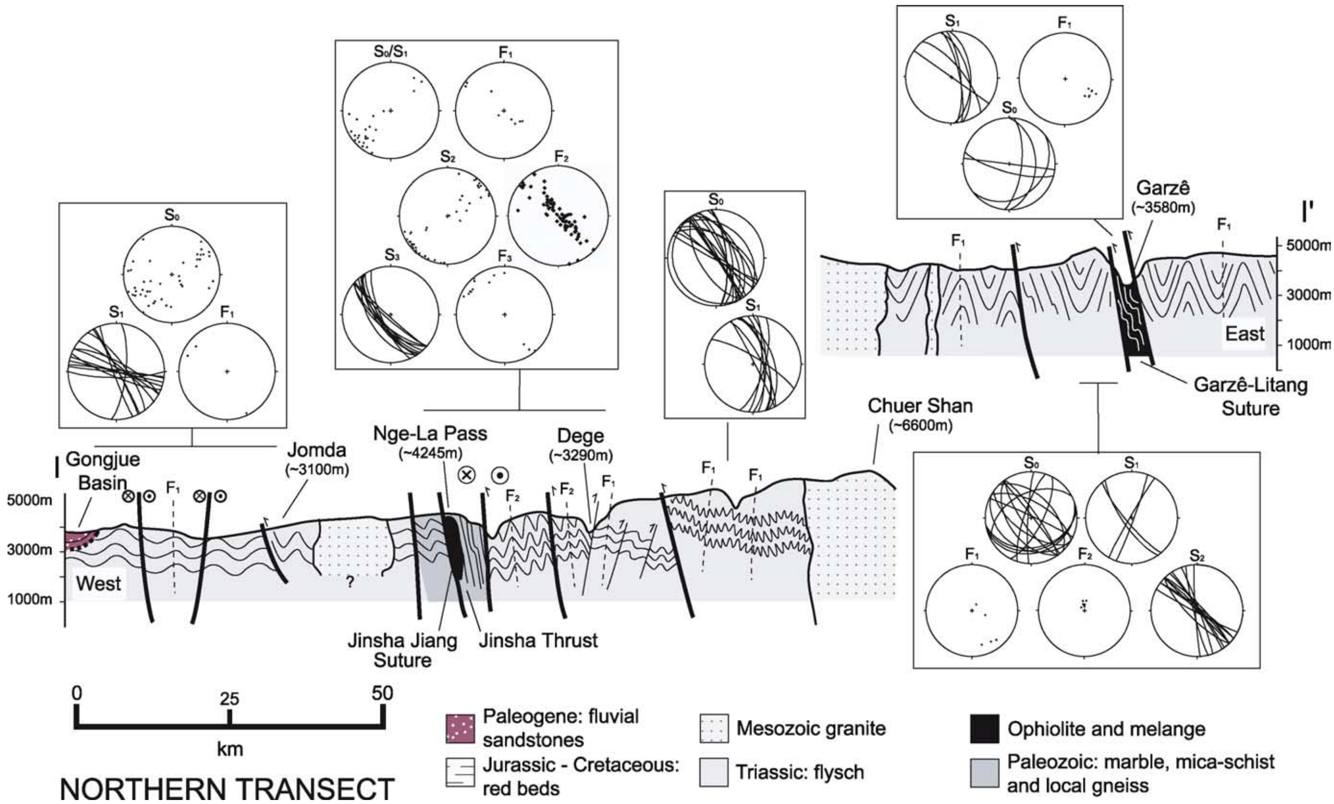

Fig. 5. Schematic cross-section I–I′, across the northern Yidun Arc, showing structural data and geographical localities mentioned in the text. Note that the melange of the Jinsha Jiang Suture is shown as subcropping, as only float material was observed in this transect. For location of cross-section see Fig. 2. All stereonets in this and subsequent figures are lower hemisphere equal area projections.

probably represent the ophiolitic melange of the Jinsha River Suture. To the west of the Nge–La Pass, within the eastern Qiangtang Block, only a single generation of upright, northwest-trending, open to tight folds were observed (Fig. 4i). In this region Middle Triassic clastic sequences include conglomerates composed of strained mafic volcanics, ultramafics and limestone clasts. The transect ends to the west of Jomda at the eastern margin of the Gongjue Basin, an early Tertiary intracontinental pull-apart basin.

3.2. Central transect: Litang to Markham (sections II–II′ and III–III′)

East of Litang in the western Songpan Garzê Fold Belt, Late Triassic flysch are deformed by tight, chevron style, upright F_1 folds, and associated thrusts with little or no S_1 cleavage apparent (section II–II′, Figs. 6 and 7a). Immediately north of Litang lies the melange of the Garzê–Litang Suture, in which brecciated limestone, foliated chloritic schist, mafic volcanics and chert units are tectonically interleaved and dissected by a network of anastomosing low-grade shear zones (Fig. 7b). The foliation in the schistose lithologies generally dips steeply to the east (section II–II′, Fig. 6). To the west of the melange, in the eastern Yidun Arc, lie a series of east-dipping weakly cleaved Late Triassic mudstones, suggesting a similar decrease in deformation intensity away from the ophiolitic melange to that observed in the north (see Section 3.1). Northwest of Litang lies the Shaluli Shan, which is composed largely of massive unfoliated granite of Cretaceous age (Reid et al., 2004). On the western side of the Shaluli Shan Pass lie Middle Triassic mudstone sandstone and mafic clast-bearing matrix supported conglomerates (Fig. 7c) that apparently unconformably overlie an upper Permian to Early Triassic sequence of intercalated limestone, mafic volcanogenics and marl units (SBGMR, 1981). Infrequent open to tight F_1 folds are found within the former

an earlier chlorite/mica defined schistosity. Pen for scale. (c) Sketch of F_1 and F_2 fold styles observed east of Dege. F_1 is generally tight to isoclinal and is refolded about large-scale open F_2 folds. A coarse L_2 mineral lineation is commonly observed in micaceous units where F_2 is often manifest as a crenulation cleavage. (d) Tight to isoclinal F_1 folding within a layered micaceous carbonate unit, Dege. Ruler for scale is 4 cm wide. (e) Photomicrograph of crenulated quartz–mica schist from near Dege, field of view 1.5 mm. (f) A steep, subparallel S_1 and S_2 fabric truncated by westerly dipping shear bands that show west-over-east sense of shear, Dege. Photo of cliff approximately 10 m high. (g) Detail of shear bands in mica-schists around Dege, showing west-over-east sense of shear. (h) Layered Silurian (SBGMR, 1981) marble boulder showing isoclinal F_1 folds indicative of the high D_1 strain, refolded by open F_2 folds. Note F_2 axial planar carbonate vein (arrow). (i) Tight F_1 folds in Triassic shale and sandstone sequence, west of Jomda.

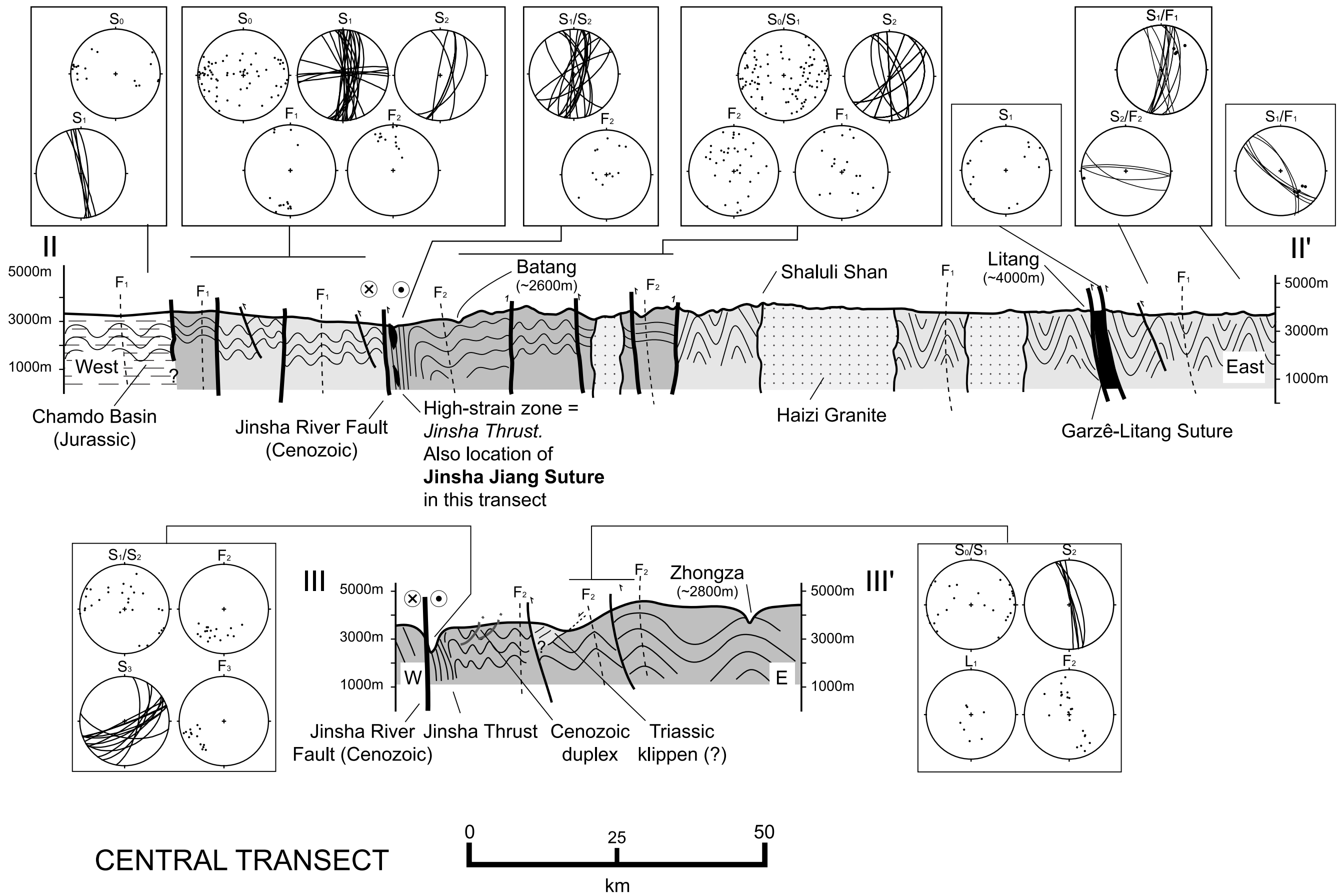

Fig. 6. Schematic cross-sections II–II′ and III–III′ across the central Yidun Arc. Legend as for Fig. 5. For location of cross-sections see Fig. 2.

sequence, which are locally refolded by open F_2 folds and minor asymmetric kinks (section II–II′, Fig. 6).

