Ordovician and Silurian Stratigraphy and Palaeontology of Yunnan, Southwest China

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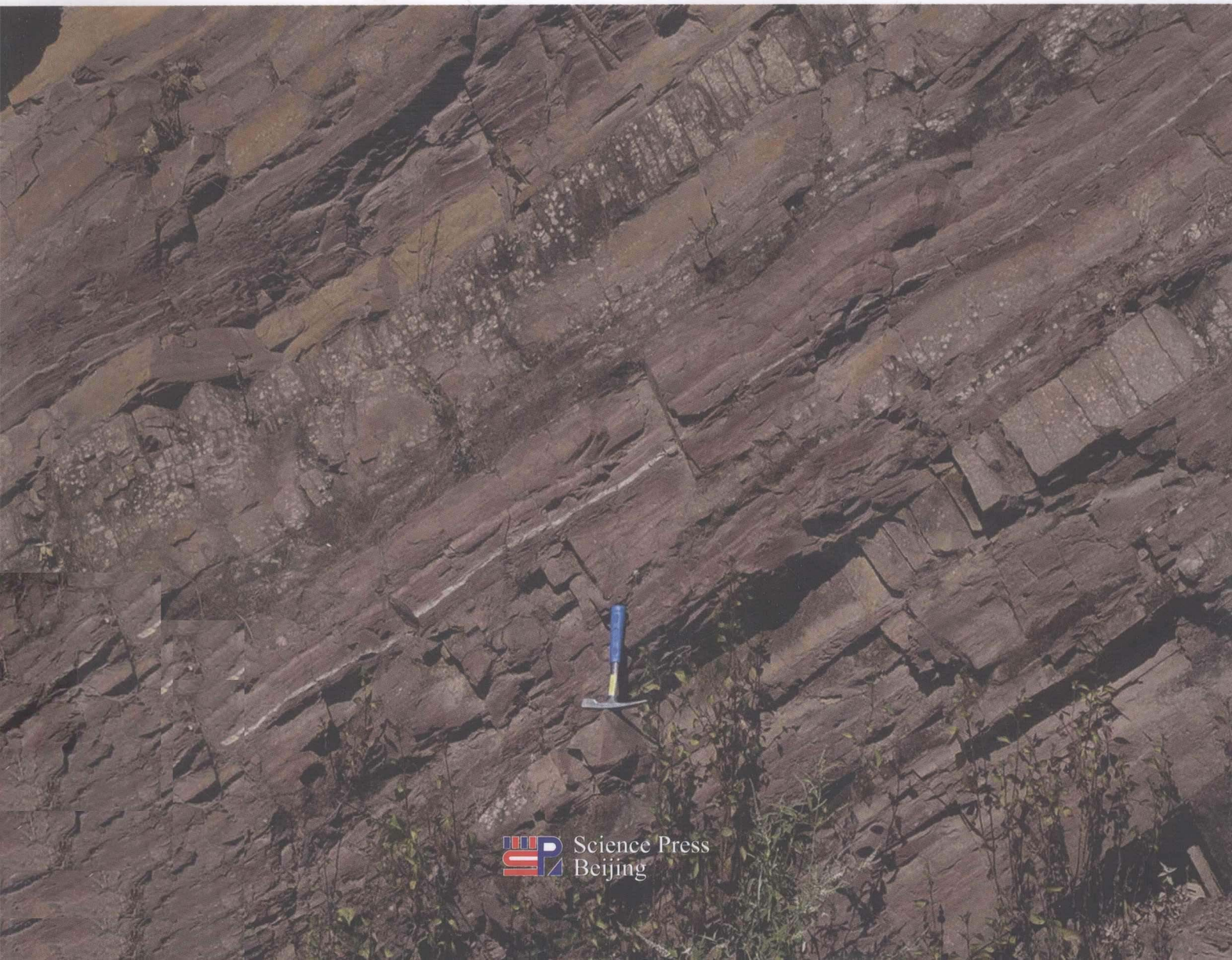

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A guide to the field excursion across the South China, Indochina and Sibumasu

ZHANG Yuandong, WANG Yi, ZHAN Renbin,
FAN Junxuan, ZHOU Zhiqiang, and FANG Xiang

with additional contributions from

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Contents

Chapter 1

Introduction

Yunnan Province is geologically unique among the provinces of China, because it comprises three parts that belonged to three separate blocks or terranes in the northeastern Peri-Gondwana Region during the Palaeozoic: South China, Indochina, and Sibumasu. This is also a critical region for understanding the opening and closure history of the Palaeo-Tethys Ocean, the opening of the Meso-Tethys Ocean, and the amalgamation of the Indian Plate into the Eurasian Continent during the Cenozoic. In recent years, intensive studies of the Changning-Menglian Suture conducted by scholars of many countries have shown that the suture represents the main Palaeo-Tethys Ocean. Even in the past two thousand years, Yunnan still played an important role, as it contained the main route of the famous "Southern Silk Road" that started from Chengdu, continued via Dali, Shihtien and Tengchong in Yunnan Province, crossed northern Myanmar (Burma), and terminated in India.

