Carbonate sedimentation in a starved pull-apart basin,
Middle to Late Devonian, southern Guilin, South China

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ABSTRACT

Geological mapping and sedimentological investigations in the Guilin region, South China, have revealed a spindle- to rhomb-shaped basin filled with Devonian shallow- to deep-water carbonates. This Yangshuo Basin is interpreted as a pull-apart basin created through secondary, synthetic strike-slip faulting induced by major NNE–SSW-trending, sinistral strike-slip fault zones. These fault zones were initially reactivated along intracontinental basement faults in the course of northward migration of the South China continent. The nearly N–S-trending margins of the Yangshuo Basin, approximately coinciding with the strike of regional fault zones, were related to the master strike-slip faults; the NW–SE-trending margins were related to parallel, oblique-slip extensional faults. Nine depositional sequences recognized in Givetian through Frasnian strata can be grouped into three sequence sets (Sequences 1–2, 3–5 and 6–9), reflecting three major phases of basin evolution.

During basin nucleation, most basin margins were dominated by stromatoporoid biostromes and bioherms, upon a low-gradient shelf. Only at the steep, fault-controlled, eastern margin were thick stromatoporoid reefs developed. The subsequent progressive offset and pull-apart of the master strike-slip faults during the late Givetian intensified the differential subsidence and produced a spindle-shaped basin. The accelerated subsidence of the basin centre led to sediment starvation, reduced current circulation and increased environmental stress, leading to the extensive development of microbial buildups on platform margins and laminites in the basin centre. Stromatoporoid reefs only survived along the windward, eastern margin for a short time. The architectures of the basin margins varied from aggradation (or slightly backstepping) in windward positions (eastern and northern margins) to moderate progradation in leeward positions. A relay ramp was present in the north-west corner between the northern oblique fault zone and the proximal part of the western master fault. In the latest Givetian (corresponding to the top of Sequence 5), a sudden subsidence of the basin induced by further offset of the strike-slip faults was accompanied by the rapid uplift of surrounding carbonate platforms, causing considerable platform-margin collapse, slope erosion, basin deepening and the demise of the microbialites. Afterwards, stromatoporoid reefs were only locally restored on topographic highs along the windward margin. However, a subsequent, more intense basin subsidence in the early Frasnian (top of Sequence 6), which was accompanied by a further sharp uplift of platforms, caused more profound slope erosion and platform backstepping. Poor circulation and oxygen-depleted waters in the now much deeper basin centre led to the deposition of chert, with silica supplied by hydrothermal fluids through deep-seated faults. Two 'subdeeps' were diagonally arranged in the distal parts of the master faults, and the relay ramp was destroyed. At this time, all basin margins except the western one evolved into erosional types with gullies through which granular platform sediments were transported by gravity flows to the basin. This situation persisted into the latest Frasnian.

This case history shows that the carbonate platform architecture and evolution in a pull-apart basin were not only strongly controlled by the tectonic activity, but also influenced by the oceanographic setting (i.e. windward vs. leeward) and environmental factors.
INTRODUCTION
Numerous studies have documented sedimentary basins tectonically controlled by strike-slip fault systems in the last two decades (e.g. Bluck, 1980; Howell et al., 1988; Steel & Gloppen, 1980; Zhang et al., 1989; Nilsen & Sylvester, 1995). They occur within various geodynamic environments, both in intraplate and interplate settings (Reading, 1980; Mann et al., 1983; Christie-Blick & Biddle, 1985). A pull-apart basin is defined as a basin formed by local crustal extension along a strike-slip fault zone (Rodgers, 1980; Mann et al., 1983; Christie-Blick & Biddle, 1985; Sylvester, 1988), and several modelling studies have addressed the progressive evolution of pull-apart basins and their syntectonic sedimentation (e.g. Rodgers, 1980; McClay & Dooley, 1995; Dooley & McClay, 1997; Basile & Brun, 1999; Sims et al., 1999).

Pull-apart basins are usually depicted as rhomb-shaped depressions bounded by two vertical, offset strike-slip faults that are linked by two steep, parallel, oblique-slip extensional faults (e.g. Aydin & Nur, 1985; Christie-Blick & Biddle, 1985). However, the actual basin geometry is more variable in nature, mainly dependent on the increasing offset (or overlap) and the initial separation of the strike-slip faults (master faults) (e.g. Rodgers, 1980; Mann et al., 1983), and also on the rheology of the basement (Laville, 1988; Dooley & McClay, 1997). These basins are not only characterized by associations of strike-slip faults and normal faults, but they also display block tilting and block rotation around a vertical axis. Thus they share some features common to extensional basins, as documented by many authors (e.g. Barr, 1987, 1991; Leeder & Gawthorpe, 1987; Jackson et al., 1988; Yielding, 1990; Gawthorpe et al., 1994; Ravanas & Steel, 1998).

Many examples of carbonate sedimentation within extensional tectonic settings have been documented from the geological record (Eberli, 1987; Burchette, 1988; Cocozza & Gandin, 1990; Santantonio, 1993, 1994; Picard et al., 1994; Rosales et al., 1994; Masse et al., 1997; Bosence et al., 1998; Rosales, 1999; Wilson, 1999; Wilson et al., 2000). However, relatively little attention has been paid to carbonate sedimentation in the strike-slip setting; examples cited include the Lower Cretaceous of northern Spain (García-Mondejar, 1989, 1990; Agirrezabala & García-Mondejar, 1992; Rosales et al., 1994; García-Mondejar et al., 1996; Rosales, 1999), and the Devonian of southern Hunan, South China (Jiang, 1989, 1990). Recently, Massaforno & Eberli (1999) presented an example of strike-slip tectonics affecting the southern Great Bahama Bank based on the interpretation of seismic data.

In this paper, an example is presented of a carbonate-dominated Devonian interplatform basin related to strike-slip faulting in the Guilin area, South China. This basin was formed in the Middle Devonian (Givetian) and persisted into the Carboniferous. Special emphasis is placed on the strata of the upper Middle Devonian (Givetian) to lower Upper Devonian (Frasnian), i.e. from the pre-Devonian stage through pull-apart basin formation. This study investigates the nature and patterns of the depositional sequences along the fault-controlled basin margins, in the basin and on the surrounding platforms. This case history illustrates how fault-controlled subsidence/uplift, carbonate production, eustasy and oceanographic setting interacted to generate specific stratigraphic geometries, and vertical and lateral facies organizations in a strike-slip setting.

GEOLOGICAL SETTING AND STRATIGRAPHY
Devonian carbonates crop out extensively in the area from Yangshuo to Guilin, structurally within an Indosinian-deformed (Late Triassic to Jurassic) synclinorium that trends approximately N–S to NNE–SSW, and is flanked by anticlinoria composed of Lower and Middle Devonian clastics with Cambrian cores (Fig. 1). Other major structural features of the area are N–S- to NNE–SSW-oriented faults. The structural patterns were mainly formed during the Indosinian orogenic stage, but were then modified by later tectonic movements. Shallow-to-deep-water carbonates are distributed in two spindle- to rhomb-shaped areas, to the north of Yangshuo and to the east of Guilin (Fig. 1); the focus here will be on sedimentation in the Yangshuo area (see inset rhomb in Fig. 1).

Devonian strata consist of a succession of Lower and upper Middle Devonian clastics, and upper Middle to Upper Devonian carbonates, locally containing organic buildups. The strata involved in this study mainly include the Tangjiawan, Rongxian, Mintang, Liujiang, Gubi and Wuzhishan Formations. Their temporal and spatial distributions are illustrated in Fig. 2. The Tangjiawan Formation is dominated by dolomitized biostrome and reefal facies, and constitutes the first carbonate succession overlying the clastic deposits (Xindu Formation). The Rongxian Formation represents open-platform and platform-margin facies, ranging in age from the Frasnian to Famennian. The Mintang Formation is characterized by the interfingering of microbialites and deep-water carbonates, with minor megabrecias, and ranges from Givetian to early Frasnian. The Liujiang Formation is characterized by starved-basin deposits of siliceous rocks with minor tentaculitid cherty limestones. The Gubi Formation (mainly Frasnian) is composed of megabrecias and calciturbidites at the basin margin, and calciturbidites and pelagic limestones in the basin centre. The Wuzhishan Formation represents the distal slope and interplatform basin deposits dominated by pelagic nodular limestones with minor calciturbidites, mainly of Famennian age.

