Permian and Triassic depositional history of the Yangtze platform and Great Bank of Guizhou in the Nanpanjiang basin of Guizhou and Guangxi, south China

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Abstract - The Nanpanjiang basin occurs in the southern margin of the south China plate. Marine sedimentation dominated from the Late Proterozoic to the Late Triassic when siliciclastic turbidites filled the basin and sedimentation regionally shifted to fluvial deposition. Permian and Triassic carbonate strata record a long history of platform evolution and include diverse architectures and evolutionary histories that reflect the impact of local depositional environments, rates of siliciclastic flux and accelerating tectonic subsidence as the basin experienced tectonic convergence and foreland basin development in the Triassic.

The Triassic margin of the Yangtze platform that rims the basin extends in a sigmoidal SW/NE trend from Yunnan through Guizhou. Several isolated platforms, including the Great Bank of Guizhou and the Chongzuo-Pingguo platform, occur within the basin in southern Guizhou and Guangxi. The basin expanded in the Late Permian during a regional transgression. The Yangtze platform and isolated platforms evolved from low-angle ramps with oolite margins in the Early Triassic to steepening *Tubiphytes* reef margins in the Middle Triassic (Anisian). Basin-wide shift from ramp to steepening-margins was stimulated by the evolution of *Tubiphytes* and other organisms that stabilized platform margins. The western Yangtze platform (Guanling and Zhenfeng) and the northernmost isolated platform (the Great Bank of Guizhou) aggraded in the Anisian and developed high-relief escarpments during the Ladinian. At the same time the eastern sector of the Yangtze platform (Guiyang) evolved from an erosionally collapsed margin to a progradational margin that advanced basinward at least 600 m over basin filling clastics. The western Yangtze platform was drowned and buried by turbidites in the Late Triassic (Carnian) whereas shallow-water carbonate sedimentation continued until burial by siliciclastics in the eastern sector. The isolated platforms exhibit a north to south pattern of greater longevity in the north, step-backed margins and pinnacle development in the south, and earlier drowning and burial by siliciclastics in the south. These differences resulted from faster subsidence rates in the southern part of the basin caused by tectonic convergence along the southern margin of the south China plate.

The Great Bank of Guizhou has the longest history of the isolated carbonate platforms in the basin. A faulted syncline exposes a continuous two-dimensional cross section through the platform interior and margins, thus facilitating a detailed assessment of its architecture and depositional history. Conformable Permian-Triassic boundary sections, and thick, continuously exposed sections through the Early to Middle Triassic biotic recovery interval make this platform an ideal area for evaluating the marine environments and biotic conditions that operated during the end-Permian extinction and its aftermath.

Figures 11-18 are found in the guide for field excursion 2 p. 167-184 this volume

Tectonic setting of south China

The Nanpanjiang basin has the longest marine history of any basin in China, having been the site of marine sedimentation during most of the Late Proterozoic through Late Triassic (Enos, 1995). During the Permian and Triassic the Nanpanjiang basin formed a deep-marine embayment in the southern margin of the south China block (fig.1).
Tan et al., 2000) and would imply that a suture runs through the northern part of the Nanpanjiang basin (fig. 1). The stratigraphic similarities among carbonate platforms developed across the basin as well as similarities in subsidence histories (Koenig et al., 2001) support the interpretation of a south China block that has been unified since the Early Paleozoic and argue against Triassic suturing of the south China fold system.

The south China block is bordered on the north by the Qingling-Dabie orogenic belt, a suture between the north and south China blocks (fig. 1; Metcalf, 1996; among many others). To the northwest it is bounded by the Songpan-Ganzi fold system interpreted to be a remnant oceanic basin filled with Triassic flysch during suturing of the south and north China blocks (Ingersoll et al., 2003). The south China block is bordered on the south and southwest by the Ailaoshan and Songma/Songda faults which have been interpreted as suture zones bounding the Siamo-Sibumasu and Indochina plates respectively (fig. 1; Klimetz, 1983; Zhang et al., 1984; Wang, 1988; Metcalf, 1996).

