by Zhiqin Xu

Large shear zones in the main orogenic belts of China

During the last ten and more years, detailed research has been undertaken on the geometry, kinematics and dynamics of more than 50 large shear zones in the main orogenic belts of China, including the Himalayas, the East Kunlun Mountains, the Bayan Har–Songpan–Ganzê, the Qilian Mountains, the Qinling–Dabie, the Tianshan Mountains and the intracontinental mountain chains of eastern China. New classifications of the shear zones are proposed. The dynamic process of formation of the initial mountain chains by plate convergence has been reconstructed using the concepts of ‘palaeo-intraoceanic’ and ‘palaeo-subduction’ types of ductile shear zones. In addition, the mechanisms of orogenesis during the formation of the main continental mountain chains in China have been re-established. It is suggested that different types of large shear zone resulted from main orogeny-, post-orogeny- or re-orogeny-phases respectively, in both the ‘collision’ and ‘intracontinental’ types of mountain chain.

The classification of large shear zones and some examples

The large shear zones of China have been defined on the basis of three criteria:

- The nature of the boundary between interacting plates.
- The regional tectonic regime.
- The P–T conditions during shear zone formation.

Details of the classification and some examples of the various types of shear zone are given in Table 1.

The intraoceanic type

The Yarlung Zangbo River suture zone is an example of a palaeo-intraoceanic ductile shear zone. There, an ophiolite zone, developed a ductile thrust-nappe system with a transverse (N–S) stretching lineation), and with garnet amphibole schist characterising the base of an obducted part. Fabric and dislocation structures in minerals in mantle-derived peridotite, indicate the existence of a (010)[100] slip system representing high temperature and flow of the upper mantle and a N–S slip vector. This demonstrates that, before the formation

Table 1 Types of large shear zones in different orogenic belts.

Classification criterion	Shear type	Typical example
Nature of the boundary between interacting plates	1 Intraoceanic	Zoulang Nanshan, northern Qilian Mountains, Yarlung Zangbo River
	2 Subduction (Obduction)	Northern Qilian Mountains, central Kunlun (A'nyêmaqên), Yushu–Jinsha River
	3 Collision and plate convergence	Himalayas, south Kunlun, north Qiling
	4 Non-collision	Shandong–Liaoning, south China
Regional tectonic regime	1 Contraction: a Decollement	South Qinling, Shandong–Liaoning, western Sichuan (Danba), Tanggula Mountains, Eastern Sichuan, Himalayas, south Kunlun, Dabie, north Qinling, south China
	b Thrust nappe	Western Shandong, southern Liaoning, central Qilian, western Sichuan, north Himalayas
	2 Extension	Western Shandong, southern Liaoning, central Qilian, western Sichuan, north Himalayas
P–T conditions during shear zone formation	3 Strike slip	Xianshui River, central Qinling, southern Kunlun, south edge of north Qilian, south edge of north Tianshan, Lancang River, Jinsha River, Honghe River
	High T–ultra High P (25–30) 105 KPa, >840°C	Southern Shandong, Dabie
	High T–Medium P (6) 105KPa, > 500°C	Western Sichuan (Danba)
	High T–Low P (3–4) 105 KPa, >650°C	Western Sichuan (Yajiang, Xianshui River)
	High P–Low T (7.5) 105 KPa, 300–400°C	North Qilian, Yarlung Zangbo River, southern Kunlun
	Low T–Low P (2–3) 105KPa, 250–300°C	Tanggula Mountains

of the initial mountain chain of the Himalayas, the closure of the Tethys oceanic basin (J–K₁) had involved intraoceanic shearing, with the oceanic crust being thrust southward onto the continental margin of the Indian plate.

The subduction type

The Zoulang Nanshan Caledonian subduction complex zone, located between the Alxa block and the Qilian block in the Sino-Korean plate, is composed of multiple accretionary volcanic island arcs, high-pressure metamorphic belts (glauco-phane, eclogite), flysch accretionary wedges, *décollement* mylonite zones and remnants of ophiolites. It belongs to a subductive, complex ductile shear zone system along a palaeo-plate boundary. Finite strain analysis shows that the northward subduction of the Qilian block beneath the Alxa block involved simple shearing dynamics. The metamorphism during subduction progressed through three stages: low-P metamorphism (greenschist facies), high-P metamorphism (blueschist facies), and low-T metamorphism (low greenschist facies). Evidently the Qilian block underwent subduction and then returned to the surface. In addition, the stage of high-P metamorphism can be subdivided into three stages: the initial stage accompanied with S1 cleavage, the main stage accompanied by S2 cleavage and the lag stage with isobar–temperature increase (zonal glaucophane). A Caledonian retrenchment subduction model with northward subduction of the Qilian block resulting in the development of the initial Qilian Mountains has been suggested. The elapsed time from subduction to return was 450–408 Ma and the subduction rate was 14 cm/a.