The Ordovician and Silurian strata of Yunnan Province are of great significance for understanding the affinities and rifting history of the three blocks. However, we know still little about them, mainly because of the rarity of outcrops, poor exposure, difficulty of access, and serious tectonic disturbance. Until now, the palaeontology, stratigraphy, sedimentology, palaeoenvironments and geological history of this region have been poorly documented. In the past ten years, we (and also many other scholars) have spent a considerable amount of time working on the palaeontology and stratigraphy of the Ordovician and Silurian rocks in the region, with the aim of improving our understanding of the geological history. On the basis of this work we have been able to update and revise some of our previous opinions, and have published some of them in a number of papers. We appreciate having the chance to present a synthesis of our studies, current understanding, and remaining questions, in this volume (Fig. 1.1).

The earliest, professional, geological work in Yunnan Province was carried out by Ludwig von Loczy, a Polish geologist attached to Count Szechenyi's expedition across China (1877–1880), who recorded his brief notes and the results of observations made while traveling in Lijiang and Dali and along the way to Bhamo in Burma, and first reported the presence of Ordovician trilobites and crinoids in the region (Loczy, 1893).

A substantial, early study of the region was conducted in 1908–1910 by J. Coggin Brown, an Assistant Superintendent in the Geological Survey of India, who published a preliminary introduction to the Ordovician and Silurian in the region and some other rocks, especially the volcanoes, volcanic rocks and hot springs in Tengchong (spelt Tengyueh at that time) (Brown, 1913, 1916). Brown collected abundant fossils during his field work, including cystoids, crinoids, brachiopods, gastropods, cephalopods, trilobites and graptolites, and was able to name the Pupiao Series (Ordovician), and the Paima Beds and Shihtien Shales (Silurian). His fossil collections were systematically studied and published by Reed (1917). The graptolites in Brown's collections, all from Silurian rocks, were identified by G.L. Elles as being of Llandovery age (in Reed, 1917). J.W. Gregory and C.J. Gregory investigated the geology of Yunnan and Xizang (Tibet) during the Percy Sladen Expedition in 1922, tried to classify the rocks they came across, and succeeded in finding some graptolites from Ordovician rocks at Howan, ca. 50 km north of Baoshan (Yungchang), which were identified by G.L. Elles to be of clearly Caradoc (Sandbian in the international scale) age (Gregory and Gregory, 1925).