Further west, within the western Yidun Arc, Paleozoic marble, micaceous carbonates and low-grade amphibolites are deformed by tight to chevon style, north–south-trending F_1 folds and are refolded by generally coaxial, open F_2 folds

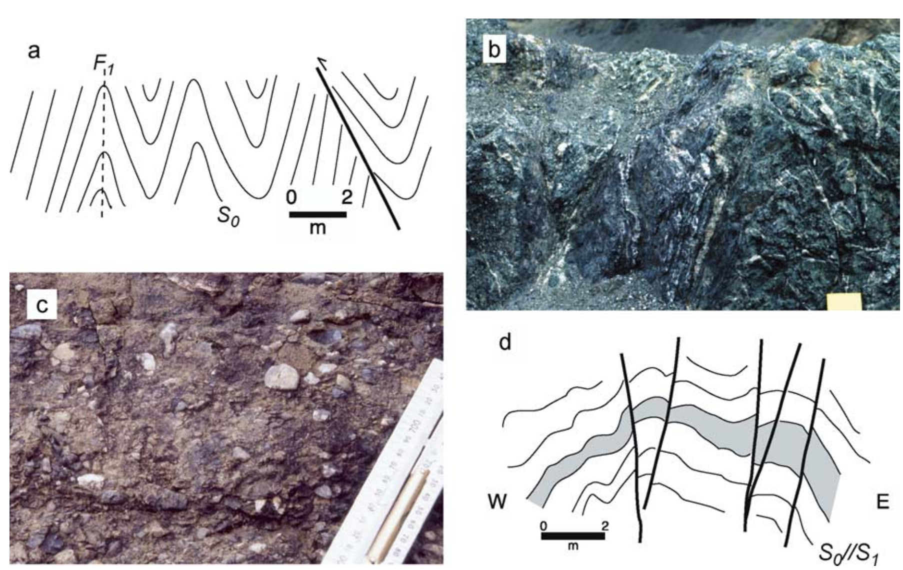

Fig. 7. Field photographs and sketches from the central transect. (a) Section view sketch of typical upright F_1 folds in Late Triassic shales of the Songpan Garzê Fold Belt, east of Litang. (b) Outcrop of chloritised mafic/ultramafic rock, typical of that observed in the melange of the Garzê–Litang Suture, north of Litang. Note abundant carbonate veining and brecciation. View looking to the northwest, notebook for scale is ∼12 cm wide. (c) Triassic polymictic conglomerate west of the Shaluli Shan containing mafic detritus. (d) Field sketch of an open F_2 fold disrupted by later faulting within Paleozoic marbles, east of Batang.

(Fig. 7d). Within the Batang Valley, mica-schists and intercalated marble units show tight to isoclinal F_1 folds, refolded by large-scale open F_2 folds (Fig. 8) and associated parasitic folds (Fig. 8a). Some mica-schist outcrops preserve a west-dipping shear band foliation (cross-section X–X′, Fig. 8) and asymmetric garnet porphyroblasts with a west-over-east sense of shear that overprint the mica-defined S_1 schistosity and are kinematically identical to D_3 shear bands observed around Dege to the north.

West of Batang, leucocratic garnet–sillimanite gneisses and garnet-bearing amphibolites preserve isoclinal folds and abundant layer-parallel boudinage (Fig. 8b) along with a generally steep mineral stretching lineation and west-over-east kinematics. This high-strain zone also preserves occasional serpentinized ultramafic pods interleaved within the gneisses, and is therefore the probable location of the Jinsha Jiang Suture (Fig. 8).

Observations were also made within Paleozoic units of the western Yidun Arc, between the town of Zhongza and the Jinsha River (section III–III′, Fig. 6). As with the region around Batang, first generation structures within this section are represented by tight to isoclinal F_1 folds and S–C fabrics within mica-schists that show an east-over-west sense of shear. These structures are overprinted by open F_2 folds, which were observed to become tight folds accompanied by a penetrative mica-defined S_2 foliation in the west of the

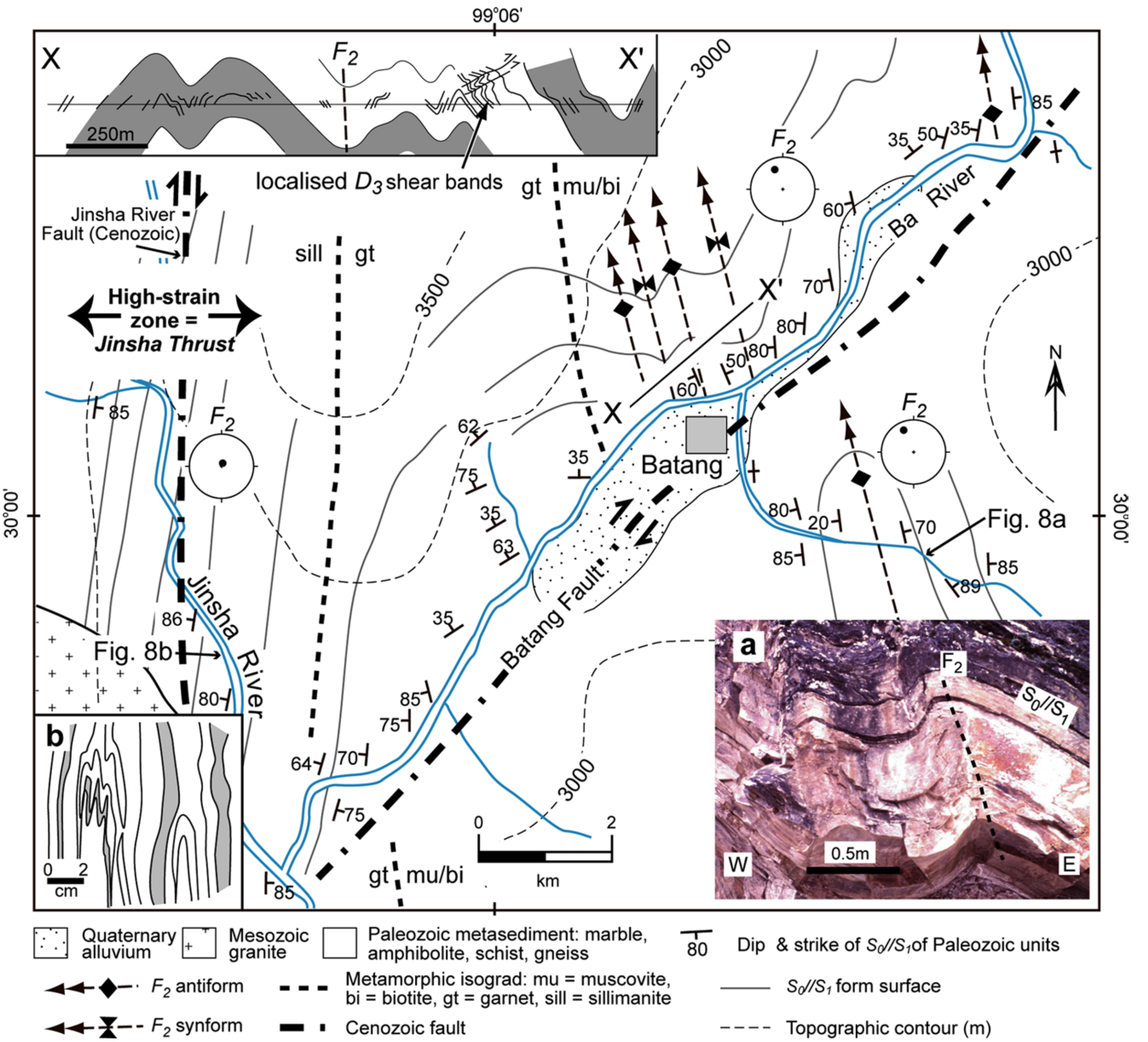

Fig. 8. Structural map of the region around the township of Batang, western Yidun Arc (see Fig. 2 for location of Batang). Orientation of F_2 fold axes are shown in synoptic stereonets within the map. Inset: cross-section X–X′ showing large-scale upright F_2 folds and west-dipping D_3 shear bands. Note the high-strain zone in the west preserves pods of ultramafic rock within the gneisses, which represent ophiolitic fragments of the Jinsha Jiang Suture that runs parallel to the high-strain zone in the central region. (a) West-vergent asymmetric F_2 fold within Paleozoic marble and mica-schist sequence, Batang. (b) Plan view detail of $S_0//S_1$ layering from leucocratic schist within high-strain zone (dark shading = biotite-rich zone), showing structures such as isoclinal folds, isolated fold hinges and layer-parallel boudinage.

transect (Fig. 9a). In places along this transect, sets of west-dipping thrust planes were also observed to overprint open F_2 folds and crenulation cleavages, and are kinematically identical to the D_3 thrusts observed around Dege and Batang.