Plate reconstructions indicate that the south China block rifted from the northeast margin of Gondwanaland probably adjacent to Australia during the Devonian (Metcalf, 1996), drifted northward across the Eastern Tethys, crossing the equator during the Permian to approximately 12° N latitude by the beginning of the Middle Triassic, and eventually docked with the north China plate along the Qinling suture during the Late Triassic (Klimetz, 1983; Sengör, 1987; Enkin et al., 1992; Van-der-Voo, 1993, Enos, 1995; Li, 1998; Paul Montgomery, 2002, unpublished paleomagnetic results from southern Guizhou). Controversy regarding whether the north and south China blocks docked instead during the Early Paleozoic (cf. Mattauer et al., 1985; Zhang et al., 1997) seems to have been reconciled with a tectonic model that includes earlier docking of a terrane along the northern Qinling followed by Late Triassic docking of south China along the southern Qinling (cf. Sun and Li, 1998 and Meng and Zhang, 1999).

The Siamo-Sibumasu and Indochina blocks converged upon and collided with the southern margin of the south China block sometime during the Late Paleozoic or Triassic (Klimetz, 1983; Zhang et al., 1984; Wang, 1988; Fan and Zhang, 1994; Metcalf, 1996, 2002). There has been controversy as to the timing of suturing of Indochina and the Siamo-Sibumasu blocks to south China and as to
whether the Songma/Songda fault zone represents a suture (Findlay and Trinh, 1997). Most authors have interpreted suturing and collision along the Ailaoshan and or Songma/Songda zones during the Triassic Indosinian orogeny (Klimetz, 1983; Zhang et al., 1984; Wang, 1988; Sengör et al., 1987; Fan and Zhang, 1994; Carter et al., 2001). Others have interpreted Paleozoic docking of Indochina and south China (Hutchinson, 1989; Metcalf, 1996, 2002; Findlay and Trinh, 1997). The Ailaoshan and Songma/Songda zones are exceedingly complex. They may include a history of docking of smaller Late Paleozoic terranes (cf. Metcalf, 2002), as well as having been involved in Triassic convergent tectonism and metamorphism (cf. Lepvrier et al., 1997; Lacassin et al., 1998); finally they were overprinted by extensive Cretaceous-Tertiary shearing and metamorphism associated with India-Asia collision (cf. Tapponier et al., 1990; Lepvrier et al., 1997). Although Indosinian convergence and arc development along the Songma/Songda in the south remains controversial, several observations in the Triassic record support this interpretation: 1) The patterns of greater longevity of carbonate platforms in the northern part of the basin (e.g. Permain-Carnian of the Great Bank of Guizhou) and shorter history, earlier drowning and stepback of platforms in the southern part of the basin (fig. 2-5), 2) earlier onset of accelerating subsidence and greater subsidence rates in the southern part of the basin (fig. 6; Koenig et al., 2001) and 3) thickening felsic volcanics in the southern part of the basin (Newkirk et al., 2002).

The Nanpanjiang basin is embayed by the Yangtze platform, a vast platform of primarily shallow-marine deposition that stretches across much of the south China block (fig. 1) (Wang, 1985; Yang et al., 1986; Liu and Xu, 1994; Enos, 1995; Xu Qiang, et al., 1996; Xu Xiaosong, et al., 1996). During the long history of marine sedimentation from Proterozoic to Late Triassic, the Yangtze platform-Nanpanjiang basin system of Guizhou and Guangxi underwent several important phases of tectonic reorganization.

The south China block (Yangtze Craton) stabilized as a cratonic block during the Neoproterozoic Yangtze orogeny, which was followed by stable cratonic sedimentation during the end of the Proterozoic (Sinian) and Early Paleozoic (fig. 6; Huang, 1978; Ren et al., 1987; Metcalf, 1996). In Guizhou and Guangxi the Proterozoic basement is unconformably overlain by Neoproterozoic (Early Sinian) glacial and glacial-marine deposits followed in the Late Sinian and Cambrian by shallow and deep marine clastics marking transgression and initiation of passive margin development (Guangxi Bureau, 1985; Guizhou Bureau, 1987). Early Paleozoic facies are dominated by mature clastics and shallow-marine carbonates, indicating the development of a vast and longstanding passive continental margin (fig. 6; Wang, 1985).