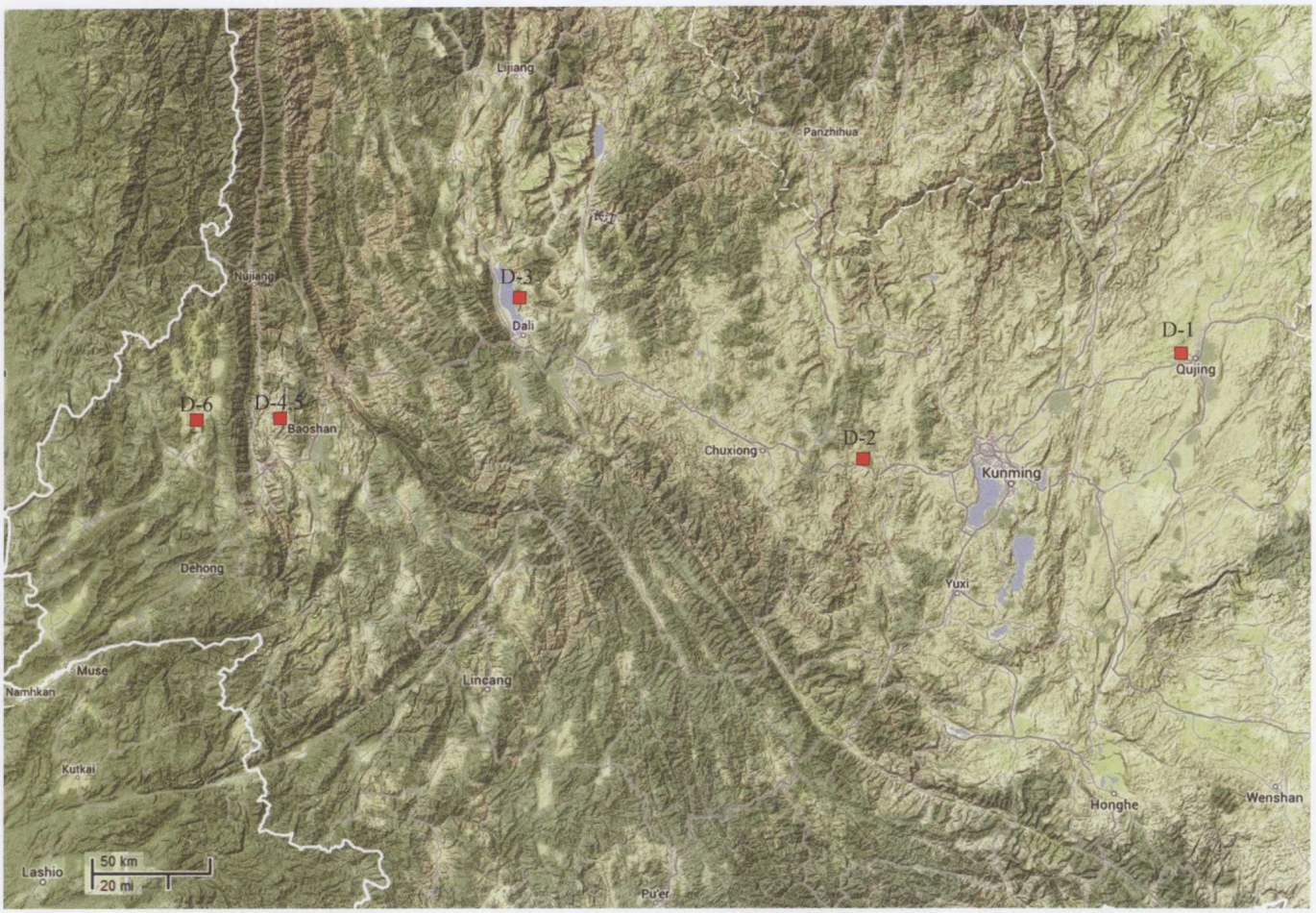

Fig. 1.1 Route map showing the localities to be visited (base map after Google).

T.H. Yin and C.H. Lu investigated the Baoshan Region, western Yunnan, in 1935, collected and described many Ordovician and Silurian fossils, and named the early Silurian Jenhochiao Series (Yin, 1937; Yin and Lu, 1937). Y.C. Sun and S.S. Szetu went to the Baoshan Region in 1945–1946 to conduct geological fieldwork. They were able to summarize the Ordovician and Silurian biozones of the region, and subdivided the Pupiao Series and the Jenhochiao Series each into a lower and an upper part (Sun and Szetu, 1947).

The most significant and substantial geological work on the Baoshan Region was carried out by the team from the Geological Survey of Yunnan Province (1980)[1], who systematically investigated the Precambrian and Phanerozoic rocks in the region, and measured and sampled several Ordovician and Silurian type sections. They subdivided the successions into a series of litho-units, redefined some of them, and established the biozonation of many fossil groups. Our studies conducted over the past few years used this work as a basis.

There has been significant progress on understanding of Ordovician palaeontology and stratigraphy of the Indochina Block as a result of the publication of the abundant trilobites, bivalves and brachiopods from the Hsiangyang Formation at Dali (Zhou *et al.*, 1998, 2001; Fang and Cope, 2004; Xu, 2012), the Silurian graptolites of the Mojiang area (Zhang and Lenz, 1997; Zhang Yuandong *et al.*, 2013), and the trilobites of the Wenshan Region, southern Yunnan (Luo *et al.*, 2014).

In eastern Yunnan, which belonged to the western part of South China in the early Palaeozoic, the Ordovician and Silurian successions are seriously incomplete due to the proximity of the region

[1] Geological Survey of Yunnan Province. 1980. Regional geological report with geological map (scale 1/200000). Geological Bureau of Yunnan Province. 1–223.

to the extensive Kangdian Oldland. Palaeontological and stratigraphic studies have concentrated on the Lower to Middle Ordovician strata near Kunming and the Ludlow to Pridoli interval in the Qujing Region (e.g. Wang, 1980; Luo, 1993; Huang *et al.*, 2011; Zhang Ju *et al.*, 2013; Zhao and Zhu, 2010).

In recent years, we have conducted more than twelve field excursions to Yunnan to undertake palaeontological and stratigraphic studies of the Ordovician and Silurian of this special region, to improve our understanding of the geological history of western South China, northern Indochina, and Sibumasu. The results of these works, including the graptolites, trilobites, brachiopods, cephalopods, bivalves, conodonts, chitinozoans, echinoderms, microfish, acritarchs, spores, carbon isotopes, and lithofacies, have been incorporated into nearly every chapter of this volume.

The substantial contributors to these studies are as follows (Fig. 1.2):

- Graptolites (Zhang Yuandong, Fan Junxuan, Chen Xu, Michael J. Melchin)
- Trilobites (Zhou Zhiyi, Zhou Zhiqiang)
- Brachiopods (Zhan Renbin, Rong Jiayu, Huang Bing)
- Cephalopods (Chen Tingen, Fang Xiang)
- Bivalves (Fang Zongjie)
- Conodonts (Wang Chengyuan)
- Chitinozoans (Tang Peng)
- Echinoderms (Chen Tingen, Zhang Yuandong)

Fig. 1.2 Some authors of this volume on fieldwork in Baoshan, western Yunnan, in 2013. From left to right: Fan Junxuan, Zhou Zhiqiang, Liu Jianbo, Zhang Yuandong, Shan Keqiang, Ma Xuan, Wang Yuan, Zhan Renbin, Wang Yi.