Towards the western end of section III–III′ (Fig. 6), a large elongate block of Middle–Late Triassic phyllite ~25 km north–south and ~4 km wide was observed to be structurally overlying the biotite–schists (see also Fig. 2). Where observed, bedding dipped gently to the west and preserved quartz veins that suggested west-side-down normal movement (Fig. 9b). These Late Triassic phyllites are clearly allochthonous and may represent a klippen structure thrust from the east during the late stages of deformation in the region.

At the far-western end of section III–III′ (Fig. 6), garnet–biotite schist grades into garnet–biotite ± sillimanite gneiss,

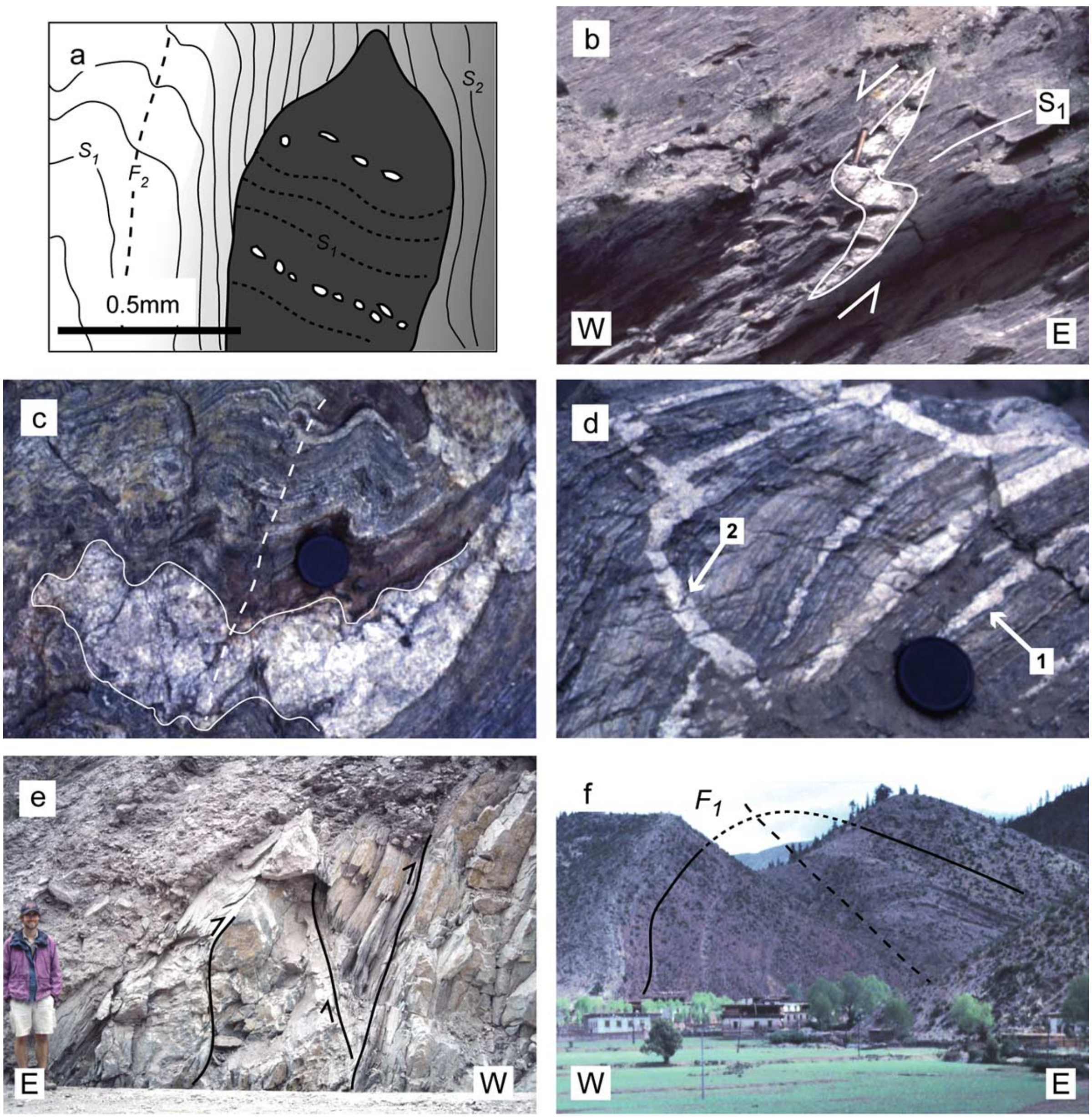

Fig. 9. Field photographs and sketches from section III–III′ and the western end of section II–II′, the central transect across the Yidun Arc. (a) Sketch of thin section of amphibole (dark shading)-bearing crenulated mica-schist, Zhongza. Field of view is 1.5 mm. Note quartz inclusion trails within amphibole porphyroblast preserve an S_1 foliation, crenulated in places by F_2 folds (left of view), and elsewhere completely overprinted by pervasive muscovite–biotite defined S_2 cleavage (right of view; light shading). (b) Quartz tension gash in Triassic phyllites, west of Zhongza, suggesting west-side-down normal movement. Hammer for scale. (c) Folding in garnet bearing quartz–biotite leucocratic gneisses, along the Jinsha River, west of Zhongza. Here the gneisses are intruded by a layer-parallel felsic dyke (outlined), which itself is folded with the gneisses. Lens cap for scale. (d) Two generations of felsic intrusion in gneisses along the Jinsha River west of Zhongza. One type is layer-parallel, folded by the macroscopic folds (1), while a second is cross-cutting, but in places becomes layer-parallel (2). (e) West-vergent thrusts within Triassic sandstone and shales, west of the Jinsha River, eastern Qiangtang Block. (f) Large-scale, west-vergent folding in Jurassic red beds of the Chamdo Basin, located to the southeast of Markham.

which is intruded by multiple generations of felsic intrusion (Fig. 9c and d). The latter gneisses are identical to those observed west of Batang and suggest the high-strain zone observed there and west of Dege in the north, is continuous along the western margin of the western Yidun Arc and strikes roughly parallel to the Jinsha River.

West of the high-strain zone along section II–II′ lie chloritic schist and intercalated limestone outcrops that preserve a strong, upright, north–south-trending foliation and west-vergent F_1 folds (Fig. 6). These rocks of the eastern Qiangtang Block also show *S–C* fabrics within schistose lithologies that suggest an east-over-west sense of shear. Further west towards Markham, Triassic limestones and intercalated red sandstone and shale are folded by open F_1 folds and dissected by a number of west-directed duplex structures and associated thrusts (Fig. 9e). Massive Devonian limestone and intercalated shale present in this area is deformed by open F_1 folds, showing no evidence of the high-strain observed in Paleozoic rocks within the western Yidun Arc.

Overlying the Triassic of the eastern Qiangtang Block are Jurassic–Cretaceous red beds of the Chamdo Basin (Fig. 2), which are folded by north–south-trending open folds at scales of tens to hundreds of metres (Fig. 9f) commonly associated with bedding-parallel thrusts. These structures post-date Triassic deformation and may relate to either the later suturing of the Lhasa Block to the Qiangtang Block or the India–Asia collision.

3.3. Southern transect: Litang to the Lancang (Mekong) River (sections IV–IV′ and V–V′)

To the southwest of Litang (Fig. 2), within the eastern Yidun Arc, Triassic flysch is folded by tight F_1 folds and intruded by a Late Triassic granodiorite pluton (section IV–IV′, Fig. 10). Like other major granitoids of the Yidun Arc, a minor contact aureole consisting of hornfels alteration and a localized zone of spotted schist was observed in the vicinity of this pluton. On the western side of the granodiorite tight, sub-horizontally plunging, F_1 folds, with little or no S_1 cleavage, fold north–south striking, Late Triassic mudstone and sandstone units (section IV–IV′, Fig. 10). West-vergent duplex structures and thrusts are also observed in these low-grade sequences (Fig. 11a). Open second-generation folds are observed infrequently around the township of Xiangcheng, although such F_2 folds become more common further west.

The contact between the Triassic of the eastern Yidun Arc and the Paleozoic of the western Yidun Arc was not observed, but is apparently faulted (SBGMR, 1981). Paleozoic micaceous schist and limestone of the western Yidun Arc outcrop around Derong and show tight to isoclinal F_1 folds (Fig. 11b) with a strong, generally