The region became tectonically active during the Early Devonian Guangxi orogeny, resulting in development of a basinwide unconformity and the regional absence of basal Devonian sediments (fig. 6; Guangxi Bureau, 1985; Guizhou Bureau, 1987; Xie et al., 1984). The unconformity bevels strata down to the Cambrian in southern Guangxi (unpublished regional stratigraphic data; Geological Survey of Guangxi). Regional tectonic syntheses have inferred extensional block faulting associated with the Devonian orogeny. The Guangxi orogeny has been widely attributed to a phase of extensional deformation impacting the region (Guangxi Bureau, 1985; Guizhou Bureau, 1987; Xie et al., 1984; Huang, 1978; Qing et al. 1991; Xu Xiaosong, et al., 1996). Plate reconstructions indicate the Early Devonian deformation and uplift probably resulted from the rifting of the south China block from Gondwanna (cf. Metcalf, 1996).

Passive-margin conditions resumed in the Late Paleozoic with widespread development of shallow-marine carbonate sedimentation in the Yangtze platform in Guizhou and around the eastern periphery of the Nanpanjiang basin in Guangxi (Wang, 1985; Enos, 1995; Xu Xiaosong, et al., 1996). Regional paleogeographic reconstructions have indicated the existence of isolated carbonate platforms developed within the basin in Guangxi during the Devonian (Xie et al., 1984; Wang 1985; Xu Xiaosong, et al., 1996).

Several authors have speculated that horst blocks formed in the Devonian set up the structural grain for the nucleation of isolated carbonate platforms that developed in Guizhou and Guangxi (cf. Xie et al., 1984; Qing et al., 1991). Regional mapping demonstrates that the margin of at least one of the isolated Triassic platforms, the Chongzuo platform in the southern part of the basin, was controlled by a fault and that another, the Great Bank of Guizhou in the northern part of the basin, nucleated on antecedent topography inherited from an Upper Permian reef margin rather than a fault block (fig. 2, 3; Lehmman et al., 1998).

The Lower-Upper Permian transition is marked by a period of renewed tectonic activity with extensional faults, eruption of the Emeishan Basalt along the western margin of the basin, and development of a disconformity that extends across the entire basin (Guangxi Bureau, 1985; Guizhou Bureau, 1987). This period of activity is commonly referred to as the “Dongwu movement” in the Chinese literature (fig. 6; Dai et al., 1978; Zhang, 1984; Guizhou Bureau, 1987; Huang and Chen, 1987). The most dramatic expression of this tectonism is vast outpourings of Emeishan Basalt. Eruption of the Emeishan flood basalt was apparently centered in southern Sichuan and eastern Yunnan, where maximum reported thicknesses exceed 2 km (Luo et al., 1990; Chung and Jahn, 1995). Emeishan tectonism has been variously interpreted to have resulted from rifting, back arc spreading, or development of a mantle plume (Yang et al., 1986; Guizhou Bureau, 1987; Qing et al., 1991; Luo et al., 1990; Xu Xiaosong, et al., 1996; Thompson et al., 2001; Song et al., 2004). The Emeishan basalt thins eastward and extends into western Guizhou where it has a maximum thickness of 500 m. The basalt thins and pinches out to the southeast and is found only within the westernmost part of the Nanpanjiang
basin, suggesting that the Dongwu movement may have had its greatest impact in the western part of the basin.

From the Late Permian through Middle Triassic the Yangtze platform was the site of a thick and expansive succession of shallow-marine carbonates with intermittent siliciclastic flux onto the platform from the west and with a variety of reef, ramp and collapsed type platform margins (Enos, 1995, Enos et al., 1997, 1998). Isolated carbonate platforms developed within the basin during the Triassic (fig. 3; Lehrmann et al., 1998). Deep-marine sedimentation in the Early Triassic basin was dominated by relatively thin “starved” pelagic carbonate and shale of the Luolou Formation (fig. 3) indicating relatively quiet tectonic conditions.