- Microfish (Zhao Wenjin, Zhu Min)
- Spores and acritarchs (Wang Yi)
- Carbon isotopes (Wang Yi, Axel Munnecke, Zhang Yuandong)
- Lithofacies (Zhang Xiaole, Liu Jianbo)

Chapter 2

Geological Setting of Yunnan during the Ordovician and Silurian

Yunnan consists of three parts that belonged to three separate blocks—South China, Indochina and Sibumasu—in the early Palaeozoic. The geological setting and history of this special region during Ordovician and Silurian time has been critical for understanding the evolution of the three blocks, especially their contemporaneous or successive rifting from Gondwana, and their eventual amalgamation with each other to form the united part of Eurasia that the region is nowadays. However, the history of this region is still poorly known, and herein we present our tentative interpretation of the geological setting based on the available literature and our studies of the region over the last few years.

South China, represented herein by eastern Yunnan, is bounded to the west with Indochina by the Ailaoshan-Red River (or Song Ma) Suture, which probably closed with the amalgamation of the two blocks in the Early Carboniferous (Metcalfe, 2011; Fig. 2.1). Some tectonic specialists have proposed that the Ailaoshan-Red River Suture extends northwards to possibly connect with the Jinshajiang Suture, and in this case the Qamdo area may be related to the Simao Region of southern Yunnan to make up the "Qamdo-Simao Block", which may form the northernmost part of the Indochina Block. However, as the two sutures were reactivated as sinistral strike-slip faults and altered in response to the collision of the Indian Plate with Eurasia in the recent Himalayan Orogeny (Xu *et al.*, 2011), such a connection requires further study.

The Indochina Block, represented herein by central and southern Yunnan, is bounded to the west with Sibumasu by the Changning-Menglian Suture, and possibly the Lancangjiang Suture in the northern part (Fig. 2.1). The Changning-Menglian Suture extends southwards into the Bentong-Raub Suture across the Malay Peninsula, forming the western boundary of Indochina, and representing the main Palaeo-Tethys Ocean (Metcalfe, 2011). The suture was proposed to have been reactivated during the recent Himalayan Orogeny as a dextral strike-slip fault during the collision of the Indian Plate with Eurasia. The collision broke the northern part of Indochina into the Qamdo and Simao terranes, and led to the southern movement of the Simao Terrane (Xu *et al.*, 2011). On the northwestern margin of the Indochina Block, there was a small terrane, the Lincang Terrane, which probably represented an isolated magmatic arc of Gondwanan affinity in the early Palaeozoic, and merged with the Simao Block (or Subterrane) prior to the Late Permian (Liu *et al.*, 1993, 2002; Sone and Metcalfe, 2008). Ordovician and Silurian rocks have a restricted distribution in the Simao Terrane, occurring largely in the eastern part, and have been seriously sheared into small pieces in subsequent orogenies, or may just represent deposits added to the Simao Terrane as accretionary wedges during amalgamation in the Late Permian.

The Sibumasu Block is an elongated terrane that includes west Yunnan, East Burma (mainly the Shan State), most of the Malay Peninsula and Sumatra. Its northern part is bounded to the east by the Changning-Menglian Suture (Liu *et al.*, 1993; Metcalfe, 1998, 2011). The northern part of the block

is bounded to the west with the West Burma Terrane by the Shan boundary, and is represented by Baoshan and Luxi in Yunnan and the Shan State. The biogeographic affinities of the Sibumasu Terrane with other blocks or continents, such as South China, North China, and Gondwana, are still disputed owing to the poorly surveyed fossil faunas in Sibumasu. Fortey and Cocks (1998, 2003) concluded that the carbonate succession of the Cambrian-Ordovician transition interval in the terrane displays strong similarities to those in North China and central Australia, whereas the younger Ordovician trilobite faunas are nearly identical to those of South China. Zhou and Zhen (2008) proposed that, during the Ordovician, the Shan State (Burma)-Baoshan (west Yunnan) Region was in low latitudes and not far from South China, whereas the West Malaysia-Thailand Peninsula block was located close to the North China Plate. The Sibumasu Block may have formed part of Gondwana prior to the Early Permian, was rapidly rifted away with the opening of the Meso-Tethys Ocean, and amalgamated with Indochina during the Triassic with the closure of the Palaeo-Tethys Ocean (Metcalfe, 2011).