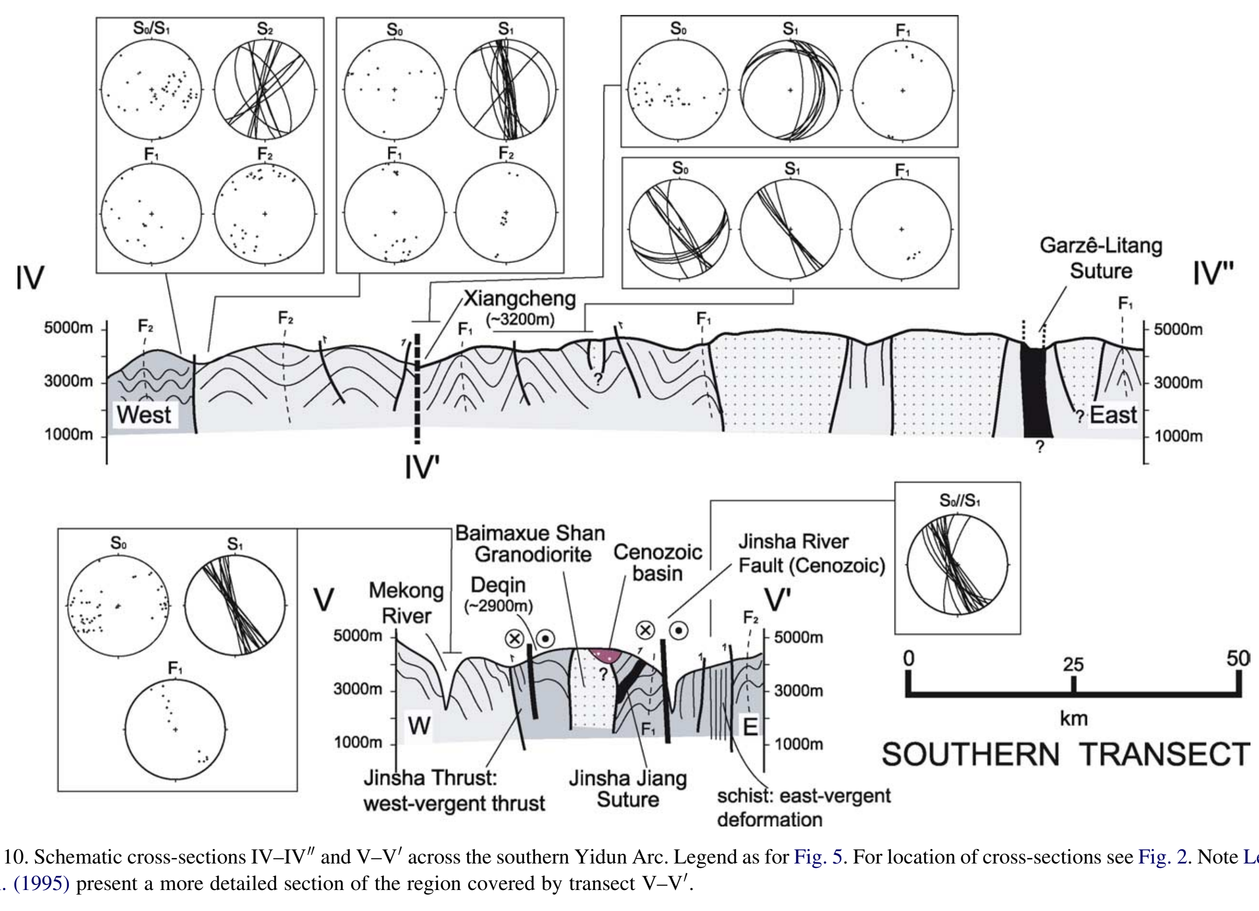

Fig. 10. Schematic cross-sections IV–IV″ and V–V′ across the southern Yidun Arc. Legend as for Fig. 5. For location of cross-sections see Fig. 2. Note Leloup et al. (1995) present a more detailed section of the region covered by transect V–V′.

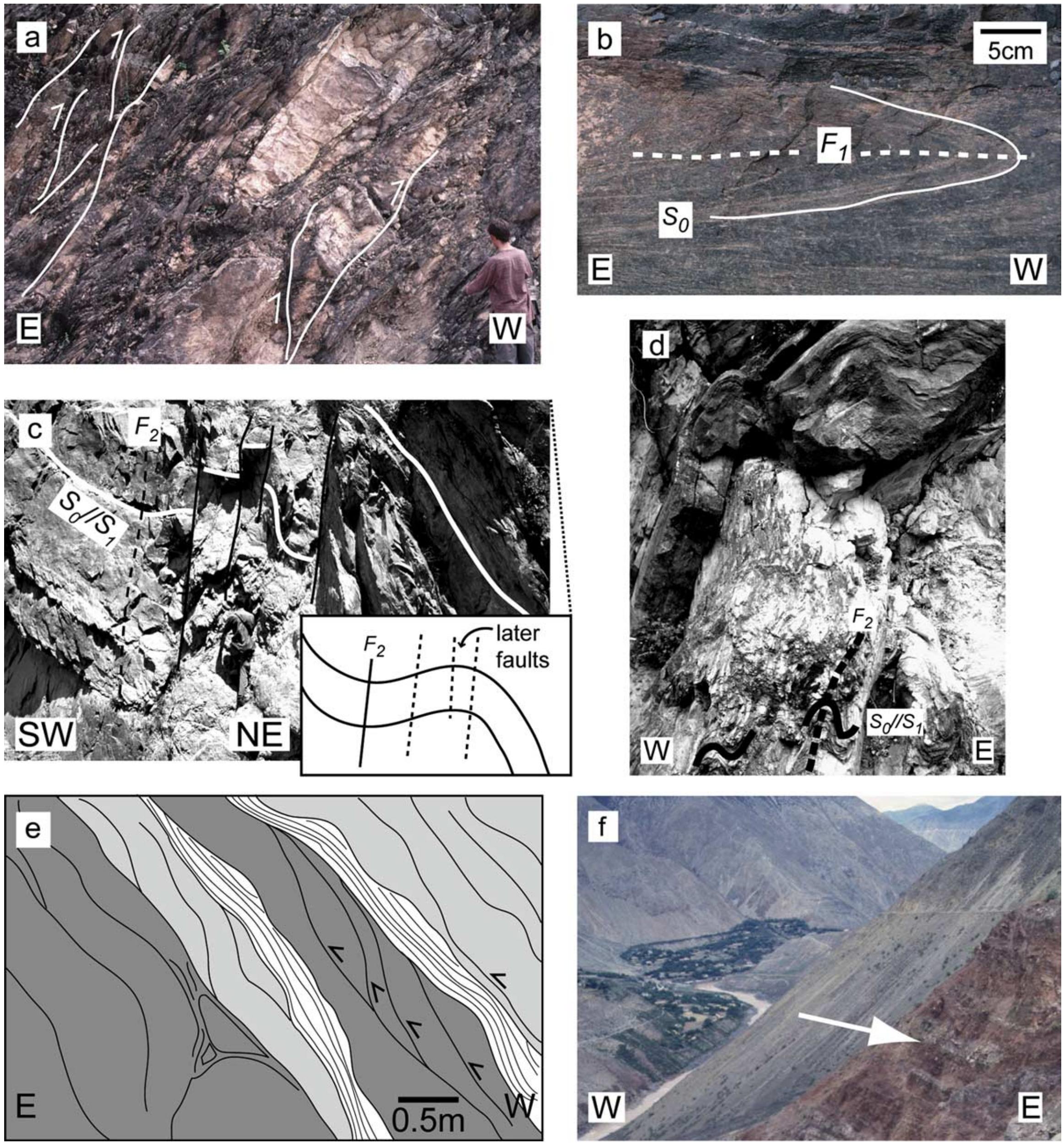

Fig. 11. Field photographs and sketches from the southern transect across the Yidun Arc. (a) West-vergent duplex structures and thrusts in Late Triassic shales and sandstones, east of Xiangcheng, eastern Yidun Arc. (b) Isoclinal F_1 fold within Paleozoic micaceous carbonate unit, Derong, western Yidun Arc. (c) Open west-vergent asymmetric F_2 fold in Paleozoic marbles and micaceous units, south of Derong (inset shows interpretation). (d) F_2 folding within micaeaous Paleozoic units of the western Yidun Arc, just north of Derong. The massive marble unit (top) shows low amplitude open folding, in comparison to the micaceous units (bottom), which show small-scale higher amplitude folds and F2 crenulations. Width of view is ~3m. (e) Field sketch of serpentinised mafic lithologies interleaved with shales within the Jinsha Jiang ophiolite sequence, west of Benzilan, showing east-directed thrusting. (f) View looking north-west upstream along the Lancang (Mekong) River Valley, north of Deqin, eastern Qiangtang Block, showing outcropping upper Triassic sandstones, shales and red beds (indicated by arrow).

sub-vertical stretching lineation (Fig. 10). Overprinting these earlier structures are north–south-trending, open, asymmetric F_2 folds (Fig. 11c and d), associated with a muscovite/chlorite-defined, spaced S_2 crenulation cleavage in micaceous units. Such asymmetric F_2 folds were dominantly west-vergent around Derong.

West of Benzilan (Fig. 2) is a prominent outcrop of disrupted ophiolitic melange, consisting of lozenge-shaped blocks of serpentinized ultramafics and mafic volcanics interleaved with extensively brecciated limestone, mudstone and chert that defines the southern extension of the Jinsha Jiang Suture (section V–V′, Fig. 10). This ophiolitic melange has also been described by Wang and Chu (1988), Leloup et al. (1995) and Chang (1997). Fault planes observed within the melange and surrounding units dip to the west and show east-directed duplex structures (Fig. 11e).

The melange and surrounding mica-schists of the southern region thus are dominated by west-over-east D_1 thrusts, which is the opposite kinematics to D_1 structures observed in the high-grade metasediments of the central transect (Section 3.2). To the northwest of the Jinsha Jiang Suture lies the Baimaxue Shan Granodiorite (245.2 ± 1.7 Ma, U/Pb zircon; Reid et al., 2004), which intrudes the southern extension of the eastern Qiangtang Block (section V–V′, Fig. 10). Outcrop in this area is scarce; however, on the eastern side of the granodiorite, above 4200 m, Cenozoic red beds lie unconformably upon massive Triassic limestone. Permian and Triassic fault-bounded packages of limestone, purple shale, sandstone and volcanic rocks outcrop along the Lancang River valley to the north of Deqin (Fig. 11f) and are infrequently folded by tight, upright, generally west-vergent F_1 folds and small-scale west-directed thrusts. Mica-schist outcrops in this area also show *S–C* fabrics with east-over-west kinematics. These mica-schist packages probably represent the southern extension of the high-strain zone that is observed in the northern and central transects. Importantly, there is a change in vergence from east-vergent within the mica-schists and melange of the Jinsha River Suture in the southern region of the western Yidun Arc, to west-vergent deformation in the eastern Qiangtang Block.

4. Discussion: the structural evolution of the Yidun Arc

Paleozoic metasediments of the western Yidun Arc are intruded by undeformed Early Triassic granites, suggesting ductile deformation within these metasediments had ceased by this time (Wang et al., 2000; Reid et al., 2004). However, the Middle–Late Triassic clastic and volcanic units of the eastern Yidun Arc are themselves deformed and intruded by Late Triassic post-tectonic plutons (Hou, 1993; Reid et al., 2004). Therefore there are at least two ‘phases’ of deformation recorded within pre-Jurassic rocks of the Yidun Arc and surrounding regions. These two phases are interpreted to represent a continuous process of subduction along the Jinsha Jiang Suture resulting in collision between the Qiangtang Block and western Yidun Arc (‘phase 1’), followed by further deposition and terminal basin closure across the region (‘phase 2’).