The deep-water strata are distributed north of Yangshuo City in a rhomb-shaped area about 12 km wide and 25 km long (see the inset polygon in Fig. 1), with a northern boundary (trending NW–SE) roughly
Fig. 1. Simplified geological map of the area south of Guilin City. The rhomb-shaped area of Devonian shallow- to deep-water deposits to the north of Yangshuo is the subject of this paper (within the inset polygon). The location of cross-sections I and II is shown in Figs 9(I) and 10(II). D1, Lower Devonian; D2, Middle Devonian; D3, Upper Devonian; C1, Lower Carboniferous.

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from Wuguijing via Shawan and Wulibei to Nashan, a southern margin from Yangshuo to Baisha, a western margin (trending nearly N–S) from Baisha to Nashan, and an eastern margin from east of Yangshuo northwards to Wuguijing.

DEPOSITIONAL FACIES

Basin-margin facies

In this paper, ‘basin margin’ refers to the narrow belt from the platform margins with reefs and shoals, basinwards to the toe-of-slope, approximately corresponding to the conventional slope environment. Main subfacies include: Organic buildups, Shoal/bank deposits and Gravity-flow deposits.

Organic buildups

Two main types of organic buildup are identified in Givetian and Frasnian strata: stromatoporoid buildups and microbial buildups.

Stromatoporoid buildups are extensively distributed in the Tangjiawan Formation, but only locally in the Rongxian Formation (lower Frasnian). Those in the Tangjiawan Formation are generally strongly dolomitized. The Rongxian buildups occur along the northern margin, and are deduced from the composition of clasts within toe-of-slope breccias, since the original buildup horizon is not exposed. These buildups are commonly associated with *Amphipora* floatstones/packstones and microbial laminites. Ecologically, they are usually stromatoporoid reefs, biostromes and bioherms. Three sublithofacies of the buildups are recognized: (1) stromatoporoid bindstone/bafflestone, (2) stromatoporoid floatstone/rudstone and (3) platy/tabular stromatoporoid floatstone/wackestone. Detailed facies descriptions are given in Chen *et al.* (2001). There are variations in the facies associations between the different margins.

Stromatoporoid reefs only occur along the eastern margin (e.g. near Yangshuo, see Fig. 1 for location). These buildups are up to 200 m thick and 200–400 m wide (Fig. 3), and commonly have a domal shape. They are characterized mainly by stromatoporoid bindstones/bafflestones, and rarely by framestones. Bulbous and domal stromatoporoids predominate, reaching several 10s of centimetres in height, with minor rugose corals, brachiopods, *Stachyodes* and *Amphipora*. Stromatoporoids commonly grew through self-encrustation with minor microbial binding, and mostly kept their in-situ growth position, apparently producing a wave-resistant structure. These buildup facies commonly rest on the platy/tabular

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**Fig. 2.** Stratigraphic relationships and nomenclature for the Givetian and Frasnian in the Yangshuo Basin. The conodont zonation is based on the data of Zhong *et al.* (1992). The previous scheme of conodont zonation is also given.

**Fig. 3.** Lithological log of eastern margin deposits, cropping out along the highway from Yangshuo to Hongjingshan and dipping north-westward (see southern boundary of inset polygon in Fig. 1 for the location). Note the three major horizons (A, B, C) of reef formation along this margin. LST, lowstand deposit; TST, transgressive deposit; HST, highstand deposit. B, boundstone; Co, conglomerate; F, floatstone; G, grainstone; M, lime mudstone; P, packstone; R, rudstone; W, wackestone.
Rothpletzella and minor Sphaerocodium in height) and so are classed as stromatoporoid bioherms. Stromatoporoid biostromes and bioherms are widely distributed along other margins, generally stratiform and rarely dome-shaped, reaching 40 m in thickness. They are dominated by stromatoporoid floatstones/rudstones with abundant bulbous and hemispherical stromatoporoids reaching 70 cm in size. Individual stromatoporoids are commonly overturned and bored, and only a few have remained in their growth position. The matrix is mainly composed of bioturbated skeletal (dolo-) wackestones/mudstones containing Amphipora, Stachyodes, gastropods, brachiopods, calcispheres, foraminifera, rugose and thammnopoid corals, rare bryozoans and crinoids. The absence of wave-resistant structures suggests they grew in relatively low-energy conditions. The buildups on the western margin show similar features to those along the eastern margin, but they are thinner (only 10s of metres in height) and so are classed as stromatoporoid bioherms.

Microbial buildups are abundant in the upper Givetian, and two subtypes, massive microbial boundstone and bedded stromatolite boundstone, are recognized on the basis of their internal structure. Massive microbial boundstones, locally thick-bedded, consist mainly of reef-forming cyanobacterial colonies such as Renalis, Epiphyton and thrombolitic microbes, and minor Rothpletzella (previously referred to as Sphaerocodium) and Wetheredella. Renalis is common in the core of buildups and decreases in abundance towards the fore-reef clinofoms. Other skeletal colonies include Amphipora and stromatoporoids, and there are also gastropods, brachiopods and rare ostracods. Bindstones and bafflestones dominate, with thrombolites locally well developed, as at Nashan (see Fig. 9). Stromatactis and irregular cavities filled with submarine cements are common in the core of buildups and also decrease in abundance towards fore-reef clinofoms. The microbial buildups initiated on the steep platform margins and mostly formed an aggradational (or stationary) to backstepping platform margin (Fig. 4), with minor pulses of progradation, and generally gave rise to fore-reef clinofoms with original dips of 30–45°. Our measurements revealed an increasing-upward trend in clinofom declivity, reflecting accelerated basin subsidence. These features suggest that the buildups possessed moderate wave-resistance, and so ecologically could be termed microbial reefs. These microbial buildups bound and trapped most of the grains and lime mud exported from the platforms, and helped to maintain the steep slopes from collapse. Similar relationships have been documented by Burchette (1988), Drachert & Dullo (1989), Kenter (1990) and Purser & Plaziat (1998).

The microbial buildups along the western margin (e.g. at Bao’an), and possibly along the southern margin too, are generally more sheet-like and domal in character, and show no obvious vertical accretion. They are more micritic in composition, and are ecologically considered as microbial bioherms.

Bedded stromatolite boundstones are not as abundant as the massive microbial boundstones, and locally pass upwards into them. Stromatolites consist mainly of laterally linked hemispherical (L.L.H) laminae reaching several 10s of centimetres in height, and rare stacked hemispherical (SH) laminae. The laminae consist of intergrown (mono-specific or hetero-specific) cyanobacterial colonies such as the beard-like Rivularia (common at Nashan), Epiphyton, Wetheredella and Rothpletzella. Macrofossils are rare, with only gastropods, ostracods and Amphipora. This kind of microbial buildup is interpreted to have formed in a deeper-water environment (e.g. the mid-upper slope) and is similar to those in the Canning Basin (Playford et al., 1976; George, 1999), where they grew at depths of 100–200 m.

**Shoal/bank deposits**

Three common shoal facies are recognized: peloidal–oncoclad grainstone/packstone, ooidal–peloidal grainstone/packstone and coquina. They occur in upper Givetian and Frasnian strata. Peloidal–oncoclad grainstones/packstones are mostly present along the western margin (e.g. at Bao’an), and the transitional area between the western and northern margins (e.g. at Nashan, see Fig. 9). The deposits are characterized by oval and oblate oncoids with minor peloids and shells. Oncoids range from several mm to 10s of cm in size, and show concentric and conical laminae (most likely Ortonella) encrusting a nucleus. Thin sharp-based, upward-finining units (up to 20 cm thick) with local shell concentrations are common. Basinwards, oncoclad floatstones/wackestones are developed. These deposits are thought to have formed in marginal shoals/banks influenced by waves and storms.

Ooidal-peloidal grainstones/packstones are common along the western margin (i.e. at Bao’an), and occur locally in lower Frasnian strata along the northern margin (e.g. at Zhongnan). They are usually present above the oncoidal facies. Compositonally, peloids usually predominate over ooids. Minor erosion surfaces are common, but current-related structures such as cross-lamination and ripples are rare. Locally a few fenestral fabrics are present, particularly in the upper part of the deposits, suggesting relatively shallow, low-energy conditions.