The contraction-type

Data on shear vectors and transverse stretching lineations of large thrust-nappes and *décollements* have shown that there was lithospheric contraction during the main orogenic stage in the Upper Proterozoic, Palaeozoic, Mesozoic and Cenozoic orogenic belts of China.

Shear zones in the Upper Proterozoic orogenic belts

The recognition of Upper Proterozoic orogenic belts of China is based on the discovery of an Upper Proterozoic high P–ultrahigh P (coesite) metamorphic zone, an ophiolite zone and a metamorphosed volcanic rock zone (700–800 Ma) in the southern Shandong–Dabie–Qinling–north-western Sichuan in central China. A glaucophane metamorphic zone accompanied by relics of oceanic crust (700 Ma) has also been found in Aksu, west Tianshan Mountains (Xiao Xuchang and Maruyama et al., 1990). Evidence that the Sino-Korean plate subducted southward below the palaeo-Yangtze plate, causing the formation of the Upper Proterozoic collision orogenic belt is provided by the presence of:

- Transverse stretching lineations, SSE 140°–160°.
- Shear strain (slipping from south to north) in the high P (ultra-high P)–high T ductile shear zones in the root of the subduction belt
- A synchronous thrust-nappe ductile shear system with a slip direction of south–north.

In the south Qinling and western Sichuan, the early S–N ductile *décollement* shear zone (Anz) has also been found between the Pt₂₋₃ metamorphosed volcanic rock and the Pz cover below the Indian *décollement* belt (200 Ma).

Shear zones in the Palaeozoic orogenic belts

In the 'Qinling–Qilian–Kunlun' Palaeozoic central orogenic belt, there is a large Caledonian–Variscan thrust-nappe ductile shear system with shear vector-stretching lineation perpendicular to the strike of the mountain chains (north Qinling: S–N; north Qilian: NE–SW; east Kunlun: S–N). Shear strains show that the shear directions of the north Qinling, north Qilian and east Kunlun are from north to south, from north-east to south-west and from south to north respectively, which suggests that the Yangtze plate subducted northward beneath

the Sino-Korean plate, the Qilian block subducted northward beneath the Alxa block and the Qaidam–north Kunlun block subducted southward beneath the Yangtze plate (southern Kunlun). The genesis of these shear zones may have included subduction, collision or intracontinental scenarios.

Shear zones in the Mesozoic and Cenozoic orogenic belts

In the south Qinling Mountains, a deep *décollement* shear zone lying between the basement (Pt₃ metamorphosed volcanic rocks) and the cover (Z–T) was formed in the Indosinian stage (190–200 Ma) with a slip direction from north to south. It is accompanied by a high-pressure metamorphic belt, which the product of intracontinental subduction brought about by the northward subduction of the Yangtze plate beneath the Sino-Korean plate.

The concentric fold belt composed of J–K strata in the Tanggula Mountains and the fold belt composed of T–J₃ strata in the eastern Sichuan Province, are related to the shallow ductile *décollement* zones formed in the Cretaceous, the slip directions of which are from north to south and from west to east respectively.

From north to south, the ductile thrust system of the Himalayan chain consists of:

- the Yarlung Zangbo 'crust-mantle type' ductile thrust shear zone (YCMT), 80 Ma;
- the Lhagoi Kangri–Kangma ductile thrust shear zone (KMT), 40 Ma;
- the north Himalayas ductile thrust shear zone (NHT), 40–20 Ma;
- the main central ductile thrust fault (MCT), 20 Ma and
- the main boundary ductile-brittle thrust fault (MBT), 10 Ma.

All of these zones dip gently northward, have a shear direction from north to south and their ages show a southward migration with time. The thrust of the YCMT has caused deep mantle rock to move 130 km southward, and the MCT has made the Himalayan crystalline rock sheet thrust southward onto the microlithon composed of Palaeozoic slightly metamorphosed sedimentary rocks. The distance of this thrust is about 70–115 km. All the ductile shear zones mentioned above formed by the continuous northward subduction of the Indian wedge. From north to south, they show the following changes:

- the formation age becomes younger;
- the depth becomes shallower;
- the temperature becomes lower;
- the palaeostress and strain rate becomes lower, and
- the deformation changes from ductile to brittle.

The partial melting of the crust accompanying the late-stage shearing led to the development of syntectonic granites.