4.1. Phase 1: the geometry of Early Triassic deformation and implications for the subduction polarity across the Jinsha Jiang Suture

The strongest deformation in the Yidun Arc region occurs within the Paleozoic metasediments of the western Yidun Arc and culminates in a high-strain zone along the western margin. Across the western Yidun Arc, D_1 structures such as isoclinal folding and layer-parallel boudinage are refolded by second-generation folds that become progressively tighter towards the west. Likewise, the associated S_2 schistosity becomes increasingly pervasive to the west and culminates in the sillimanite-bearing

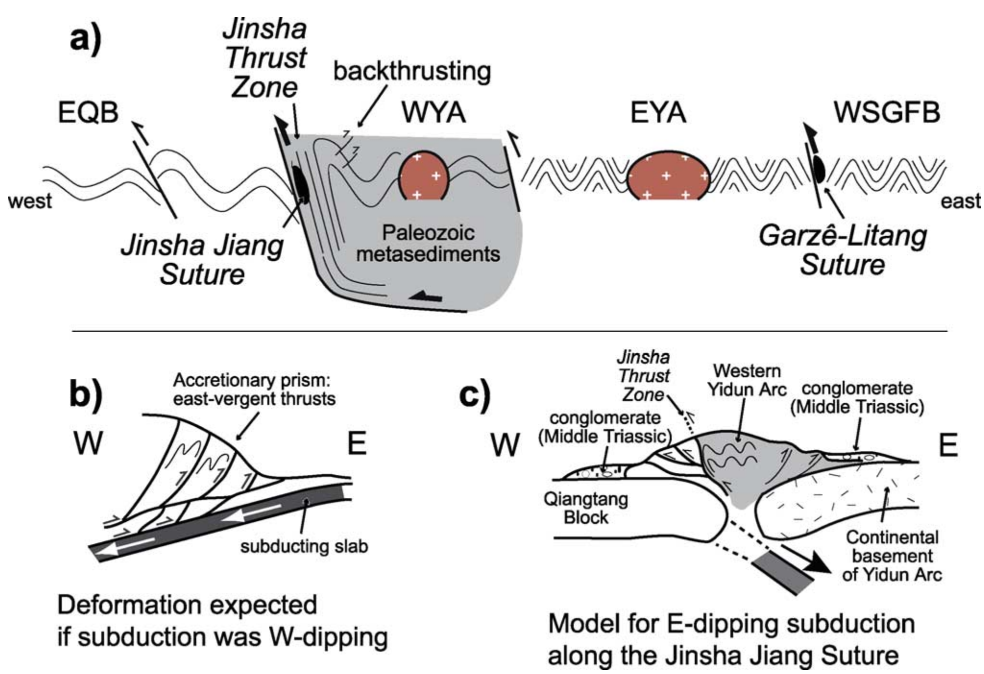

Fig. 12. Schematic profiles illustrating the relationship between structure and subduction geometry across the Yidun Arc. (a) Schematic east–west cross-section of the main structural elements across the Yidun Arc region. EQB = eastern Qiangtang Block, WYA = western Yidun Arc, EYA = eastern Yidun Arc, WSGFB = western Songpan Garzê Fold Belt. (b) Idealised section through an accretionary prism developed above a west-dipping subduction zone, showing the predominance of east-vergent structures (e.g. Byrne et al., 1993). Such a distribution of structures is not observed across the western Yidun Arc. (c) Suggested Permo-Triassic geometry for east-dipping subduction underneath the western Yidun Arc, contemporaneous with localised exhumation and deposition of conglomerates in active Triassic volcano-sedimentary basins of the eastern Yidun Arc and eastern Qiangtang Block.

gneissic fabric observed in the central transect. The structural complexity and metamorphic grade of the western Yidun Arc stands in stark contrast to the weakly deformed, low-grade Paleozoic and Triassic sediments of the eastern Qiangtang Block. The high-strain zone that separates these domains preserves east-over-west *S–C* fabrics, down-dip stretching lineations and west-vergent F_2 folds suggesting that it is a large-scale east-dipping thrust (Fig. 12a). This thrust is here termed the Jinsha Thrust, across which the western Yidun Arc was thrust onto the eastern Qiangtang Block during pre-Early Triassic deformation. The following discussion centres on two aspects of this structural geometry; (1) the along-strike extent of the Jinsha Thrust and its relationship to ophiolitic material, and (2) implications for the polarity of subduction along the Jinsha Jiang Suture.

The Jinsha Thrust incorporates ophiolitic material within it in the central and northern transects and thereby defines the location of the Jinsha Jiang Suture (Sections 3.1 and 3.2). In the southern transect, however, the Jinsha Thrust—as defined by west-directed thrusting west of Deqin—does not coincide with the ophiolite of the Jinsha Jiang Suture (Section 3.3). This along-strike variability in the location of the ophiolitic material suggests that ophiolite obduction may have been spatially variable, or that it occurred at different structural levels and in different locations within the deforming sedimentary pile.

What is the significance of the Jinsha Thrust in terms of subduction polarity along the Jinsha Jiang Suture? The Jinsha Jiang Suture is generally interpreted as recording a west-dipping subduction zone (e.g. Mo et al., 1994). However, an accretionary prism that developed above a west-dipping subduction zone would be expected to show an abundance of east-directed structures, consistent with reverse shear between the down-going plate and the overlying sediments (Fig. 12b). The structural data presented above strongly suggests that west-vergent structures are dominant on either side of the Jinsha Jiang Suture. This geometry is more easily reconciled with east-dipping subduction (Fig. 12c); a suggestion that is at variance with previous descriptions of subduction along the Jinsha Jiang Suture.

There are two exceptions to the generally west-vergent deformation across the region that must be evaluated in

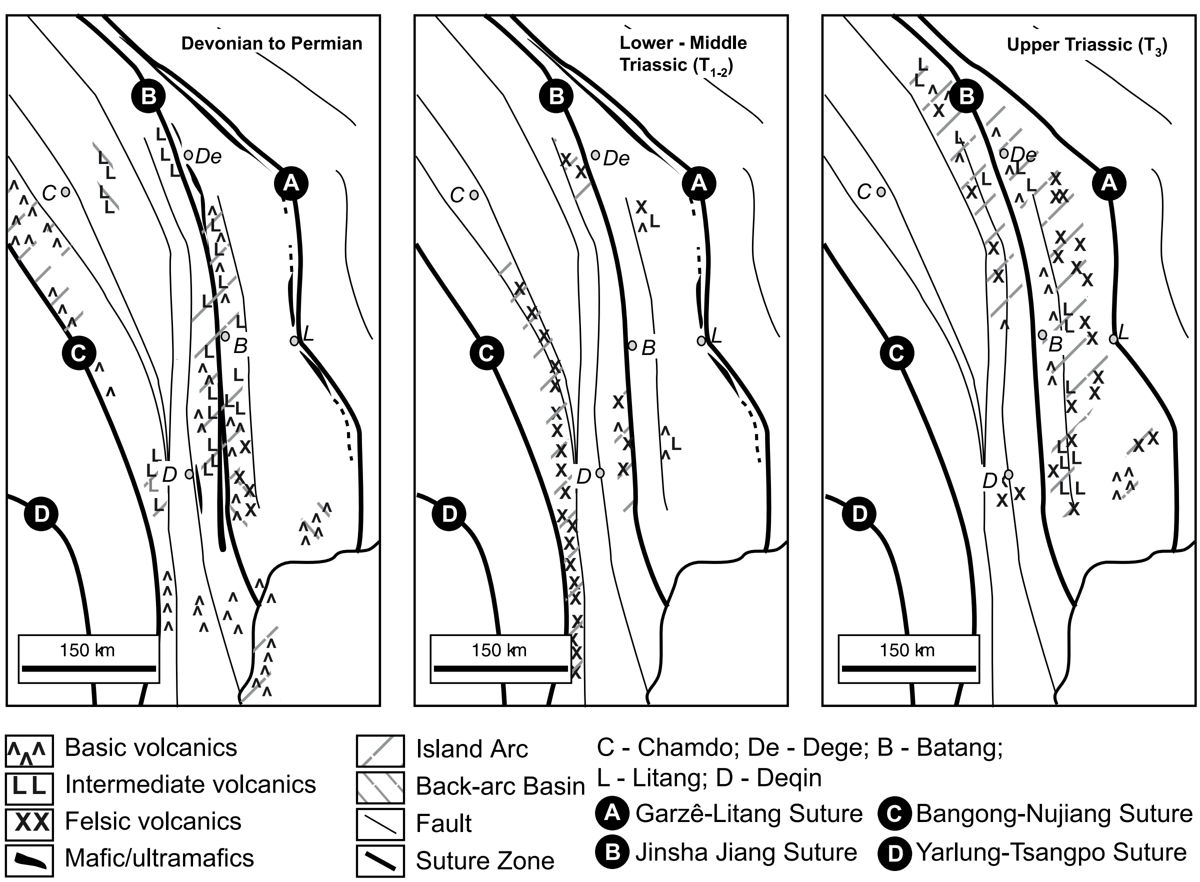

Fig. 13. Outcrop map of volcanic rocks of the study area through the Paleozoic to early Mesozoic from Chen et al. (1987). Note that these 'outcrop' maps are not necessarily representative of the abundance of volcanism throughout the region, in that the apparent lack of Early–Middle Triassic volcanics may reflect the small percentage of outcrop of sediments of this age across the region. Furthermore, the classification of the various volcanic rocks and their genetic assignment as 'island arc' or 'back arc' etc., is treated with some caution, particularly in light of potential for incorrect classification of magmas as a result of possible crustal differentiation processes (e.g. Tatsumi and Eggins, 1995). Consequently, these maps can be taken as a guide only. A more detailed study of volcanism in this region will be critical to further assess the Permo-Triassic subduction geometry.

terms of their bearing on the apparent subduction geometry. The first of these exceptions are the west-dipping D_3 thrusts and associated shear bands observed in micaceous units around Dege (Section 3.1, Batang and Zhongza (Section 3.2). These late-stage structures show west-over-east kinematics and are uniformly localized to the east of the Jinsha Thrust, which suggests that they are back-thrusts (Fig. 12a). These back-thrusts presumably developed in response to progressive strain accumulation within the hanging wall of the Jinsha Thrust. Importantly, these D_3 back-thrusts have not facilitated large-scale east-directed thrusting as would be expected above a west-dipping subduction zone and therefore cannot be used as evidence to support previous interpretations of west-dipping subduction along the Jinsha Jiang Suture.