Coquinas are commonly present in the Mintang Formation (i.e. at Wulibei and Shihedong, see Fig. 1 for location), and are thin- to thick-bedded. The shells are mainly brachiopods and ostracods with minor gastropods; they are commonly disarticulated and abraded, and have parallel-preferred orientations. Other grains include microbial lumps, intraclasts, peloids and skeletal fragments. The coquinas are found either below microbial buildups (see Fig. 9) or as thin beds intercalated with
basinal facies. These deposits were shell banks in front of buildups, and storm lags in deeper water.

**Gravity-flow deposits**

Common facies include: calciturbidite, pebble conglomerate and breccia and megabreccia.

Calciturbidites are the most common facies in Frasnian strata, and form the middle and lower slope successions. They commonly interfinger with basinal facies (e.g. nodular limestones) at the toe-of-slope (Fig. 9), and locally contain chert nodules (e.g. in the lower part of the Gubi Formation). Individual beds generally are platy to thin-bedded, ranging from several cm up to about 1 m in thickness, and commonly display normal grading with minor inverse grading, and incomplete Bouma sequences (Fig. 5A). They consist of peloidal or ooidal–peloidal grainstones/packstones with minor intraclasts, oncoids and skeletal fragments. Generally, the thicker the bed, the coarser the grain size, and vice versa. Deformation structures including translational slides, minor rotational slides (slumps) (Fig. 5B) and rare intraformational truncation surfaces suggest downslope creep and glide. Erosional scours and flute marks occur locally. Thickening- and coarsening-upward cycles are common in calciturbidite successions, and locally they pass up into pebble conglomerates and megabreccias. Increasing energy, shallowing and increasing sediment export off platforms or slope instability could have been responsible. As the sediment loads on the slope progressively accumulated and exceeded the shear strength, slope failure would have occurred, causing substantial sliding and slope erosion followed by debris flows.

Pebble conglomerates are mainly composed of tabular clasts, rarely mixed with boulder-sized clasts. Individual clast beds range from a few cm to several m in thickness. Tabular pebbles consist of lime mudstone or calciturbidite. The clasts are generally mud-supported, locally clast-supported, and show subparallel orientation, and locally upslope imbrication. The basal and top surfaces of
the deposits are nearly planar. The conglomerates locally grade upwards into calciturbidites. The pebble conglomerates are thought to have been largely transported and deposited by debris flows (cf. Mullins & Cook, 1986), which may have been capped by viscous, high-density turbidite flows.

Breccias and megabreccias commonly occur on the lower slope. The clasts range in size from 10s of cm up to a few m (olistoliths), and commonly are mixed with pebble conglomerates (Fig. 6A,B). These beds commonly commence with a basal erosion surface (Fig. 6B), then grade upward into or alternate with pebbly conglomerates and coarse calciturbidites. They are finally overlain by finer calciturbidites and/or pelagic limestones. The composition of the breccias is variable, depending on the nature of the upper slope and platform margin, and two subtypes can been recognized: fore-reef breccias and slope breccias.

Fore-reef breccias are mainly related to marginal buildups, and are present in the Mintang Formation, the lower Liujiang Formation (one horizon) and the top of the Gubi Formation (locally). The breccia beds range from a few m up to 20 m thick. Breccias are mostly made of microbial and stromatolite boundstone, particularly along the northern margin; those in the lower Liujiang Formation are made of stromatoporoid boundstone. They are generally disorganized, poorly sorted and clast-supported, and show no obvious clast grading. The breccia beds are lens-shaped with planar basal surfaces and wavy upper surfaces, and pinch out into the toe-of-slope and basinal deposits. Some breccia units grade laterally, basinwards, into relatively fine-grained stromatoporoid rudstone (e.g. in the Mintang Formation at Yangshuo, Fig. 3).

Slope breccias are mostly present in Frasnian strata. The lithology of the clasts is mainly hemipelagic lime mudstone and calciturbidite packstone, locally boundstone and rarely skeletal grainstone. The clasts are generally poorly organized, mud- or clast-supported, and exhibit crude normal grading. Inverse grading is locally present in the lower part of the breccia deposits, especially at localities close to the platform margin. In such a case, the breccia successions commence with slump-folded calciturbidites, which are remolded into tabular clasts upwards and overlain by coarser breccias.

Fig. 5. (A) Outcrop photo of an incomplete Bouma sequence (Tₐ-b) of an individual calciturbidite bed with a sharp basal surface overlain by tabular lime mudstone clasts and weak parallel lamination in the upper part. Gubi Formation, Fube. (B) Translational folds in thin-beded calciturbidites, overlain by megabreccias. Hammer for scale (37 cm). Gubi Formation, Shihedong.
and megabreccias (Fig. 6A). The breccia beds generally rest on the mildly folded or overfolded underlying horizons with concave-upward basal surfaces (locally slide scars) (see Fig. 11) and have hummocky upper surfaces, overlain by thin-bedded calciturbidites. They are believed to have been transported predominantly by debris flows (cf. Cook et al., 1972; Cook & Mullins, 1983), which were probably initiated through slope failure in view of the slump-deformed horizons below the breccias and megabreccias.

These breccias and megabreccias are conventionally interpreted as having been produced through platform collapse or slope failure, and trigger mechanisms include tectonic-controlled seismic activity, sediment liquefaction, storms, gravitational instability and relative sea-level fall (e.g. Mullins et al., 1986, 1991; Hine et al., 1992; Harris, 1994; Spence & Tucker, 1997).

**Basinal facies**

Argillaceous skeletal wackestones/mudstones are present in the Tangjiawan Formation. They commonly occur below stromatoporoid buildups and are intercalated with thin argillaceous beds. They are locally nodular bedded. Biota are characterized by a highly diversified open-marine fauna with disarticulated brachiopods, echinoids, crinoids, rugose corals, bryozoans and rare tentaculitids. The skeletal fragments are commonly concentrated in thin layers and lenses. These deposits formed in a low-energy, open-marine, moderately deep subtidal environment below fair-weather wave base, influenced by episodic storm events (cf. Markello & Read, 1981).

Thin-bedded mudstones/wackestones are present in the Mintang Formation. They generally have a fine lamination, a high organic content, and locally argillaceous partings. Biota are common with tentaculitids, brachiopods, gastropods and ostracods, but the benthic fauna decreases upwards in abundance; bioturbation is rare with only fine tubular burrows. Thin concentrations of shells are intercalated locally (mainly in the lower part of the Mintang Formation). Vertical successions commonly exhibit upward-thickening cycles. These deposits are thought to have formed in deep subtidal environments...
with poor circulation, below fair-weather wave base. Water depths increased and the basin floor became more dysoxic–anoxic later, as indicated by the high organic content, fine lamination and sparse bioturbation.

Microbial laminites are present in the Mintang Formation and normally occur above the thin-bedded mudstones/wackestones to form an upward-shallowing cycle. They are characterized by wavy to planar laminae (Fig. 7A), locally intercalated with nodular microbialites (e.g. at Yangshuo). The laminae are created by intergrown (mono-specific or hetero-specific) cyanobacterial colonies such as *Angulocellularia* (or *Epiphyton*) and *Rothpletzella* (cf. Riding, 1991) (Fig. 7B) and *Ursoscopulus* (cf. Weller, 1995) in which benthic macrofossils are absent. Slump-deformed laminae can be seen locally (e.g. at Yangshuo). The nodular microbialites commonly have a fitted fabric with argillaceous seams. Stromatactis occurs locally, but microstromatactis is common. The predominance of microbial micrites, absence of grains (e.g. peloids, which are common in shallow-water microbial laminites, Chen et al., 2001) and total lack of evidence of subaerial exposure indicate deep subtidal, quiet-water conditions with little storm activity.