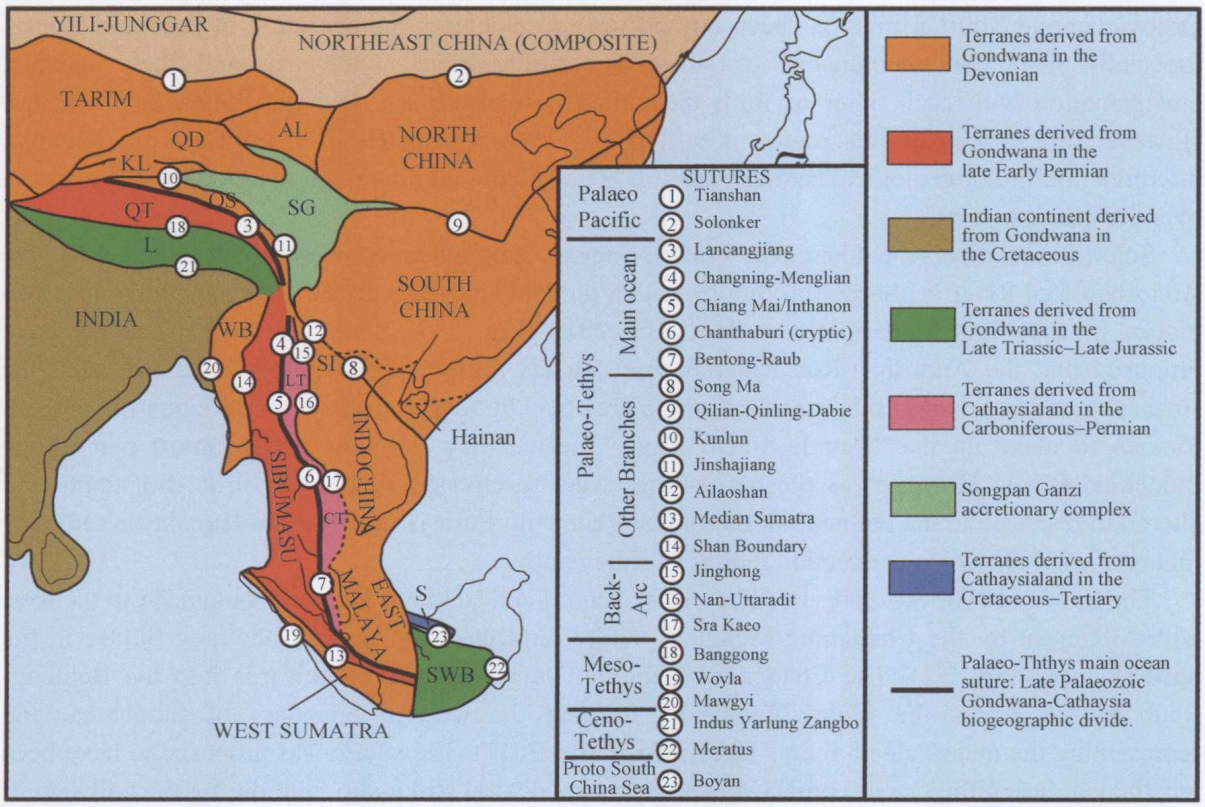

Fig. 2.1 Distribution of principal continental blocks, arc terranes and sutures of eastern Asia (after Metcalfe, 2011). WB. West Burma; SWB. SW Borneo block; S. Semitau block; L. Lhasa block; QT. Qiangtang block; QS. Qamdo-Simao block; SI. Simao block; SG. Songpan Ganzi accretionary complex; KL. Kunlun block; QD. Qaidam block; AL. Ala Shan block; LT. Linchang arc terrane; CT. Chanthaburi arc terrane.

2.1 Eastern Yunnan

Eastern Yunnan, which is bounded with central Yunnan (Indochina) by the Ailaoshan-Red River (or Ailaoshan-Song Ma) Suture, belonged to the South China Block (or the Yangtze Block) in the early Palaeozoic (Metcalfe, 2011; Fig. 2.1).

The Ordovician and Silurian of most of northeastern Yunnan (the northern part of the Zhaotong Region) resembles that of the Upper Yangtze Region, South China. In the Kunming-Qujing Region, however, the Ordovician and Silurian are characterized by thick successions of largely coarse clastic deposits intercalated with a few carbonates, and represent a shallow-water marine environment of largely inshore or nearshore facies (Luo, 1993; Zhang Ju *et al.*, 2013). The clastic material came from the nearby Kangdian Oldland (geographically subaerial) that had formed since the Jinning Orogeny at ca. 1000 Ma, and was located at the western margin of the South China Block throughout the Palaeozoic. Accordingly, Palaeozoic deposits are largely absent to the west of the Kunming-Qujing Region (Fig. 2.2); there is a large gap spanning the Late Ordovician to Early Devonian in the Kunming area, and a hiatus between the mid Cambrian and the Wenlock (Silurian) in the Qujing area (Fig. 2.3). Ludlow to Pridoli strata accumulated only within a narrow, elongated bay, called Qujing Bay (Huang *et al.*, 2011). Even in the relatively distal Qiaojia-Zhaotong Region, the Ordovician and Silurian strata are interrupted by frequent gaps, and the successions are rather thick and contain abundant coarse clastic material (Fig. 2.3).

In the Wenshan Region, southeastern Yunnan, Ordovician strata are present but with poorly-exposed outcrops, whereas Silurian strata are absent. Palaeontological and palaeobiogeographical studies on some of the available fossils from the region have suggested a close relationship between the region and northern Viet Nam (Luo *et al.*, 2014).