Conditions changed dramatically during the Middle and Late Triassic **Indosinian orogeny**. During the Middle and Late Triassic the basin rapidly subsided and was eventually filled with siliciclastic turbidites (fig. 4, 5, 6). Carbonate platforms were progressively drowned and buried with siliciclastics from the beginning of the Middle Triassic Anisian (in southern basin) to the beginning of the Late Triassic (northern basin) (fig. 3, 4, 5). Marine turbidites changed upward to fluvial clastics marking the end of marine sedimentation in the Late Triassic (fig. 7). The Indosinian orogeny marks the termination of marine conditions across the south China block. Although the Indosinian orogeny is an important turning point in the evolution of the Nanpanjiang basin, the specific tectonic cause is still unclear.

During the Triassic, the Nanpanjiang basin has been variously interpreted as a back arc or foreland basin with an arc developed in southern Guangxi or within a southerly continent (He, 1986; Xia et al., 1993), as a back arc extensional basin (Hou and Huang, 1984), as a foreland basin developed along the eastern side of collision zone along the Ailaoshan suture (Qing et al., 1991), and as a flysch nappe thrust over a suture zone from the Huanan block onto the Yangtze craton (Hsu et al., 1990). The Middle Triassic history adequately classifies the Nanpanjiang basin as a foreland basin as a perisutural basin developed on continental lithosphere associated with compressional tectonics (Allen et al., 1986), as south China was involved in convergence and collision potentially along its north-

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Figure 2: Upper Permian lithofacies and interpreted paleogeography of the Nanpanjiang basin and Yangtze platform in Guizhou, Guangxi, and Yunnan. Compiled from regional geologic maps of the Yunnan Bureau of Geology, 1984; Guangxi Bureau of Geology, 1985, and Guizhou Bureau of Geology, 1987. Maps have been modified and updated with results from our regional mapping. Data control (colored facies polygons) is the distribution of surface exposure of various facies (Formations) indicated in the legend.
Enos et al. (1998) noted that the facies succession formed during Late Triassic termination of the Yangtze platform in southern Guizhou forms a classic flysch to mollasse sequence typical of a foreland basin (fig. 7). However, the directions of the source areas and the timing of silicilastic flux are complex and poorly understood. The flysch in southern Guizhou (Bianyang Formation) seems to have been derived from the east based on paleocurrents (Sun et al., 1989; Chaikin, 2004). The sandstone petrology and heavy mineral suite are consistent with derivation from the Jiangnan massif (fig. 5; Chaikin, 2004). The rapid rate of supply (Carnian, adjacent to the Great Bank of Guizhou) is surprising, however, and indicates uplift and rejuvenation. Siliciclastics in the southern part of the basin must have arrived earlier as evidenced by the Anisian and Ladinian burial of isolated carbonate platforms in Guangxi (fig. 3, 4, 5). On the other hand, the mollasse (Bannan, Houbachong and Erqiao Formations; fig. 7) in Guizhou thins and fines rapidly eastward and more slowly northward (Enos et al., 1998). A source to the west, likely the Khamdian massif, is indicated (fig. 5).

Permian-Triassic stratigraphy and depositional setting of the Yangtze platform and Nanpanjiang basin

Permian and Triassic stratigraphy of the Yangtze platform in Guizhou

The Yangtze Platform of south China formed a stable palaeogeographic element from late Proterozoic to the end of Middle Triassic. Mature sedimentary facies, in particular shallow-water carbonates, accumulated during much of this time. The Yangtze Platform bordered or surrounded several persistent massifs (“oldlands”), notably the Jiangnan massif in southeast Guizhou and adjacent provinces and the Khamdian massif in eastern Yunnan (fig. 2). The southern margin of the platform was embayed by the Nanpanjiang Basin that extended into central Guizhou (fig. 2). Persistent deep-water deposits surrounded various isolated carbonate platforms within the basin.

The Early Permian deposits on the platform in southern Guizhou were dominated by fossiliferous limestone with minor dolostone (the upper part of Maping Formation and lower Houziguan Formation; table 1). The Lower Permian platform-interior strata are capped by a regional subaerial exposure surface. The Nanpanjiang basin was broad, although rather shallow, but in southern Guizhou it was confined to a narrow gulf (Liu and Xu, 1994). The Early Permian deposits in the basin were dark-gray to black thin-bedded limestone, chert and mudstone, intercalated with debris-flow breccia (Nandan Formation; 300–500 m thick, table 1). Within in a very limited area of the platform in western Guizhou, at the transition belt between platform and basin, argillaceous limestone, sandstone, mudstone (Longyin Formation) and black shale (Baomoshan Formation; table 1) were conformably deposited over the top of the shallow-water limestone (Maping Formation; table 2).