Cherty mudstones/wackestones are present near the base of the Liujiang Formation (lower Frasnian), and pass up into siliceous deposits. They are generally platy to thin-bedded, and intercalated with chert nodules. They are locally interbedded with siliceous shales and bedded cherts (e.g. at Shawan, see Fig. 9), showing an upward increase in the amount of chert. Individual beds range from a few cm up to 30 cm in thickness, and commonly are finely laminated. Biota are dominated by the planktic tentaculitids with minor planktic ostracods and calcisponges, and rare radiolarians. The deposits are rich in organic matter. In vertical succession, upward-thickening cycles in bed thickness can also be recognized. They are believed to have been deposited in the basin at a time of deep and oxygen-deficient waters with poor circulation. The long residence time of bottom waters may have allowed them to reach saturation with respect to opal, resulting in accumulations of biogenic and authigenic silica (cf. Fischer & Arthur, 1977).

Siliceous facies are present in the upper part of the Liujiang Formation, and range from 15 to 40 m thick. Finely laminated, banded cherts predominate the basal succession, grading upwards into siliceous shales with
manganese nodules. Biota are mainly planktic tentaculitids and rare radiolarians. These siliceous deposits are thought to have been deposited in the basin during a long-term highstand of relative sea-level, when nearly stagnant bottom waters existed with a low sedimentation rate, and no carbonate influx. It is probable that biogenic silica only made a minor contribution to the silica source, and that most of the silica was supplied by hydrothermal fluids rising up through deep-seated fault zones. This assumption is based on the evidence of volcanic ash partings in the cherts and synchronous extensive volcanic activity (e.g. trachytic lavas and intrusive sheets and sills) elsewhere in Guangxi (Wu et al., 1987, 1997; Zhong et al., 1992). The depth of deposition was not as deep as their modern oceanic analogues (e.g. c. 4500 m), and based on the basin and platform geometry would have been in the range of 500–700 m.

Nodular limestones are mainly present in the Gubi Formation (upper Frasnian), and interfinger with slope deposits that mostly consist of calciturbidites. They are mainly greenish grey, rarely red. The nodular argillaceous lime mudstones locally exhibit a brecciated appearance. Biota are mainly planktic tentaculitids and a rare benthic fauna, but bioturbation is locally intensive. They are thought to have been deposited in a deep, quiet environment with weakly oxygenated bottom water, periodically disturbed by weak turbidity currents. Analogous examples occur in the Devonian of Western Europe (Tucker, 1973, 1974; Vai, 1980).

SEQUENCE DEVELOPMENT AND BASIN EVOLUTION

Sequence recognition

Following the Exxon model (cf. Van Wagoner et al., 1988), sequence boundaries are the key to sequence identification, and they will have different appearances at different localities and times in a tectonically active setting. In the lower Givetian, approximately corresponding to the interval of the Tangjiawan Formation, the transition from platforms to basin is mostly gradual; sequence boundaries generally occur at the top of stromatoporoid buildups, although there is usually no indication of subaerial exposure (e.g. Fig. 3). From the middle Givetian time onward, the basin architecture changed dramatically; basin margins became steep, especially on the windward eastern side. On the upper slope close to the platform margin, organic buildups and shoal facies were deposited, and sequence boundaries are again placed at the top of these units, but here exposure dissolution features only occur locally. The sequence boundaries are commonly overlain by relatively thin-beded, deep-water deposits.

As a result of the relative sea-level fall associated with sequence boundary formation, rapid sediment accumulation on the upper slope of material shed from the platform led to gravitational instability, and downslope remobilization of sediment through slope failure. Erosion surfaces were generated on the slope. Large blocks of semiconsolidated upper slope sediments moved downslope to the lower slope, and were deposited on the erosion surface there. The erosion surfaces grade into correlatable, conformable surfaces in the basin. These surfaces can either cap the upward-shallowing successions, which in the Givetian consist of microbial buildups on the slope and microbial laminates in the basin, or they overlie the relatively fine-grained muddy calciturbidites/hemipelagic deposits, which are commonly seen in the Frasnian strata (see Fig. 9). The latter case suggests that a rapid erosive process (i.e. downcutting) may have acted upon the underlying slope deposits, and have probably been triggered by a sudden geological event (e.g. tectonic-controlled seismic activity). Along the western margin, the sequence boundaries are generally located on the top of progradational successions consisting of microbial buildups and peloidal–oncoidal shoal complexes because
of a relatively gentle slope (see Fig. 10). Breccias and megabreccias in this basin are similar to facies elsewhere that have been interpreted as lowstand deposits (cf. Sarg, 1988; Kennard et al., 1992; Bosellini et al., 1993; Enos & Stephens, 1993; García-Mondéjar & Fernández-Mendiola, 1993; Rosales et al., 1994; Spence & Tucker, 1997; Gómez-Pérez et al., 1999). The presence of stacked upward-coarsening calciturbidite successions below the

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**Fig. 9.** Cross-section showing the sedimentological variations along the northern margin from Nashan to Shawan. See Fig. 1 for location of these outcrops and cross-section. The arrows on the right side of logs of Nashan and Shawan are the direction of slump fold axes. LST, lowstand deposit; TST, transgressive deposit; HST, highstand deposit. M, mudstone; W, wackestone; P, packstone; G, grainstone; Co, conglomerate; Br, breccia/megabreccia.
breccia units suggests smaller-scale cyclical loss of accommodation space on the platforms and the transportation of the excess sediment off platform margins during highstand times. The occurrence of resedimented, tabular clast intercalations within these units indicates relatively large-scale periodic slope erosion. Moreover, rare, thin calciturbidites within the breccia units, especially near the base, imply that during the formation of breccia units the carbonate factory on the platforms had essentially shut down with little productivity until relative sea-level started to rise (i.e. the late lowstand times).

Nine sequences on the scale of 15–240 m in thickness are recognized in the Givetian through Frasnian succession (see Figs 2, 3, 9 and 10). They can be correlated well with the sequences elsewhere in South China (Chen et al., 2001), but they do not fit well with those of Euramerica (cf. Johnson et al., 1985). These sequences can be grouped into three sets based on their internal facies organization and stratal patterns: (1) Sequences 1–2, characterized mainly by ramp systems dominated by stromatoporoid biostromal deposits; (2) Sequences 3–5, characterized mainly by rimmed systems with abundant microbialites; and (3) Sequences 6–9, dominated by erosional bank systems with abundant gravity-flow deposits. This sequence stacking pattern represents the three major stages of basin evolution. Overall within the basin there is an upward-deepening (deepest facies occur in Sequence S7 with banded cherts), and then a shallowing trend to the top of the succession.

Phase I: Incipient Stage (Sequences 1–2)

During this stage, carbonate sedimentation was initiated in the study area, and two sequences (S1–S2) were deposited (corresponding to the Tangjiawan Formation). They are characterized by extensive highstand stromatoporoid buildups, which overlie thin, deep-water transgressive facies. Lowstand breccias and megabreccias were only developed locally along the steep eastern side of the basin (Fig. 3).

Stromatoporoid reefs with a significant thickness were only developed along the eastern margin, whereas other

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Fig. 10. Cross-section showing stratal patterns from the platform to basin across the western and northern margins. An asymmetrical basin configuration with a relatively gentle slope along the western margin is revealed. See Fig. 1 for location of the outcrops and cross-section.
During this stage, the stromatoporoid stratal patterns were deposited under these conditions. Subsequently, extensive cyanobacterial colonies bloomed, reduced the current circulation and increased sediment differentiation of platforms from the basin occurred during this incipient stage (see Fig. 14A).

**Phase II: Early Syntectonic Stage (Sequences 3–5)**

After deposition of the first two sequences, the accelerated subsidence of the basin through local tectonism further differentiated the basin from surrounding platforms. This reduced the current circulation and increased sediment starvation and environmental stress within the basin. Subsequently, extensive cyanobacterial colonies bloomed, and open-marine faunas were suppressed. Sequences 3–5 were deposited under these conditions.