2.2 Central and southern Yunnan

In the early Palaeozoic, central and southern Yunnan formed the northern part of the Indochina Block. The area is bounded to the east by the Ailaoshan-Song Ma Suture, which extends southeastwards from northern Yunnan into northern Viet Nam (Xu *et al.*, 2011; Metcalfe, 2011), and is bounded to the west by the Changning-Menglian suture zone, which continues southwards into the Bentong-Raub Suture across the Malay Peninsula (Liu *et al.*, 1993; Metcalfe, 1998, 2011) (Fig. 2.1).

The Ordovician and Silurian outcrops of this block are mostly restricted to the Dali, Shangri La-Ninglang and Jinping-Lüchun regions, and close to the Ailaoshan-Song Ma Suture. They are completely absent in the vast western part, which is covered by thick terrestrial red deposits of Mesozoic age (Fig. 2.3). Among the three regions, the Ordovician stratigraphy and palaeontology in Dali have been relatively well-documented based on the abundant fossils of many groups from the Haidong section at the east bank of Erhai Lake, whereas the Silurian successions and faunas are poorly known. The Ordovician successions in this region are largely composed of clastic rocks, and contain abundant fossils, representing a shallow-water environment corresponding to Benthic Assemblages BA1 to BA3. Based on the trilobites from the Hsiangyang Formation, four biofacies have been differentiated, indicating an environmental gradient from intertidal to deep outer shelf (Zhou *et al.*, 1998). The trilobites include typical representatives of Gondwanan cold-water faunas, and suggest a close biogeographic relationship with south-central Europe, the Yangtze Region of South China, and Tarim (Zhou *et al.*, 1998, 2009).

There are also some outcrops of Ordovician and possibly Silurian in the Shangri La-Ninglang Region, northern Yunnan (Leng, 1983; Zhou *et al.*, 2001), but these strata are poorly biostratigraphically constrained and the faunas are poorly known, largely because of rarity of fossils, the light metamorphism and the obvious deformation of the rocks. Generally the Ordovician successions resemble those of the Dali Region. The Lower and Middle Ordovician rocks are characterized by thick (>2000 metres) sandstones and siltstones, commonly with light metamorphism and rare trilobites and brachiopods; the Upper Ordovician strata consist of

metamorphic dolomites and micritic limestones. The Ordovician succession is disconformably overlain by Devonian or Carboniferous rocks. The presence of Silurian strata in the area is doubtful and has yet to be confirmed. The tectonic attributes and the biogeographic affinities of the region with South China and Indochina have been controversial: some scholars regarded the region as part of South China (in this case the west boundary of South China would be placed at the Jinshajiang Fault; Fig. 2.1), whereas others have though the region to be the northernmost extension of Indochina based on palaeontological evidence. From this region, a trilobite fauna similar to, but less diverse than, that of the Hsiangyang Formation in the Dali Region has been reported (Zhou *et al.*, 2001), suggesting that the region is likely to have formed part of the Indochina Block (Fig. 2.2). The region was in a shallow-water environment and in the vicinity of adjacent subaerial regions (Kangdian Oldland?) in the Ordovician, and it is possible that South China and Indochina were rather close to each other at that time, without significant separation.

The presence of Ordovician and Silurian rocks in the Lüchun-Jinping Region has been confirmed by the occurrences of Darriwilian and Telychian graptolites, Llandovery conodonts and