The second exception to the overall west-vergent deformation within the western Yidun Arc occurs within the schists of the southern transect, south of Derong (Section 3.3; Fig. 10). In this region, east-directed D_1 and D_2 structures are observed within chloritic-schists and within serpentinized ultramafics of the Jinsha Jiang Suture (Section 3.3; see also Leloup et al., 1995). To the west, along the Lancang River Valley, a reversal in thrust kinematics is observed such that west-directed structures become common (Section 3.3), marking the probable southern extent of the Jinsha Thrust. The southern region thus shows bi-vergent deformation.

In terms of Permo-Triassic subduction along the Jinsha Jiang Suture, the bi-vergent deformation in the southern region may be more easily reconciled with the west-dipping subduction advocated by previous authors, although this structural architecture certainly does not preclude a model of east-dipping subduction. Furthermore, the southern region lies between the Indian continental shield and the Yangtze Craton (Fig. 1) and is composed essentially of north–south-trending elongate fault-bound blocks of Paleozoic to Cretaceous lithologies. These units have undergone considerable structural modification during the Tertiary as a result of the Indian collision alone (Wang and Chu, 1988; Leloup et al., 1995; Wang and Burchfiel, 1997), notwithstanding any unrecognised effects of the collision of the Lhasa Block. For example, a major Tertiary greenschist facies ductile décollement has been documented less than 200 km south of Benzilan (Lacassin et al., 1996), while the northern extension of the Tertiary Ailao Shan-Red River shear zone must also extend into this region (Leloup et al., 1995). The complex post-Triassic intracontinental deformation of this southern region implies that some phases of structural development (D_1, D_2, etc.) recognized in the southern transect may not correlate in age with similarly designated phases recognized in the other transects and therefore cannot be used as evidence for the subduction polarity along the Jinsha Jiang Suture. Finally, even if the bi-vergent thrusting in the southern region is wholly Permo-Triassic in age, this architecture is a non-unique indicator of subduction orientation and may argue for either west- or east-dipping subduction geometry.

To further clarify the subduction geometry across the Jinsha Jiang Suture, the volcanic record in the region must be examined. Maps of outcropping volcanic rocks in the region for Devonian–Triassic strata (Chen et al., 1987) show Devonian–Permian ‘island arc’ volcanics outcropping on the eastern side of the Jinsha Jiang Suture along with a small region of ‘back-arc basin’ volcanism to the east (Fig. 13). Taken at face value this distribution of volcanic rocks alone suggests subduction was east-dipping. Along the northern margin of the Qiangtang Block, northwest of the boundary with the Yidun Arc, Pierce and Mei (1988) describe Permian volcanic rocks with a range of compositions that they consider characteristic of intracontinental rather than active-margin magmatism. Pierce and Mei (1988) also describe Late Triassic volcanic rocks from the northern margin of the Qiangtang Block as being “characteristic of volcanic arc lavas erupted on oceanic or thinned continental lithosphere”. This volcanic evidence appears to suggest that the northern margin of the Qiangtang Block was not active during the Permian but had become active by the Late Triassic (see also Section 4.2 below). It is critical to recognise that closure of the Jinsha Jiang Suture between the western Yidun Arc and the Qiangtang Block had occurred by the Permian or Early–Middle Triassic and thus, the distribution of Late Triassic arc–volcanic rocks in the region has little bearing on models for the geometry of subduction across the Jinsha Jiang Suture.

It should also be noted that the structural geometry described above could have developed due to west-dipping subduction along the Jinsha Jiang Suture, if the Jinsha Thrust represents a retro-thrust within the accretionary prism. For the present, however, a model of east-dipping subduction appears to best describe the structural (and available magmatic) evidence for Early Triassic deformation across the western Yidun Arc. To emphasize, this interpretation relies upon; (1) the timing of deformation being constrained by the emplacement of undeformed granites into metasediments of the western Yidun Arc during the Early Triassic ($\sim$245 Ma), (2) the west-vergent structural geometry of this pre-Early Triassic deformation, particularly the Jinsha Thrust, observed in the central and northern transects from rocks that appear to have suffered less post-Triassic structural modification than the southern transect, and (3) the available Permo-Triassic volcanic evidence from the Yidun Arc and the Qiangtang Block. If correct, this interpretation has implications for reconstructions of the Paleozoic–Mesozoic accretion of terranes to the south-east of the Yidun Arc, in particular those that attempt to correlate the Jinsha Jiang Suture into southeast Asia.

4.2. Phase 2: Middle–Late Triassic deposition, volcanism and deformation

The Late Triassic arc-type volcanic rocks of the eastern

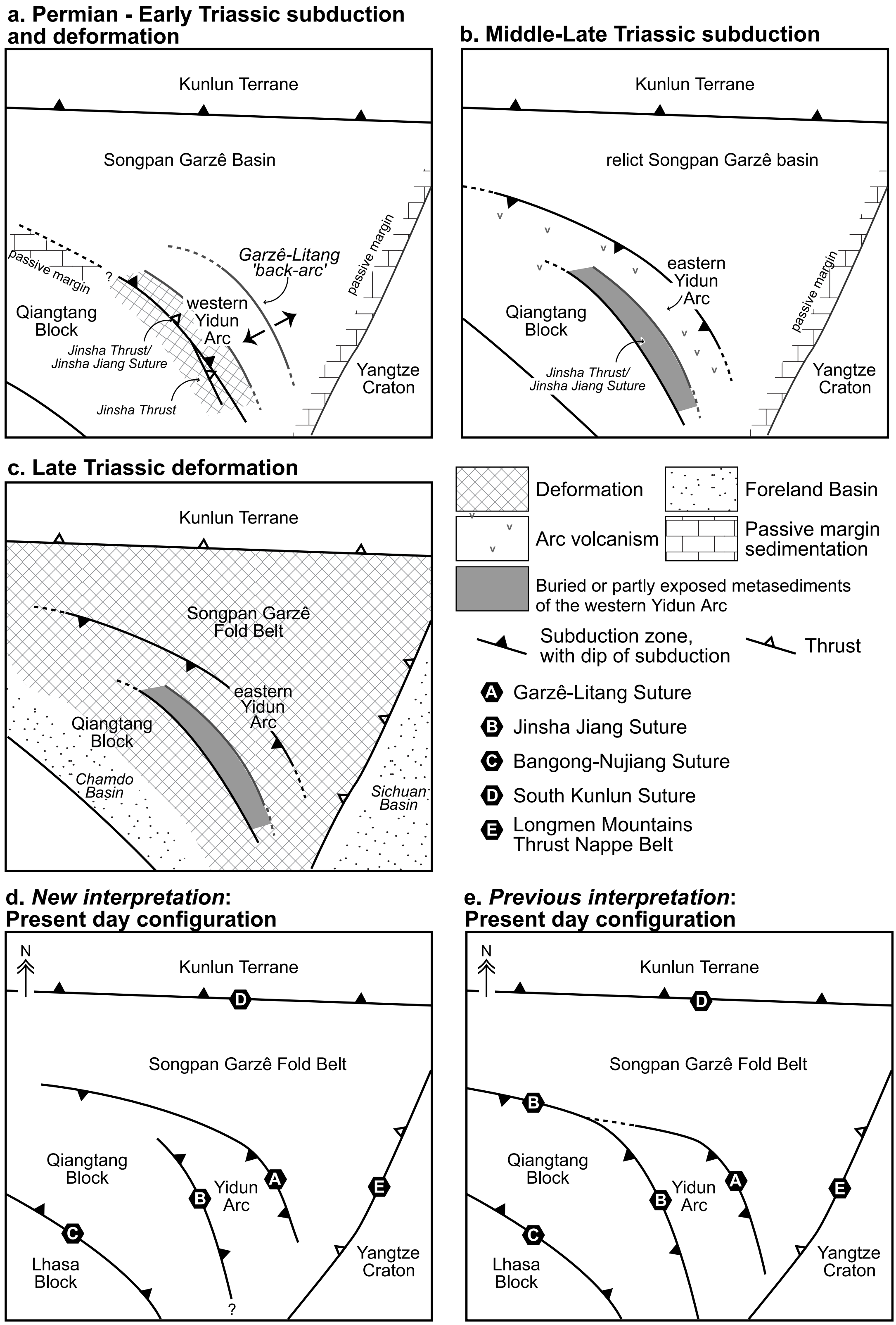

Fig. 14. Schematic map view diagram of the progressive Permo-Triassic tectonic development across the Yidun Arc region. (a) Subduction underneath the western margin of the Yangtze Craton at the leading edge of the Qiangtang Block, leads to the development of back arc basin, the Garzê–Litang Basin. The closure of the suture between the rifted sliver from the Yangtze Carton—the western Yidun Arc—and the Qiangtang Block during the Early Triassic leads to deformation of the Paleozoic metasediments within the collision zone, including the formation of the Jinsha Thrust. Passive margin sedimentation continued along the northern margin of the Qiangtang Block and across the northwestern margin of the Yangtze Craton at this time. Note that active subduction appears to have occurred only in the region of interaction between the Qiangtang Block and the Yantze Craton as no subduction-related volcanism is reported for this time

Yidun Arc are interpreted to have resulted from westwards subduction of the Garzê–Litang oceanic crust (Hou et al., 1993). Late Triassic subduction is also interpreted to have occurred under the northern margin of the Qiangtang Block (Pierce and Mei, 1988; Shen et al., 1995), and has also been implicated in the formation of Late Triassic–Early Jurassic core complexes in the central Qiangtang Block (Kapp et al., 2000). In fact, the coincidence of west and southwards Middle–Late Triassic subduction across the eastern and northern margins of the Yidun Arc and Qiangtang Block during the Late Triassic, suggests that the suture along the northern margin of the Qiangtang Block may be better correlated with the Garzê–Litang Suture instead of with the Jinsha Jiang Suture as is usually described. Further work may be necessary to prove this correlation, in particular in terms of the timing of subduction and subduction-related volcanism in the region.