**Stratal patterns**

*Northern margin* During this stage, the stromatoporoid buildups disappeared and were replaced by microbialites along the northern margin (see Fig. 1 for location). Breccias and megabreccias with microbialite clasts were deposited at the toe-of-slope as lowstand deposits. Coquina and ooidal grainstone wedges (e.g. in Sequences 3 and 5 at Wulibei) that overlie and onlap the breccia units are interpreted as transgressive deposits, and these grade basinwards into thin-beded lime mudstones/wackestones, locally with coquinas (see Fig. 9). Microbial buildups on the upper slope and platform margin and their basal equivalents, microbial laminites, represent highstand deposits. The microbial buildups constructed an aggradational to retrogradational architecture along the platform margin (e.g. Fig. 4), and apparently formed an effective barrier preventing transportation of granular sediments downslope. Gravity deposits therefore only constitute a minor component in the late highstand deposits, but they do increase in volume up through these sequences, especially in the slope deposits (e.g. in Sequence 5). This indicates an increase in erosion at the basin margin. Microbialites disappear at the top of Sequence 5, both on the margins and in the basin, due to a sudden environmental change. On the platform, features of subaerial exposure such as microkarst and meteoric cements at the top of Sequence 5 reflect an obvious shallowing or uplift.

*Western and Southern Margins* These two margins were located on the leeward side of the basin (cf. Wu *et al.*, 1987). Geological mapping by GMBGX (1994) and our observations indicate that similar depositional features characterized the two margins. In the upper Givetian, low-energy, lower-relief microbial buildups (microbial mud mounds, stromatolites and thrombolites) predominated on the upper slope, and graded basinwards to deep-water microbial laminites (cf. Fig. 10). Sequences 3–5 are commonly composed of a lower (transgressive) part of microbial buildups and an upper (highstand) part of back-reef facies (i.e. *Amphipora* packstones/ grainstones) or fenestral limestones near the buildups. These grade downslope to a succession composed of lower deep-water microbial laminites and upper microbial buildups (e.g. at Nashan, see Fig. 9). Microkarstic features are present on the top of Sequence 5 near the platform margin. The depositional features and sequences of the platform interior (e.g. at Tangjiawan, see Fig. 1 for location) are documented elsewhere (Chen *et al.*, 2001). *Basin centre* As a result of restricted, quiet and sediment-starved conditions, basin-centre sequences have a lower part of thin-beded, organic-rich, lime mudstones and wackestones, representing the transgressive deposits, and
an upper part of cyclical deep-water, microbial laminites, representing highstand deposits (e.g. at Fuhe, Fig. 10; at Shawan, Fig. 9; Chen et al., 2001, fig. 9).

**Basin geometry**

Deposition during this stage was characterized by the spectacular, widely distributed microbial deposits, indicating restricted circulation in the basin, with only minor stromatoporoid buildups along the eastern margin in the early stage (e.g. Sequence 3). Both eastern and northern basin margins exhibit an aggradational to slightly backstepping architecture with minor pulses of progradation, which was constructed mainly by microbial buildups with minor stromatoporoid buildups just along the eastern margin in the early stage as described earlier, indicating an accelerated subsidence of the basin floor controlled by deep-seated faults. These rimmed margins with vertical buildup accretion reflect a rough balance between the rate of accommodation space increase produced by relative sea-level rise and the rate of sediment production controlled by environmental factors (cf. Gómez-Pérez et al., 1999). However, this balance was broken by a jerky subsidence at the end of Sequence 5, leading to termination of these microbial buildups in the basinal realm and subaerial exposure on platforms. The stromatoporoid buildups along the eastern margin, rather than along the northern margin, were most likely related to the combined effects of the rapid subsidence of the basin margin and its position relative to the prevailing winds (i.e. winds from the west and south-west, Wu et al., 1987; Zhong et al., 1992). Buildup breccias and megabreccias were deposited on the toe-of-slope, when relative sea-level fell rapidly. On the other hand, the western margin and southern margin are characterized by a lower-energy, slightly progradational microbial bioherm succession (e.g. Fig. 10) mainly composed of *Rivularia*, implying a relatively gentle slope with slow subsidence.

Based on studies of facies distribution and architecture, a spindle-shaped basin is revealed during this phase (see Fig. 14B), in which a SE-deepening trend in water depth existed along the northern margin (cf. Fig. 9), and a subdeep of rapid subsidence occurred around the northeaster corner (near Wuguijing). The relatively rapid subsidence and steep slope along the eastern and northern margins suggest more tectonic activity along these two margins. The western and southern margins, on the other hand, were still not differentiated, and both displayed a relatively gentle slope. A transfer zone was present around the north-western corner (near Nashan), at the tapering end of the ‘spindle’ (see Fig. 14B), based on the depositional features described above. Moreover, a subbasin, the Xiangshui’er Basin (2–3 km wide, 5–6 km long) dominated by extensive deep-water microbial laminites with minor storm deposits, was formed to the east of the Yangshuo Basin (see Fig. 14B).

**Phase III: Late Syntectonic Stage (Sequences 6–9)**

**Stratal patterns**

Rapid subsidence associated with strong platform collapse at the end of Sequence 5 (i.e. latest Givetian) greatly changed the basin configuration. This, together with environmental factors, led to the decline of the microbialites and quite different stratal patterns in succeeding sequences.

**Northern margin** From Sequence 6 through 9 (Fig. 9), sequences are mainly composed of gravity-flow and hemipelagic deposits, quite different from those of underlying sequences. Breccias and megabreccias are present on the lower slope/toe-of-slope as lowstand wedges, pinching out basinwards and platformwards. As relative sea-level rises were fast, little sediment was deposited during the transgressions. On the lower slope, the breccia units are overlain by cyclical upward-coarsening successions of calciturbidites (highstand deposits), in which minor debris beds and rare microbial bioherms (e.g. in Sequence 9) are intercalated. These grade basinwards to cyclical (hemi-) pelagic/calciturbidite successions or totally pelagic successions (e.g. Sequences 6 and 7). The transition from the platform to basin was ~ 2 km, and the slope declivity was in the range of 35–45°, based on outcrop data. It is interesting to note that the thickest basal breccia units accumulated in Sequences 6 and 7, and significant hemipelagic to pelagic deposits predominate in these two sequences in the basin, implying a rapid deepening of the basin at this time (Figs 9 and 10). The breccias in Sequence 6 are dominated by clasts of microbial buildup at the base, and in Sequence 7 are almost all composed of blocks of stromatoporoid framestone. This suggests that stromatoporoid buildups occurred on the margin in the upper part of Sequence 6 (likely the highest horizon for stromatoporoid buildups), and then were resedimented to form the lowstand breccia of Sequence 7. Moreover, basal boundaries of the sequences can be traced upslope to meet two extensive subaerial exposure horizons on the platforms, indicating an obvious uplift of the platform. It appears that a seesaw movement between the platform and the basin, or block tilting, occurred during this time (cf. Chen et al., 2001).

**Eastern margin and Southern margin** Sequences 6–9 cropping out at Hongjingshan, in the basinward direction from Yangshuo, have a more gentle dip (2–5°) northwards, but also display NE-dipping stratal patterns. This suggests that deposition was influenced both by the eastern and the southern margins in this vicinity. In Sequence 6, there is no lowstand wedge, but more highstand debris beds are present. Sequence 7 is characterized by the siliceous deposits in the lower part
and calciturbidites with minor conglomerate intercalations in the upper part (Fig. 3), as described earlier. Sequences 8 and 9 are generally composed of a lower breccia unit that is overlain by cyclical upward-coarsening calciturbidite successions with minor conglomerate horizons, similar to those described from the northern margin. A spectacular, NE-dipping, undulatory slide scar surface occurs at the top of Sequence 9, and is overlain by a large megabreccia unit up to 50 m thick (Fig. 6B), which likely records large-scale slope collapse of the southern margin and downcutting at the end of the Frasnian. These megabreccias are linearly distributed along the southern margin from Hongjingshan to Baisha.