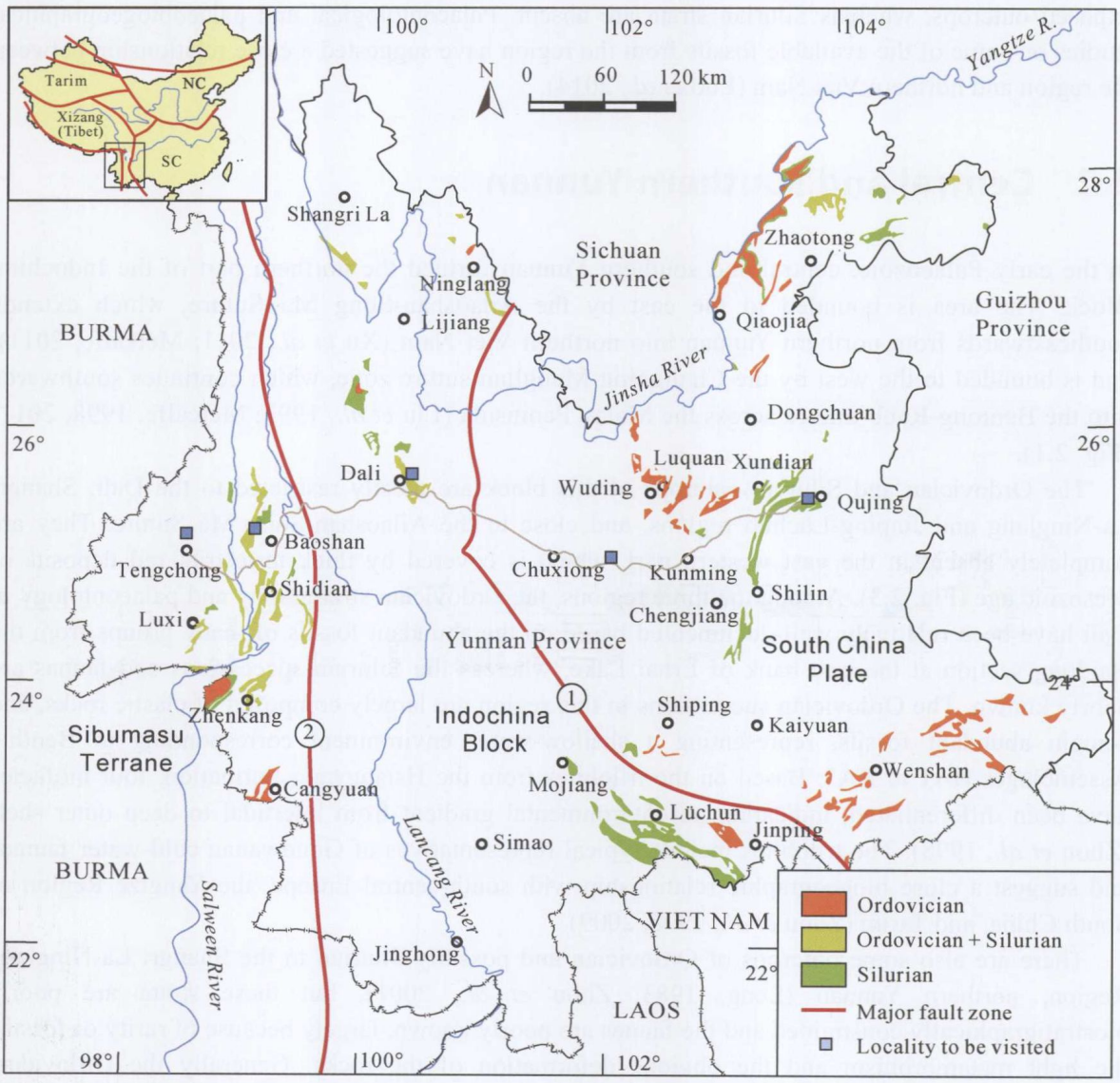

Fig. 2.2 Ordovician and Silurian outcrops in Yunnan Province. ①Ailaoshan-Red River (Song Ma) Suture; ②Changning-Menglian Suture.