Intracontinental shear zones in the Mesozoic

Since the Mesozoic, the continental regions of eastern China have undergone intensive structural alteration and orogeny, resulting in large-scale intracontinental deep thrust-*décollement* structures overlapping the palaeo-Asian tectonic system (Palaeozoic). The most typical example is the Jiao (eastern Shandong)–Liao (eastern Liaoning) orogenic belt. A subhorizontal amphibole mylonite zone, 2 km wide characterising the deep *décollement*, lies between the Archaeozoic Anshan group metamorphic basement (Ar), the Proterozoic Liaohe group low metamorphic basement and the sedimentary cover (Z–P).

The nearly east–west (90°–110°) transverse stretching lineation; sheath folding; the east–west strain direction and partial melting caused by shear heating can be clearly observed in the shear zone. The *décollement* age falls in the Indosinian period (198 Ma). A *décollement* granite mylonite zone striking east–west, possibly of the same age, has been founded in the eastern Shandong, superimposed on the earlier strained rock beds and was modified by the Yunshan granite.

Postorogenic extensional shear zones

Extension-type ductile shear zones which may be normal or strike slip, can be divided into three types: 'lag extension', 'gravity extension' and 'thermal uplifting-extension'.

Typical examples of the lag extension type of shear zone include a series of low-angle ductile normal shear zones in the backland of the north Himalaya and in the Xainza–Nam Co ductile *décollement* between the Gangdise composite basement and the Mesozoic–Cenozoic sedimentary cover at the north slope of Gangdise–Nyainqêntanglha Mountain. This resulted from stress relaxation on the backland of the thrust.

In the Shandong–Liaoning and Songpan–Ganze orogenic belts, there are ductile shear zones, with syntectonic migmatization and dynamic partial melting accompanying postorogenic uplift of the metamorphic basement and the thermal dome as a result of granite intrusion.

In southern Liaoning, dynamic myrmekites, which developed perpendicular to the foliation, have also been discovered in the deep *décollement* mylonite zone and in felsic veins. The dynamic myrmekites with the features of the syn-rotation or reverse-rotation, have developed along the direction from high-strain energy (plagioclase) to low-strain energy (K-feldspar), and some of them developed parallel to the foliation, deformational lamina and twin crystals. Our studies suggest that the myrmekite does not come from deep high-temperature fluids (the formation temperature is about 570°C), but is the product of the dynamic partial melting and alteration. The structural features of the myrmekite reflect the stress status as vertical, which indicates that the orogeny had changed from contraction to extension.

The formation of the Laiyang Basin (J_3 – K_2) to the north of southern Shandong is related with the ENE ductile normal-strike-slip shear zone on the south margin of the basin (Yang Tiannan, 1994). From the *en échelon* arrangement of Mesozoic–Cenozoic continental facies basins on an Archaean metamorphic basement, it can be inferred that the basin and range system in West Shandong was controlled by a ductile shear zone with north–south slip

Strike-slip shear zones in the Variscan

The Qinling orogenic belt:

The Shangdan mylonite zone, 2 km wide and located between the south Qinling and the north Qinling belt, exhibits sinistral strike-slip movement. This demonstrates the westward movement of the north Qinling with respect to the south Qinling since 315 Ma and that the zone is related to the subduction of the Yangtze plate beneath the Sino- and Korean plate.

The Qilian orogenic belt:

The ductile strike-slip shear zones on the north and south edges of the Qilian Mountains which are parallel to the trend of the mountain chain and intersect the Caledonian fold belt, developed 300–299 Ma ago and reflect rotation between the Alxa and the Qilian blocks.

The Tianshan orogenic belt:

The existence of the huge strike-slip ductile shear zone with a width over 10 km at the south edge of north Tianshan Mountain indicates

large-scale dextral strike slip movement between the north Tianshan and the central Tianshan since the Variscan stage.

The Kunlun orogenic belt:

Large-scale sinistral strike-slip movement occurred at the end of the Indosinian stage along the southern Kunlun suture zone (P– T_1), when the syntectonic granite zone was formed (198 Ma, 150 Ma).

Tertiary shear zones

Most Tertiary shear zones lie on the east edge of the Qinghai–Xizang Plateau. The Xianshuihe sinistral strike-slip shear zone, aligned NW–SE, was formed at 15 Ma and divides the Songpan–Ganze orogenic belt into two parts. Sinistral displacement reaches 80 km. The Jinshajiang, Lancangjiang and Honghe sinistral strike-slip zones were formed at 15–20 Ma. The strike-slip of the eastern edge of Qinghai–Xizang Plateau is related to the eastward extrusion of the China continent due to the plunge of the Indian wedge beneath Eurasia.

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