Western margin In the Frasnian, microbial buildups disappeared, and oncoidal shoal deposits dominated the platform margin and upper slope. On the platform margin, Sequences 6–9 are generally composed of transgressive deposits dominated by peloidal–oncoidal grainstones/packstones (locally peloidal grainstones/packstones) and highstand deposits dominated by fenestral limestones (Fig. 10). These grade downslope to transgressive deposits composed of calciturbidites, and highstand deposits dominated by peloidal–oncoidal shoal facies on the slope (e.g. at Nashan, Fig. 9). Further basinwards, they consist of lower pelagic limestones overlain by calciturbidite-dominated deposits (locally totally pelagic deposits, i.e. Sequence 6). Such stratigraphic patterns in the sequences suggest overall progradation and a relatively gentle slope on this western basin margin. The calciturbidite deposits immediately overlain by oncoidal shoal deposits (e.g. at Nashan, Fig. 9) also imply a relatively gentle slope. Upward-shallowing, high-frequency cycles (commonly 0.2–3 m thick) occur in most of these sequences. Features of karstic dissolution are found at the top of Sequence 5 and 6 upon shoal facies (e.g. at Ba’an, Fig. 10). In contrast, rapid deepening occurred in both Sequence 6 and 7 within the basin. Although deposits of the toe-of-slope do not crop out, the equivalent lowstand breccia units are present in the two sequences in the neighbouring northern basin.

Basin centre A rapid deepening was recorded in Sequence 6 by the pelagic, cherty lime mudstones rich in organic matter, locally interbedded with banded cherts/siliceous shales (e.g. at Shawan, Fig. 9). A sharp deepening of the basin was recorded at the base of Sequence 7, as indicated by the banded cherts/siliceous shales, the deepest facies of all the basinal successions (cf. Figs 9 and 10; Chen et al., 2001, fig. 9). Upwards, the sequences consist of pelagic nodule limestones, which are capped by calciturbidites close to the basin margins. Two deeper-water areas were developed diagonally in the basin, in the north-eastern corner (near Wuguijing) and in the south-western corner (near Baisha) (see Fig. 14B), in view of the thickest pelagic deposits and thinnest gravity-flow deposits occurring there. These features record the areas of most rapid subsidence in the basin itself.

Basin geometry

A significant subsidence of the basin at the end of Sequence 5, simultaneously accompanied with the uplift of surrounding platforms, led to a drastic change in basin geometry. During this stage, all margins except for the western margin were affected by platform collapse, backstepping and slope erosion. Up to the Frasnian (Sequence 6), the basin margins were dominated by gravity-flow deposits (calciturbidites, breccias and megabreccias). Organic buildups only formed locally (mainly along the northern margin) during the late time of Sequence 6, based on the nature of the blocks in lowstand breccias at the base of Sequence 7.

After the collapse of platform margins at the end of Sequences 5 and 6, all rimmed margins except for the western margin evolved into erosional margins (cf. Bosellini, 1998) with indented embayments through which platform sediments were exported to the toe-of-slope, forming abundant gravity-flow deposits. Above the top of Sequence 6, a sharp deepening is recorded by the presence of cherty calcisiltitic to calcilutitic turbidites overlying lowstand breccias at the toe-of-slope, which grade basinwards to entirely siliceous deposits. The breccias were commonly spalled from the mid-lower slopes, and are variable in thickness along the margins. The collapse, retreat of carbonate platforms and associated platform uplift are most likely related to the tectonism induced by deep-seated fault activity (Mullins et al., 1986, 1991; Bosellini, 1989, 1998; Bosellini et al., 1993; Chen et al., 2001) or tectonically controlled relative sea-level changes (e.g. Ward, 1999). Even along the western margin, the slope also became steeper as suggested by the presence of calciturbidites from Sequence 6 and upward-increase in occurrence of slump deformation structures (e.g. at Nashan, Fig. 9).

During this phase, the basin was longer, wider and deeper, and more rhomboïdal in shape due to the platform collapse and rapid subsidence of the basin. The southern margin differentiated from the western one by its rapid subsidence and abundant gravity-flow deposits, as noted earlier. An extra subdeep was then formed around the south-western corner (near Baisha) related to the rapid subsidence there (see Fig. 14C). The slope of the basin margins was relatively steep, approximately in the range of 35–45°, except for the western margin, which still exhibited a relatively gentle slope. The transition from most platform margins to the basin was narrow, generally about 2 km across. Thus the water depth of the basin can be estimated as approximately in the range of 500–800 m. The Xiangshui’er Basin, located to the east of the Yangshuo Basin, also became larger and deeper as a result of the sharp subsidence which took place at the base of Sequences 6 and 7 (Fig. 11). However, this basin was filled earlier (in Sequence 8) than the Yangshuo Basin, as a result of its relatively small size and shallow depth.
CONTROLS ON THE FORMATION OF YANGSHUO BASIN

Caledonian basement tectonics

During the Caledonian (‘Guangxi’) Orogeny, collision between the Yangtze and Cathaysian plates initially took place along the Jiangshan–Shaoxing segment (Fig. 12). At the end of the Silurian, a united South China Continent was formed through the gradual consumption of the South China Ocean (approx. equivalent to E in Fig. 12) between the two plates, and only a narrow remnant basin named the Qinfang Trough (F in Fig. 12) survived in the southern corner of the continent (Shui, 1987; Wu et al., 1987; Zhong et al., 1992; Liu et al., 1993). This remnant basin is interpreted as the seaway linking Palaeo-Tethys south-westwards to northern Vietnam (e.g. Wu et al., 1987; Chen & Zeng, 1990; Zeng et al., 1992, 1995; Liu et al., 1993; Liu, 1998). The Caledonian suture zone between the two plates was approximately located between Qinzhou and Lianxian, Pingxiang, Jiangshan to Shaoxing (see F4 in Fig. 12). Figure 12 presents the Caledonian tectonic framework of the South China Continent. The boundary of each tectonic division was demarcated by deep-seated (crustal or mantle) fault zones (F1–F6) supported by the evidence of volcanic activity, as well as sedimentological, geochronological and geophysical data (e.g. Shui, 1987; Liu et al., 1993; Qiu et al., 1999). The boundary fault zones were basement fault zones or antecedent plate boundaries with a long history of reactivation. For instance, faults F1 and F3 were the south-eastern boundary of the proto-Yangtze plate (1700–1000 Ma) and then reactivated later. Similarly, F5 was the site of the subduction zone of the Palaeo-South China oceanic plate during the early Jinningian (1000–850 Ma) and was reactivated in the Caledonian stage (cf. Liu et al., 1993; Qiu et al., 1999). The coalesced South China Continent was therefore quite complicated in nature due to the multiphased collision and separation of different continental blocks since Archaean times. The coupling zones tended to be the weakest parts within the continent and were readily subjected to reactivation in subsequent tectonic events. The study area is located on the Caledonian foreland flexural basin (foredeep); this tectonic unit was bounded by the basement fault zones, F2 and F4 in Fig. 12, both on the east and on the west (cf. Shui, 1987; Qiu et al., 1999; for details). This basement tectonic pattern exerted a fundamental control on subsequent Devonian basin formation and evolution in South China.