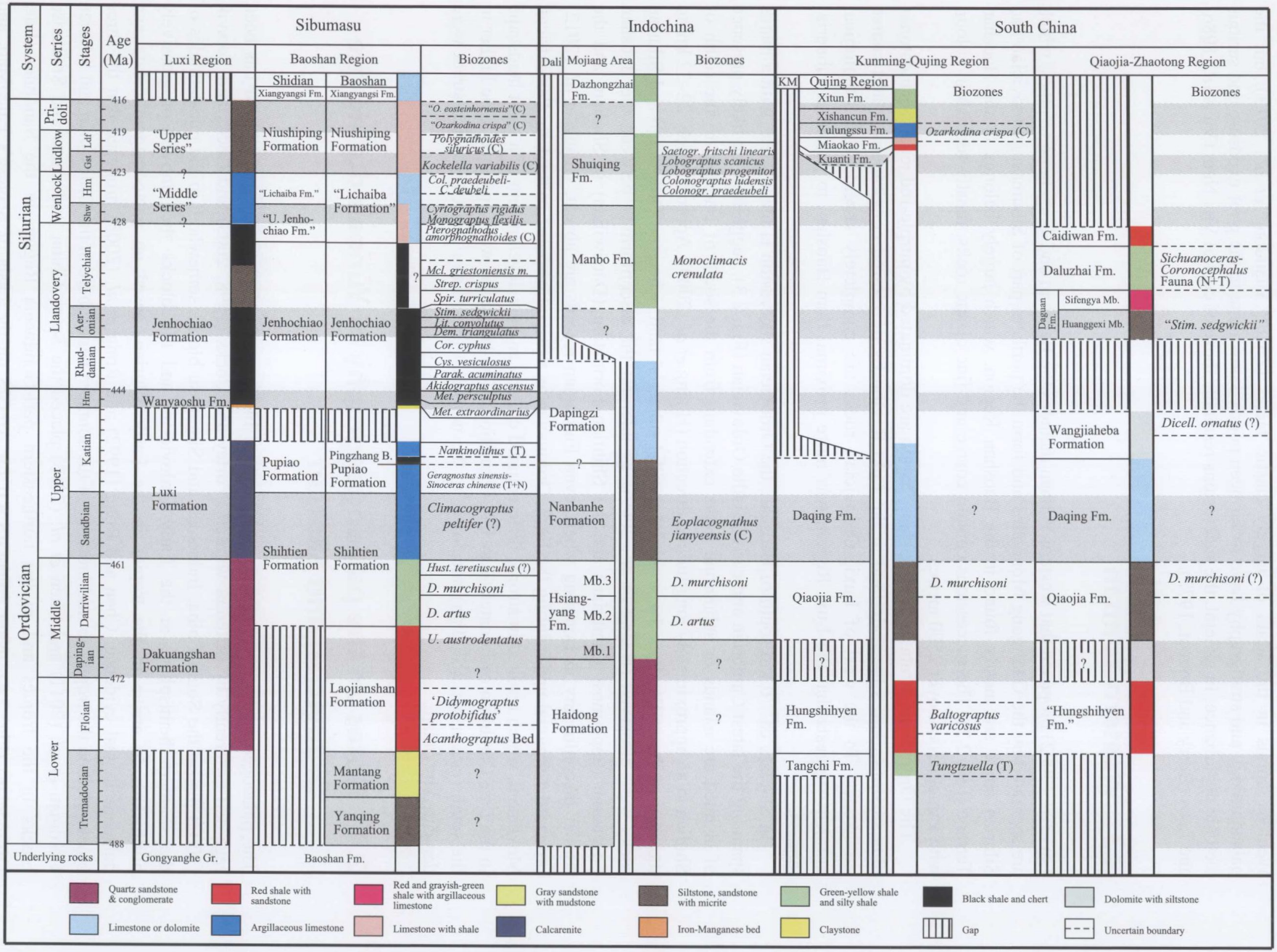

Fig. 2.3 Lithostratigraphy and biostratigraphy of the Ordovician and Silurian successions of Yunnan Province, southwest China. C, conodont; N, nautiloid; T, trilobite.

Wenlock corals in the strata of largely clastic facies (Zhang Yuandong *et al.*, 2013), but the palaeontology and stratigraphy have so far been poorly known due to the poor exposure and serious tectonic disturbance. In general, the successions resemble those of central Viet Nam (Vu *et al.*, 1986), and Laos (Berry and Boucot, 1972).

2.3 Western Yunnan

Liu *et al.* (2002) proposed that western Yunnan includes the Baoshan and Tengchong terranes, which are separated by the Gaoligong Mountains and form the northern part of Sibumasu. Ordovician and Silurian strata are mostly found in the Baoshan Region, which largely belongs to the Baoshan Terrane (Fig. 2.2). The successions contain coarse and fine clastic rocks, mostly reddish in colour, with a thickness of over 2500 metres.

The Ordovician strata in the Baoshan Region are dominated by purple-red, coarse sandstones plus siltstones and silty shale, and in the Luxi Region by purple-red conglomerates and coarse sandstones. To the west of Luxi, Ordovician rocks are completely absent. This lithological gradient suggests that the Luxi Region was more proximal than Baoshan to potential subaerial land(s).

In Shidian, ca. 70 km south of Baoshan, the Ordovician succession is incomplete, with a hiatus spanning the latest Cambrian and early Middle Ordovician (Fig. 2.3), suggesting the likely presence of chained arc islands or submarine highs extending from the south of Baoshan to the south of Shidian in an approximately longitudinal direction (Huang *et al.*, 2009). Approximately 22–32 km to the west of these islands is the proposed parallel subaerial land, where no Ordovician and Silurian rocks were preserved (Huang *et al.*, 2009). To interpret the disconformity between the Baoshan Formation (uppermost Cambrian) and the Shihtien Formation (Darriwilian) in Shidian, and the similar disconformity in Longling where even Furongian records are absent, Huang *et al.* (2012) proposed a regional uplift during the Early Ordovician as a distant response to the Late Pan-African Movement, which resulted in strong, differentiated erosion and the development of a karst landscape in the Late Cambrian carbonates (Baoshan Formation). The landscape was suggested to be higher in the southwestern part (Shidian) and lower in the northeast (Baoshan), and Ordovician strata were deposited by onlap.

2.4 Notes on the palaeogeography of Yunnan during the Ordovician and Silurian

The palaeogeographic reconstruction of the three blocks in the Ordovician and Silurian has been regarded differently by different workers. Fortey and Cocks (1998, 2003) and Cocks and Torsvik (2002) placed the South China, Indochina and Sibumasu blocks somewhere in the mid-latitudes of the southern hemisphere in the Early Ordovician, and the blocks then moved progressively northwards to arrive in the tropics in the Early Silurian, based on palaeomagnetic data and palaeontological evidence. Chen and Rong (1992) and Rong *et al.* (2003) proposed that the three blocks were in the tropics to mid-latitudes of the southern hemisphere in the Ordovician and Silurian. Goldman *et al.* (2011) and Chen *et al.* (2013) placed the South China, Indochina and Sibumasu blocks in the tropics and in the northeastern peri-Gondwana Region in the Sandbian (Late Ordovician) (Fig. 2.4), using PaleoGIS 4.0 for ArcGIS on the basis of Scotese's PaleoMap, and suggested that the blocks moved slightly southwards from then to the earliest Silurian.