The Middle Permian deposits in the basin were claystone and marl with subordinate limestone and shale (Sidazhai Formation; 350-650 m thick table 1, fig. 7). The initial Middle Permian deposits on the platform were well differentiated. Argillaceous sandstone and claystone with some coal flanked the Khamdian massif in the west (Liangshan Formation; table 1). Shale layers with brachiopods record marine incursions. Eastward, in southern Guizhou, the shore zone produced cleaner sandstone and siltstone that interfinger with coal, shale, marl and fossiliferous marine limestone, and finally graded into limestone. Later on, cherty, nodular lime mudstone (Qixia Formation; table 1) and fossiliferous limestone, locally cherty (Maokou Formation; table 1) dominated across the entire platform. The carbonate content and energy increased seaward to produce pure bioclastic limestone and Tubiphytes-sponge boundstone at the platform margin (Houziguan Formation, table 1, fig. 7). The Jiangnan massif was submerged essentially throughout the Permian, as witnessed by scattered outcrops of marine limestone across the massif, a lack of facies differentiation, and overstepping of older formations by Permian deposits around the massif (Guizhou Bureau, 1987; Liu and Xu, 1994; Enos, 1995). Deposition was interrupted in mid-Permian by a great outpouring of tholeiitic lava, the Emeishan Basalt, that extended across the Yangtze Platform from the Khamdian area (table 1, fig. 7).

Facies distributions and migrations in the Late Permian were similar to those of the Middle Permian. The Nanpanjiang Basin in Guizhou became even narrower, presumably because of gradual progradation of the platform rimmed by reefs and bioclastics (fig. 2). Basinal deposits are claystone and bedded chert that enclose carbonate breccias and bioclastic limestones, probably turbidites (Shaiwa Formation, table 1, figs. 2, 7). Cherty, bioclastic limestone with sponge and coral reefs at the platform margin pass into cherty, micritic and argillaceous limestones, calcareous siltstones and claystones in the platform interior (Wujipiaping and Changxing Formations, respectively; table 1, figs. 2, 7). These interfinger toward the Khamdian massif with claystone and coal and finally with alluvial sandstone (Longtan, Wangjiazhai and Xuanwei Formations; table 1, figs. 2, 7). Terrestrial deposition persisted in the Khamdian massif throughout the Late Permian, indicating less extensive flooding than in the Middle Permian. Eventually the carbonate platform was covered by chert and spiculitic mudrock, a deepening phase that marked the permanent drowning of large areas of the Yangtze platform (Dalong Formation, table 1, figs. 2, 7).

Deposition continued uninterrupted into the Early Triassic in most areas. The drowning event toward the end of the Permian (Dalong Formation; table 1, fig. 2) resulted in a reconfiguration of the platform margin to a sigmoidal SW/NE trend involving more than 100 km of retreat of the eastern margin in southern Guizhou (Luodian, Guiyang; fig. 3). Following initial deposition of bivalve-
## TABLE 1. STRATIGRAPHIC UNITS AND DEPOSITIONAL ENVIRONMENTS OF THE PERMIAN SYSTEM SOUTHWESTERN GUIZHOU