Devonian platform–basin system and tectonic pattern of South China

During the Devonian, marine waters gradually transgressed north-eastwards across the South China Continent (Wu et al., 1987; Zeng et al., 1992; Zhong et al., 1992; Liu et al., 1993; Liu, 1998). In the Devonian marine realm of South China, two elongate basins trending NNE–SSW existed and extended curvilinearly for about
800 km from Guangxi to Hunan provinces. Their width was generally 10–30 km, and they locally tapered to a few km in the region of bends (A & B of Fig. 13A2). In a bend segment, small-scale palaeohighs commonly occurred along the basin margins, indicating local compressional stress. Biostratigraphical and sedimentological studies revealed that an early onset of sedimentation occurred in the two basins. Basin A was initiated on the Caledonian remnant basin (see Fig. 13A2) in the Early Devonian, and it gradually expanded north-eastwards later, to become well established in the Givetian. Basin B was formed in the Givetian and expanded south-westwards, to connect eventually with Basin A (cf. Shen et al., 1987; Wu et al., 1987; Jin, 1990; Zhong et al., 1992). The range and extension of the two basins correlate well with two prominent Caledonian basement fault zones (F2 & F4) (see Figs 12 and 13). This suggests that the basins were genetically related to the reactivation of the Caledonian basement faults during the Devonian. Furthermore, the configuration of the basins supports a transtensional rather than a simple extensional origin for the basins, as has been proposed by other authors (Shen et al., 1987; Zeng et al., 1992, 1995; Liu et al., 1993; Liu, 1998). On the basis of palaeomagnetic data, from Early to Late Devonian times the South China Continent migrated north- and north-eastwards (Wu et al., 1987; Bai & Bai,
Fig. 13. (A) Palaeogeography showing the Devonian carbonate platform-basin systems in South China (modified from Chen et al., 2001). Note that elongate basins and carbonate platforms were arranged approximately in NNE–SSW directions from south-eastern Guangxi to Hunan (see A2). Basins: A: Lingshan–Hexian basin, trending NE–SW; B: Liuzhou–Chengbu–Lengshuijian basin, trending NNW–SSE; C: Xiangnan (South Hunan) basin; D: Xiangzhou–Lipu basin, trending NE–SW; E: Lingchuan–Quanzhou basin, trending NE–SW; F: Lipu–Yangshuo basin, trending NNW–SSE; G: Daxu–Lingchuan basin, trending NNW–SSE. Localities: LP, Lipu; HX, Hexian; LC, Lingchuan; QZ, Quanzhou. Inset box around Guilin is the area of Fig. 1. (B) Interpretation of synsedimentary structural styles of the Devonian interplatform basins in eastern Guangxi and Hunan (area of A2). A sinistral strike-slip tectonic setting is believed to have been responsible for the formation of such a pattern. F2d coincided with Caledonian basement fault zone F2. Faults F4s and F4n coincided, respectively, with the southern and northern segments of basement fault zone F4 (see Fig. 12). Note the tectonic setting of the Yangshuo Basin (see the dashed arrow). The pattern and orientation of the fault zones are expressed with the strain ellipse, top right of the diagram. PDZ, principal displacement zone, *en echelon* strike-slip faults along A–A’, synthetic strike-slip faults along B–B’, antithetic strike-slip faults along C–C’, extensional faults along D–D’.
1990; Zhong et al., 1992). As a result of this, the sinistral strike-slip movement along the southern segment of the Caledonian suture zone (F1 in Fig. 12; F4s in Fig. 13B) was initially induced, and gradually propagated north-eastwards (e.g. Shen et al., 1987). The progressive northward migration of the continent further initiated the strike-slip movement along the northern segment of the Caledonian suture zone and the basin fault zone between the Caledonian forebulge and foredeep (i.e. F2 in Fig. 12), due to the rigid nature of the Jiangnan upland along the western and northern sides of the South China Continent. Strike-slip basins were simultaneously formed along the reactivated basement fault zones (e.g. A & B of Fig. 13A2). The resistant rigid masses of the Caledonian intrusives along the basin faults led to the local stress accumulation during strike-slip movement, and resulted in the basin narrowing and bending commonly along with (submerged) highhils in the bend segment, corresponding to the restraining bend along the strike-slip fault zone (cf. Harding et al., 1985).

Several subbasins were formed in relation to the two elongate basins (Fig. 13A2). The Xiangnan (Southern Hunan) rhomb-shaped basin (C of Fig. 13A2) was located at the northern end of basin A, and was interpreted as a pull-apart basin formed by sinistral strike-slip offset between the Lingshan–Hexian–Chenzhou (F4s) and Pingxiang–Hengyang faults (F4n) (Jiang, 1990) (northern and southern segments of reactivated basement fault F4) (compare Fig. 12 with Fig. 13B). Two en echelon arranged basins (Xiangzhou–Lipu & Lingchuan–Quanzhou; D & E in Fig. 13) trending NE–SW occurred east of basin B and made an acute angle with the main basin; these are interpreted as secondary, en echelon strike-slip fault-induced basins, based on the stress field analysis of the main strike-slip systems (F1 & F2 of Fig. 13B). Another two subbasins (F & G in Fig. 13A2), trending NNE–SSW, similar to the strike of the main elongate basins, occurred between the two en echelon basins (D & E); these are interpreted as secondary, synthetic (sinistral) strike-slip fault-induced basins (F3 & F4 of Fig. 13B).

The Yangshuo Basin (Fig. 14) was located between basins F and G, and was spindle- to rhomb-shaped with a nearly N–S-trending basin axis (Fig. 13A). It is therefore interpreted as a basin induced by synthetic strike-slip faulting (Fig. 13B), based on its basin geometry, extension and time of formation. The smaller-scale, NW–SE-trending Xiangshui’e Basin (Fig. 14), which was located to the east of the Yangshuo Basin, was likely formed in relation to antithetic strike-slip faulting (F5 of Fig. 13B), based on the features of stress behaviour of the strike-slip system.

Structural style and evolution of the Yangshuo Basin

The formation of the Yangshuo Basin is related to secondary, synthetic (sinistral) strike-slip faulting in the main transtensional tectonic setting of South China, as discussed above. The spindle- to rhomb-shaped basin geometry and the architecture of the basin margins described earlier suggest a pull-apart basin origin for the Yangshuo Basin, in comparison with published examples (e.g. Bluck, 1980; Howell et al., 1980; Steel & Gloppen, 1980; Hempton et al., 1983; Mann et al., 1983; Zhang et al., 1989; Nilsen & Sylvester, 1995). In this case, the eastern and western margins are attributed to the master strike-slip faults, which corresponded to the synthetic strike-slip faults striking approximately NNE–SSW, with a slight anticlockwise rotation to a nearly N–S direction. The northern and southern rectilinear margins aligning roughly NW–SE are attributed to the oblique-slip, extensional sidewall fault zones, which terminated at the master fault zones at both ends and made an angle with the master faults of 30–45° (see Figs 1, 13B and 15). However, the small difference in the direction (approximately 10–15°) between the northern and southern segment of the master faults gave rise to an asymmetrical rhomb-shaped basin configuration. It is noted that the master strike-slip fault zones are curvilinearly oriented along strike and bend to the east in the northern part of the basin; they splay to the south-east, showing a slight anticlockwise rotation against the principal basin axis (Fig. 1). The north-eastward propagation of the Xiangzhou–Lipu fault (F1 in Fig. 13B) may have induced the near NW–SE-trending, releasing (antithetic) strike-slip fault (F5) to the east of the Yangshuo Basin, leading to the formation of smaller subbasins such as the Xiangshui’e Basin, and simultaneously resulting in the anticlockwise rotation (Fig. 13). A similar tectonic pattern involving the formation of pull-apart basins and related releasing splay faulting along a strike-slip fault zone was documented by Harding et al. (1985). The kinematic behaviour and orientation of these fault zones is expressed with a strain ellipse in Fig. 13(B).

The Yangshuo Basin was nucleated on an antecedent clastic intrashelf depression in the early Givetian, and then modified and defined by later progressive and episodic sinistral transtensional block-faulting, which reached a climax in the early Frasnian. The evolution of the Yangshuo Basin can be divided into three stages as described earlier.

(1) During the incipient phase, the rapid subsidence with thick stromatoporoid reef successions along the eastern margin suggests an early onset of faulting offset along the eastern master fault zone. The lack of differentiation between platforms and the basin along the other margins reflects relatively weak fault activity there at this time (Figs 14A, 14a).

(2) During phase II, the spindle-shaped basin geometry (or ‘lazy S’, cf. Mann et al., 1983) (Fig. 14B) suggests a pull-apart process between the sinistral strike-slip faults. The aggradational architecture rimmed with microbial buildups along the northern margin implies the onset of the oblique, NW–SE-orientated, extensional faulting along this margin, which was induced by the more
active, earlier displacement on the eastern master fault (Fig. 14b). This oblique, extensional fault delineated the northern boundary of the basin, and terminated at the western master fault with an angle of about 30–40° (Fig. 14b). A subdeep formed near the north-eastern corner (Fig. 14B) shows that the greatest tensional stress field was generated in the distal part of the eastern master fault. The relatively gentle slope of the western and southern margins, and the little differentiation between them suggest a relatively passive, western master fault zone with a small offset, which produced relatively slow subsidence to the south of its distal part. In this case, no subdeep was created in the south-western corner due to the slow subsidence. The asymmetrical basin geometry probably resulted from the small difference in orientation (10–15°) of the two master faults (Fig. 14b). The SE-deepening of the basin along the northern margin (Fig. 9) and the relatively gentle slope along the western margin

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![Tectono-sedimentary evolution of the Yangshuo Basin.](image)

**Fig. 14.** Tectono-sedimentary evolution of the Yangshuo Basin. Three main phases of basin formation and their basin configuration (A, B and C) are shown with corresponding tectonic patterns (a, b and c) (at approximately half size). Surrounding non-ornamented areas are shallow-water carbonate platforms. See A for names of the localities. SD, Shihedong; WL, Wulibei; ZN, Zhongnan. The dashed areas within the basin in B and C represent the sub-deep centres.
suggest that a relay ramp (or transfer zone, e.g. Gawthorpe & Hurst, 1993; Bosence et al., 1998) was likely present in the north-western corner near Nashan between the two margins. However, no surficial expression of these faults, including the master faults and sidewall normal faults, was discovered in the field. This situation is quite common for synsedimentary tectonic activity, especially in carbonate depositional systems (cf. Bosellini, 1998). The Xiangshui’er Basin to the east was also initiated at this time, and resulted from the SE-releasing splay fault induced mostly by the north-eastward propagation of the Xiangzhou–Lipu fault (Figs 13B, 14b).