The terminal deformation observed within Middle–Late Triassic rocks of the eastern Yidun Arc, eastern Qiangtang Block and Songpan Garzê Fold Belt thus appears to have resulted from the consumption of the relict basin underneath the combined western Yidun Arc–Qiangtang Block in the south, and underneath the Kunlun suture to the north. Structures resulting from this basin closure are identical across the region and suggest deformation was essentially thin-skinned, with a mafic/ultramafic substrate exposed in local structural culminations, such as near Daofu and along a north–south-trending zone between Garzê and Litang—the Garzê–Litang Suture. This style of deformation bears a strong resemblance to that described in other turbidite-dominated fold–thrust belts, such as the Lachlan Fold Belt, southeastern Australia (e.g. Foster and Gray, 2000; Spaggiari et al., 2004).

The timing of deformation in the eastern Yidun Arc, eastern Qiangtang Block and Songpan Garzê Fold Belt is constrained by the emplacement of Late Triassic–Jurassic post-tectonic granodiorite batholiths across the region (Roger et al., 2003, 2004; Reid et al., 2004). The generation of these Late Triassic plutons in the eastern Yidun Arc may be related to rebound of the geothermal gradient underneath the thickened sedimentary pile, as has been inferred for the post-tectonic granites from the Songpan Garzê Fold Belt to the east (Burchfiel et al., 1995). Alternatively, the granites of the eastern Yidun Arc have been interpreted to be the result of subduction-related melting, and thus to represent the roots of arc magmatism (Hou, 1993).

Even as the Late Triassic basin closure was occurring, the Chamdo Basin on the eastern Qiangtang Block remained a depocentre, and preserves approximately 5 km of Jurassic continental red bed sediment (Chen et al., 1987). This sediment presumably accumulated in response to the erosion of the evolving orogenic front to the east, in particular the deeply exhumed central region of the Jinsha Thrust. The Chamdo Basin is analogous to the Sichuan Basin (Fig. 1) that developed syn-tectonically in the foreland of the Longmen Mountains Thrust Nappe Belt, the southeastern margin of the Songpan Garzê Fold Belt (Chen et al., 1995; Li et al., 2003).

5. Conclusions

The dip of paleo-subduction zones may be inferred from the structures present within deformed rocks associated with suture zones that preserve their remains, in addition to the geochemistry of volcanic rocks that lie either side of the ophiolite belts. In the case of the Yidun Arc, structural evidence suggests subduction along the Jinsha Jiang Suture was east-dipping, while subduction along the Garzê–Litang Suture was apparently west-dipping. On the basis of this structural evidence along with timing constraints placed by the intrusion of granitic plutons, the tectonic evolution of the region may be interpreted (summarized in Fig. 14). Following deposition of Paleozoic sediments on the passive margin of the Yangtze Craton, it appears subduction was initiated underneath the southwestern margin of the Yangtze Craton, possibly during the Permian (?), which caused back-arc extension—the Garzê–Litang 'back-arc'—and the rifting of the western Yidun Arc from the craton (Fig. 14a). While this model implies east-dipping subduction along the Jinsha Jiang Suture and is at variance with some previous interpretations (e.g. Chen et al., 1987; Li et al., 1999), such a paleo-subduction geometry appears to explain the structural data for the western Yidun Arc and the presence of Late Triassic arc-type volcanic rocks as well as the Permian mafic and volcanogenic material now exposed within the Garzê–Litang Suture and the 'melange' near Daofu in the western Songpan Garzê Fold Belt. The metasediments of western Yidun Arc have undergone multiple phases of deformation and show an increase in structural complexity and metamorphic grade towards the Jinsha Thrust, the high-strain zone at the western margin of the western Yidun Arc. In the central region the Jinsha Thrust is also the locus of numerous ophiolite fragments that represent the Jinsha Jiang Suture. The timing of suturing of the Qiangtang Block and western Yidun Arc is constrained

along the northern margin of the Qiangtang Block. Subduction of the Songpan Garzê Basin also occurred underneath the Kunlun terrane. (b) During the Middle–Late Triassic, subduction was initiated underneath the eastern Yidun Arc and the northern Qiangtang Block, forming arc volcanism in each region, possibly defining a continuous south-southwest dipping subduction front. (c) During the Late Triassic, terminal deformation of the Middle–Late Triassic sequences occurred across the region, and the subsequent formation of the Chando and Sichuan foreland basins. (d) Interpretation of the pattern of sutures across the eastern Tibetan Plateau based on the above tectonic reconstruction. In this interpretation the Garzê–Litang Suture is continuous with the suture at the northern margin of the Qiangtang Block. Note that some degree of the curvature in the Garzê–Litang and Jinsha Jiang Sutures is due to the Cenozoic indentation of India. (e) Previous interpretations of the suture geometries across the region based on Chen et al. (1987) and Li et al. (1999).

by the emplacement of post-tectonic plutons into deformed Paleozoic metaediments along the Jinsha Thrust at ~245 Ma. We note also that formation of paragneiss in the northeastern Qiangtang Block has been dated at 244±4 Ma (U/Pb, zircon; Roger et al., 2003), which suggests the Early Triassic deformation documented here for the western Yidun Arc also affected parts of the eastern Qiangtang basement (Fig. 14a).

Arc volcanism developed in the eastern Yidun Arc during the Middle–Late Triassic, apparently in response to westwards subduction of the Garzê–Litang ocean/back-arc (Fig. 14b). Subduction also occurred underneath the northern margin of the Qiangtang Block resulting in arc volcanism (Fig. 14b), which was synchronous with the deposition of extensive turbidite sequences across the region. These Middle–Late Triassic sequences were deformed as a result of the progressive closure of the relict Songpan Garzê (Paleotethyan) basin (Fig. 14c). Based on this similarity in timing and polarity, the suture across the northern margin of the Qiangtang Block is interpreted to correlate with the Garzê–Litang Suture and not the Jinsha Jiang Suture as has been previously described (compare Fig. 14d with Fig. 14e). Further work, particularly on the geochemistry of the volcanic rocks of this region, is required to substantiate these interpretations.

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References

Burchfiel, B.C., Chen, Z., Liu, Y., Royden, L.H., 1995. Tectonics of the Longmen Shan and adjacent regions, central China. International Geology Review 37, 661–735.

Byrne, D.E., Wang, W., Davis, D.M., 1993. Mechanical role of backstops in the growth of forearcs. Tectonics 12, 123–144.

Calassou, S., 1994. Étude tectonique d'une chaine de décollement—tectonique Triasique et Tertiaire de la chaine de Songpan Garzê (Est Tibet). Diplome de Doctorate, Université de Montpellier II.

Chang, C., 1997. Geology and Tectonics of Qinghai–Xizang Plateau. Science Press, Beijing.

Chang, C., Pan, Y., Sun, Y., 1989. The tectonic evolution of the Qinghai–Tibet Plateau: a review, in: Sengör, A.M.C. (Ed.), Tectonic Evolution of the Tethyan Region. Kluwer Academic Publishers, Dordrecht, pp. 415–476.

Chen, B., Wang, K., Liu, W., Cai, Z., Zhang, Q., Peng, X., Qiu, Y., Zheng, Y., 1987. Geotectonics of the Nujiang–Lancangjiang–Jinshajiang Region. Geological Publishing House, Beijing (in Chinese).

Chen, M., Lou, J., 1999. Sedimentary characteristics and evolution of the Yidun Foreland Basin, western Sichuan, during the early Late Triassic. Tethyan Geology 23, 108–120 (in Chinese).

Chen, S.F., Wilson, C.J.L., Worley, B., 1995. Tectonic transition from the Songpan–Garzê Fold Belt to the Sichuan Basin, southwestern China. Basin Research 7, 235–253.

Dewey, J.F., Shackelton, R.M., Chang, C., Sun, Y., 1988. The tectonic evolution of the Tibetan Plateau. Philosophical Transactions of the Royal Society of London A 327, 379–413.

Du, D., Luo, J., Hui, L., 1998. Late Palaeozoic sequence stratigraphy and sea-level changes in the Qamdo block. Tethyan Geology 22, 68–75 (in Chinese).

Foster, D.A., Gray, D.R., 2000. Evolution and structure of the Lachlan Fold Belt (Orogen) of eastern Australia. Annual Review of Earth and Planetary Sciences 28, 47–80.

Harrowfield, M.J., 2001. The tectonic evolution of the Songpan Garzê Fold Belt, southwest China. PhD thesis, The University of Melbourne.

Harrowfield, M.J., Wilson, C.J.L., 2004. Indosinian deformation of the Songpan Garzê Fold Belt, northeast Tibetan Plateau. Journal of Structural Geology this issue (doi: 10.1016/j.jsg.2004.06.010).