<table>
<thead>
<tr>
<th>STAGE*</th>
<th>TERRESTRIAL</th>
<th>PARALIC</th>
<th>PLATFORM INTERIOR</th>
<th>PLATFORM MARGIN</th>
<th>BASIN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper Permian</td>
<td><strong>CHANGXING</strong></td>
<td>XUANWEI FM. Alluvial &amp; lacustrine sandstone, shale &amp; coal</td>
<td>WANGJIAZHAI FM. Interfingering marine &amp; continental siliciclastics &amp; coal</td>
<td>DALONG FM. Dark, spiculitic mudrock &amp; chert</td>
<td>SHAIWA FM. and LINGHAO FM Shale, thin siltstone, lime mudstone &amp; breccia</td>
</tr>
<tr>
<td></td>
<td><strong>LEPING</strong></td>
<td>LONGTAN FM. Interbedded continental sandstone, mudrock, coal &amp; marine limestone</td>
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<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>EMEISHAN BASALT Cherty bioclastic limestone, locally cherty &amp; coal</td>
<td>WUJIAPING FM. Cherty bioclastic limestone, coral/sponge reefs</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Middle Permian</td>
<td><strong>MAOKOU</strong></td>
<td>No record</td>
<td>MAOKOU FM. Fossiliferous, micritic &amp; dolomitic limestone</td>
<td>HOUZIGUAN FM. Bioclastic packstone sponge boundstone</td>
<td>SIDADZHAI FM. Cherty lime mudstone &amp; shale</td>
</tr>
<tr>
<td></td>
<td><strong>QIXIA</strong></td>
<td>No record</td>
<td>QIXIA FM. Fossiliferous, micritic cherty limestone</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>LIANGSHAN FM. Argillaceous sandstone, claystone, coal, &amp; shale with brachiopods</td>
<td>HUAGOANG FM. Quartz arenite, siltstone, shale, bioclastic limestone, marl &amp; coal</td>
<td>SAZHI FM Argillaceous &amp; bioclastic limestones, silty claystone &amp; shale</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lower Permian</td>
<td><strong>LONGYIN</strong></td>
<td>No record</td>
<td>BAOMOSHAN FM</td>
<td>NANDAN FM</td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>MAPING</strong></td>
<td>MAPING FM</td>
<td>LONGYIN FM</td>
<td></td>
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</tbody>
</table>


* Designation of Permian stage names in China is still in flux (cf. Enos, 1995; International Union of Geological Sciences, 2000). Guizhou stage names are used here. Changxing (Changshiangan) and Wujiaaping (Wuchiapinian) are recognized as semiformal stages by IUGS (2000), although the formations on which they are based are considered partially time equivalent in Guizhou (Guizhou Bureau, 1987, p. 271).
bearing mudrock, a carbonate ramp developed in the Induan across the flat top of the Permian platform. Distal ramp deposits are thin, commonly laminated, beds of dark-gray lime mudstone with ammonoids and thin-shelled bivalves (Luolou Formation; table 2, fig. 3, 7). Interspersed carbonate breccias reflect intrabasinal slumps and debris flows from shallower environments to the northwest. Thin-beded lime mudstones with prominent burrowed horizons formed on the mid-ramp (Daye Formation; table 2, fig. 3, 7). Updip, three to five thick intervals of oolite are interspersed within mudrock and lime mudstone (Yelang Formation; table 2, fig. 3). Mudrock and sandstone predominate westward toward the Khamdian massif. Basinal deposits in the Olenekian are alternating lime mudstone and terrigenous mudrock totaling only 100 m thick (upper Luolou Formation; table 2, fig. 3, 7). Peritidal carbonate cycles capped by tepee molds of gypsum crystals and rosettes. Peritidal cycles are subtidal lime mudstones with sparse but widespread molds of gypsum crystals and rosettes. Peritidal cycles are confined to near the platform margin (Guanling Formation; table 2, fig. 4). Numerous thin shale interbeds that give a ledged appearance to outcrops were probably derived from the east, where red mudrock and sandstone signal the emergence of the Jiangnan massif. The first well-developed reefs of the Triassic formed a narrow, elevated rim on the platform. *Tubiphytes, Plexoramea*, arborescent corals, and sponges formed a framework with copious encrustation by other problematic fossils and cements (Poduan Formation; table 2, fig. 4, 7). Episodic collapse of the reef margin produced an apron of bioclasts and debris at the basin margin that includes reef blocks up to 100 m long (Qingyan Formation; table 2, fig. 4; Enos et al., 1997). The lagoon became very restricted toward the end of the Olenekian with the deposition of evaporites, represented by extensive solution-collapse breccias.