(3) During phase III, The more rhomb-shaped basin geometry, stronger platform collapse and slope erosion accompanied with obvious platform uplift suggest more intense offset of the strike-slip faults and oblique extensional faulting. These processes induced dramatic downthrow of the basin floor (hangingwall) and uplift of surrounding platforms (footwalls), especially in the early Frasnian (i.e. Sequence 6), causing slope erosion and platform collapse (e.g. Fig. 4). The southern oblique extensional fault was likely activated through progressive stepover of the western master fault, based on the extensive gravity-flow deposits along the southern margin and the occurrence of another subdeep around the south-western corner (near Baisha). All these processes caused the basin to be longer, wider and deeper, and more rhomboidal in shape. Two diagonally arranged deeper depressions, possibly bounded by minor faults, were then well established in the corners of the distal part of the offset strike-slip faults through the progressive, pull-apart process between them (Figs 14C, 14c and 15; Table 1). However, the relay ramp zone in the north-western corner of the basin was greatly damaged through more intense strike-slip faulting. During the early Frasnian, the enlarged basin configuration and S- to SE-dipping slide scarps in the Xiangshui’er Basin (Fig. 11) suggest more intense SE-releasing splay faulting, induced by the continued north-eastward propagation of the Xiangzhou–Lipu fault (Figs 14C, 14c & 15).

CONCLUSIONS

1 In the Devonian, the northward migration of the united South China Continent reactivated and induced a series of NNE–SSW-trending, sinistral strike-slip fault zones along rigid, intracontinental, antecedent basement fault zones. Elongate basins extending several 100 km were created along the transtensional deformation zones. These large-scale strike-slip fault zones further induced numerous secondary strike-slip fault systems, and associated subbasins were created along them simultaneously. The Yangshuo Basin was generated by a secondary, synthetic (sinistral) strike-slip fault zone through the pull-apart process, during the late Givetian to Frasnian. Two nearly N–S-trending, offset strike-slip faults, linked by two NW–SE-trending, parallel, oblique-slip extensional faults, generated a spindle- to rhomb-shaped basin. The eastern master fault was relatively active compared with the western one as a result of the propagation direction of the fault zones.

2 Nine sequences are recognized within the Givetian through Frasnian basin-fill, based on key surfaces and internal facies organization. These are largely controlled by the tectonically induced subsidence and oceanographic setting. The sequences can be grouped into three sequence sets: (1) Sequences 1–2, (2) Sequences 3–5 and (3) Sequences 6–9, representing the three main phases of basin development.

3 During the basin nucleation stage (Sequences 1–2), most basin margins exhibited a low-gradient profile, and were characterized by stromatoporoid biostromes and bioherms. Only the eastern margin was rimmed with stromatoporoid reefs, representing a more rapid subsidence and steeper slope morphology, probably resulting from the early onset of movement on the eastern master fault.

4 During the early stages of basin development (Sequences 3–5), the basin had a spindle-shaped configuration. The progressive transtensional deformation intensified the differential subsidence between the basin and surrounding platforms, leading to poor circulation. Hence, depositional packages are dominated by microbialites, with only minor stromatoporoid buildups facing prevailing winds. Windward basin margins exhibit aggradational to slightly backstepping architectures, whereas leeward basin margins display a slightly progradational stratal pattern. A relay ramp developed around the north-western corner between the proximal, passive western master fault and the oblique, northern extensional fault. A subdeep was formed around the north-eastern corner due to rapid extensional subsidence induced by the further offset of the more active, eastern master fault. The sudden subsidence of the basin floor occurring at the end of Sequence 5 (in the latest Givetian), accompanied by rapid uplift of the platforms, caused considerable platform collapse, slope erosion and termination of microbialite deposition.

5 Following the latest Givetian tectonic event, intense stress relaxation caused jerky subsidence of the basin, accompanied by substantial uplift of platforms, leading to further platform margin collapse, slope erosion and basin deepening. The basin became more restricted and stagnant, allowing siliceous sediments to be deposited, aided by upwelling volcanogenic fluids from deep-seated faults. All organic buildups disappeared through this event, possibly due to environmental stress and poisoning triggered by the volcanotectonic activity.

6 The basin subsequently became wider and displayed a rhomb-shaped configuration. An extra sub-deep was formed around the south-western corner due to the progressive offset of the western master strike-slip fault. Similarly, the relay ramp in the north-western corner was nearly obliterated. The small difference in orientation
Table 1. Depositional architecture and basin geometry in response to basin evolution.

<table>
<thead>
<tr>
<th>Margin</th>
<th>Incipient (Sequences 1–2, early Givetian)</th>
<th>Early syntectonic (Sequences 3–5, late Givetian)</th>
<th>Late syntectonic (Sequences 6–9, Frasnian)</th>
<th>Orientation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eastern Margin</td>
<td>Rimmed with stromatoporoid reefs, high subsidence.</td>
<td>Rimmed with stromatoporoid reefs in early stage (S3), later with microbial buildups; aggradational to slightly retrogradational.</td>
<td>Gravity-flow deposits dominant; erosional, backstepping.</td>
<td>Nearly N-S; E master fault; windward margin.</td>
</tr>
<tr>
<td>Western Margin</td>
<td>Stromatoporoid bioherms.</td>
<td>Microbial bioherms and mounds; progradational.</td>
<td>Progradational oncoidal shoals in general; later became steep.</td>
<td>Nearly N-S; W master fault; leeward margin.</td>
</tr>
<tr>
<td>Northern Margin</td>
<td>Stromatoporoid biostromes.</td>
<td>Microbial buildups, aggradational to retrogradational.</td>
<td>Rimmed with stromatoporoid reefs early (S6); later gravity-flow deposits dominant; erosional, backstepping.</td>
<td>NW-SE; oblique extensional fault; windward margin.</td>
</tr>
<tr>
<td>Southern Margin</td>
<td>Same as W and N margins.</td>
<td>Microbial bioherms and mounds; progradational.</td>
<td>Gravity-flow deposits dominant; erosional backstepping.</td>
<td>NW-SE; oblique extensional fault; leeward margin.</td>
</tr>
<tr>
<td>Basin Centre</td>
<td>Open-marine, deep subtidal, storm-influenced facies.</td>
<td>Sediment starvation; microbial sheets with few storm influences.</td>
<td>Cherty mudstones and banded cherts/siliceous shales early (S6–7); nodular limestones later.</td>
<td>Two subdepocentres diagonally arranged in NE and SW corners during the late stage.</td>
</tr>
<tr>
<td>Basin Geometry</td>
<td>flat oblate, depocentre close to the eastern margin.</td>
<td>‘S’ to spindle-shaped; subdepocentre initiated in NE corner; a relay ramp in the NW corner.</td>
<td>Asymmetrical rhomboidal shape; two subdepocentres formed in NE and SW corners; the relay ramp being destroyed.</td>
<td>Nearly N-S orientated, a slightly anticlockwise rotation, related to the sinistral strike-slip faulting with a slight SE releasing extension.</td>
</tr>
</tbody>
</table>
between the two master faults led to the asymmetrical basin configuration. Most basin margins retreated and evolved into erosional ones with little protection, from which granular sediments were shed to the slope and basin floor. The western margin, related to the more passive master fault there, and in a leeward position, was still relatively gentle. Depositional packages were dominated by gravity-flow deposits along basin margins, and pelagic deposits in the basin centre.

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