Horton, B.K., Yin, A., Spurlin, M., Zhou, J., Wang, J., 2002. Paleocene–Eocene syncontractional sedimentation in narrow, lacustrine-dominated basins of east-central Tibet. Geological Society of America Bulletin 114, 771–786.

Hou, Z., 1993. Tectonic–magmatic evolution of the Yidun island-arc and geodynamic setting of kuroko-type sulfide deposits in Sanjiang region, SW China. In: Ishihara, S., Urabe, T., Ohmoto, H. (Eds.), Mineral Resources Symposia; Volume C. Selected Papers from the Symposia I-3-47, II-16-5, II-16-10 and II-16-12, Ferro-Manganese Deposits, Anoxic Sediments and Massive Sulfide Deposits. Shigen Chishitsu Special Issue 17. Shigen Chishitsu Gakkai—Society of Resource Geologists of Japan, Tokyo, Japan, pp. 336–350.

Hou, Z., Mo, X., 1991. A tectono-magmatic evolution of Yidun island arc in Sanjiang region, China. Contribution to the Geology of the Qinghai–Xizang (Tibet) Plateau 21, 153–165.

Hou, Z., Mo, X., Tan, J., Hu, S., Luo, Z., 1993. The eruption sequences of basalts in the Yidun island arc, Sanjiang region and evolution of rift to island arc. Bulletin of the Chinese Academy of Geological Sciences 26, 49–67.

Hou, Z., Wang, L., Zaw, K., Mo, X., Wang, M., Li, D., 2003. Post-collisional crustal extension setting and VHMS mineralisation in the Jinshajiang orogenic belt, southwestern China. Ore Geology Reviews 22, 177–199.

Kapp, P., Yin, A., Manning, C.E., Murphy, M., Harrison, T.M., Spurlin, M., Ding, L., Deng, X.G., Wu, C.M., 2000. Blueschist-bearing metamorphic core complexes in the Qiangtang Block reveal deep crustal structure of northern Tibet. Geology 28, 19–22.

Lacassin, R., Schaerer, U., Leloup, P.H., Arnaud, N., Tapponnier, P., Li, X., Zhang, L., 1996. Tertiary deformation and metamorphism SE of Tibet; the folded Tiger-leap décollement of NW Yunnan, China. Tectonics 15, 605–622.

Leloup, P.H., Lacassin, R., Tapponnier, P., Schaerer, U., Zhong, D., Liu, X., Zhang, L., Ji, S., Trinh, P.T., 1995. The Ailao Shan–Red River shear zone (Yunnan, China), Tertiary transform boundary of Indochina, in: Hilde, T.W.C., Flower, M.F.J. (Eds.), Southeast Asia Structure and Tectonics Tectonophysics Tectonophysics, 251(1–4). Elsevier, Amsterdam, Netherlands, pp. 3–84.

Li, X., Liu, C., Pan, G., Luo, J., 1996. Geology and Tectonics of Hengduan Mountains. Geological Publishing House, Beijing.

Li, X., Liu, W., Wang, Y., Zhu, Q., Du, D., Shen, G., Liu, C., Que, M., Yang, S., 1999. The Tectonic Evolution and Metallogenesis in the Tethys of the Nujiang–Lancangjiang–Jinshajiang Area, South-western China. Geological Publishing House, Beijing (in Chinese).

Li, Y., Allen, P.A., Densmore, A.L., Qiang, X., 2003. Evolution of the Longmen Shan Foreland Basin (western Sichuan, China) during the Late Triassic Indosinian Orogeny. Basin Research 15, 117–138.

Metcalfe, I., 1996. Gondwanaland dispersion, Asian accretion and evolution of eastern Tethys, in: Li, Z.X., Metcalfe, I., Powell, C.M. (Eds.), Breakup of Rodinia and Gondwanaland and Assembly of Asia Australian Journal of Earth Sciences, 43(6). Blackwell, Melbourne, Victoria, Australia, pp. 605–623.

Mo, X., Deng, J., Lu, F., 1994. Volcanism and the evolution of Tethys in Sanjiang area, southwestern China, in: Metcalfe, I. (Ed.), Gondwana Dispersion and Asian Accretion; Proceedings of the First International Symposium, IGCP Project 321 Journal of Southeast Asian Earth Sciences, 9(4). Pergamon, Oxford, UK, pp. 325–333.

Pierce, J., Mei, H., 1988. Volcanic rocks of the 1985 Tibet Geotraverse: Lhasa to Golmud. Philosophical Transactions of the Royal Society of London A 327, 169–201.

Reid, A.J., Wilson, C.J.L., Liu, S., Pearson, N., Belousova, E., 2004. Mesozoic plutons of the Yidun Arc, SW China: U/Pb geochronology and Hf isotopic signature. Ore Geology Reviews, in press.

Roger, F., Arnaud, N., Gilder, S., Tapponnier, P., Jolivet, M., Brunel, M., Malavieille, J., Xu, Z., 2003. Geochronological and geochemical constraints on Mesozoic suturing in East Central Tibet. Tectonics 22, 1037–1057.

Roger, F., Malavieille, M., Leloup, P.H., Calassou, S., Xu, Z., 2004. Timing of granite emplacement and cooling in the Songpan Garzê Fold Belt (eastern Tibetan Plateau) with tectonic implications. Journal of Asian Earth Sciences 22, 465–481.

Searle, M.P., Windley, B.F., Coward, M.P., Cooper, D.J.W., Rex, A.J., Rex, D., Li, T., Xiao, X., Jan, M.Q., Thakur, V.C., Kumar, S., 1987. The closing of Tethys and the tectonics of the Himalaya. Geological Society of America Bulletin 98, 678–701.

Sengör, A.M.C., 1984. The Cimmeride Orogenic System and the Tectonics of Eurasia. Geological Society of America, Boulder.

Sengör, A.M.C., Natal'in, B., 1996. Paleotectonics of Asia: fragments of a synthesis, in: Yin, A., Harrison, M. (Eds.), The Tectonic Evolution of Asia. Cambridge University Press, Cambridge, pp. 486–640.

Shen, S., Zhang, B., Wei, Q., 1995. Volcanic rocks in southern Jomda–Weixi Arc in the Nujiang–Lancang–Jinsha Rivers area. Tethyan Geology 19, 54–69 (in Chinese).

SBGMR (Sichuan Bureau of Geology and Mineral Resources), 1981. Sichuan 1:200,000 Geological Map Series, including: Danba Sheet (H-47-XII), Yidun Sheet (H-47-XVI), Litang Sheet (H-47-XVIII).

Spaggiari, C.V., Gray, D.R., Foster, D.A., 2004. Ophiolite accretion in the Lachlan Orogen, Southeastern Australia. Journal of Structural Geology 26, 87–112.

Sun, X., Zhang, B., Nie, Z., Liang, D., 1997. Formation, age and environment of opiolite and opiolitic melange in the Jinshajiang Belt, northwestern Yunnan. Geological Review 43, 113–120.

Tatsumi, Y., Eggins, S.M., 1995. Subduction Zone Magmatism. Blackwell Science, Cambridge.

Wang, E., Burchfiel, B.C., 1997. Interpretation of Cenozoic tectonics in the right-lateral accommodation zone between the Ailao Shan shear zone and the eastern Himalayan syntaxis. International Geology Review 39, 191–219.

Wang, E., Burchfiel, B.C., 2000. Late Cenozoic to Holocene deformation in southwestern Sichuan and adjacent Yunnan, China, and its role in formation of the southeastern part of the Tibetan Plateau. In: Geissman J.W., Glazner A.F. (Eds.), Special Focus on the Himalaya. Geological Society of America (GSA). Boulder, CO, US, pp. 413–423.

Wang, E., Chu, J.J., 1988. Collision tectonics in the Cenozoic orogenic zone bordering China, India and Burma. Tectonophysics 147, 71–84.

Wang, E., Burchfiel, B.C., Royden, L.H., Chen, L., Chen, J., Li, W., Chen, Z., 1998. Late Cenozoic Xianshuihe–Xiaojiang, Red River, and Dali Fault Systems of Southwestern Sichuan and Central Yunnan, China. Geological Society of America, Boulder.

Wang, L., Pan, G., Li, D., Xu, Q., Lin, S., 1999. The spatio-temporal framework and geological evolution of the Jinshajiang arc–basin systems. Acta Geologica Sinica 73, 206–218 (in Chinese).

Wang, X., Metcalfe, I., Jian, P., He, L., Wang, C., 2000. The Jinshajiang–Ailoshan Suture Zone, China: tectonostratigraphy, age and evolution. Journal of Asian Earth Sciences 18, 675–690.

Yin, A., Harrison, T.M., 2000. Geologic evolution of the Himalayan–Tibetan orogen. Annual Review of Earth and Planetary Sciences 28, 211–280.

Zhang, N., Cao, Y., Lio, Y.a., Zhao, Y., Zhang, H., Hu, D., Zhang, R., Wang, L., 1998. Geology and Metallogeny in the Garze–Litang Rift Zone. Geological Publishing House, Beijing (in Chinese).

Zhang, Q., Zhou, D., Zhao, D., Huang, Z., Han, S., Jia, X., Dong, J., 1994. Ophiolites of the Hengduan Mountains, China; characteristics and tectonic settings, in: Metcalfe, I. (Ed.), Gondwana Dispersion and Asian Accretion. Proceedings of the First International Symposium, IGCP Project 321 Journal of Southeast Asian Earth Sciences, 9(4). Pergamon, Oxford, UK, pp. 335–344.

Zhong, D., 2000. Palaeotethysides in West Yunnan and Sichuan, China. Science Press, Beijing.

Zhou, D., Graham, S.A., 1996. The Sonpan–Ganzi complex of the west Qinling Shan as a Triassic remnant ocean basin, in: Yin, A., Harrison, T.M. (Eds.), The Tectonic Evolution of Asia. Cambridge University Press, Cambridge, pp. 281–299.