The Early-Middle Triassic boundary in Guizhou is demarcated by a widespread acid tuff layer, dated at 247 Ma (Martin et al., 2001). Anisian deposits in the Nanpanjiang basin are predominately siliciclastic mudrocks, only 250 m thick in central Guizhou, but more than 1000 m thick to the southwest (Xinyuan and Zuman Formations; table 2, fig. 4, 7). Platform-interior deposits are subtidal lime mudstones with sparse but widespread molds of gypsum crystals and rosettes. Peritidal cycles are confined to near the platform margin (Guanling Formation; table 2, fig. 4). Numerous thin shale interbeds that give a ledged appearance to outcrops were probably derived from the east, where red mudrock and sandstone signal the emergence of the Jiangnan massif. The first well-developed reefs of the Triassic formed a narrow, elevated rim on the platform. *Tubiphytes, Plexoramea*, arborescent corals, and sponges formed a framework with copious encrustation by other problematic fossils and cements (Poduan Formation; table 2, fig. 4, 7). Episodic collapse of the reef margin produced an apron of bioclasts and debris at the basin margin that includes reef blocks up to 100 m long (Qingyan Formation; table 2, fig. 4; Enos et al., 1997). The total absence of reef facies, except in the transported blocks, along most of the 175-km-long debris apron in the northeast (Guiyang area, fig. 4) suggests a uniform retreat of at least 3 to 7 km, the average width of the reef belt elsewhere. The platform margin apparently grew higher and steeper.
### TABLE 2. STRATIGRAPHIC UNITS AND DEPOSITIONAL ENVIRONMENTS OF THE TRIASSIC SYSTEM SOUTHWESTERN GUIZHOU

<table>
<thead>
<tr>
<th>STAGE</th>
<th>PLATFORM INTERIOR</th>
<th>PLATFORM MARGIN</th>
<th>BASIN</th>
<th>GUIYANG AREA (PLATFORM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>RHAETIAN</td>
<td>ERQIAO FM.</td>
<td>NO STRATA PRESERVED</td>
<td>ERQIAO FM.</td>
<td>Thinner sandstone and mudstone. Distal stream deposits</td>
</tr>
<tr>
<td></td>
<td>Braided-stream gravel to mudstone</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NORIAN</td>
<td>HUOBACHONG FM.</td>
<td></td>
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<td>HIATUS</td>
</tr>
<tr>
<td></td>
<td>Cyclic braided-stream deposits; marine mudstone incursions;</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>paralic coals</td>
<td></td>
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</tr>
<tr>
<td>CARNIAN</td>
<td>BANAN FM.</td>
<td></td>
<td></td>
<td>HIATUS</td>
</tr>
<tr>
<td></td>
<td>Cyclic sandstone and mudstone; shallow-shelf to coastal</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>LAISHIKE FM.</td>
<td>LAISHIKE FM.</td>
<td>SANQIAO FM.</td>
<td>Shallow-marine sandstone, mudstone, limestone</td>
</tr>
<tr>
<td></td>
<td>Flysch; turbidite sandstone &amp; mudrock</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>WAYAO FM.</td>
<td></td>
<td>BIANYANG FM.</td>
<td>Partly or entirely Carnian?</td>
</tr>
<tr>
<td></td>
<td>Condensed black shale &amp; mudrock</td>
<td></td>
<td></td>
<td>GAICHA FM.</td>
</tr>
<tr>
<td></td>
<td>ZHUGANPO FM.</td>
<td></td>
<td></td>
<td>Peritidal limestone with minor sandstone &amp; mudrock</td>
</tr>
<tr>
<td></td>
<td>Deep-water, nodular lime mudstone</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LADINIAN</td>
<td>YANGLIUJING FM.</td>
<td>LONGTOU FM.</td>
<td>BIANYANG FM.</td>
<td>LONGTOU FM.</td>
</tr>
<tr>
<td></td>
<td>Cyclic peritidal dolostone tepees common</td>
<td>Cyclic peritidal limestone tepees common</td>
<td></td>
<td>Cyclic peritidal limestone tepees common</td>
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<tr>
<td>ANISIAN</td>
<td>GUANLING FM.</td>
<td>PODUAN FM.</td>
<td>XINYUAN FM. (thin)</td>
<td>PODUAN FM. (Same)</td>
</tr>
<tr>
<td></td>
<td>Subtidal argillaceous limestone; evaporite molds</td>
<td>Framework reefs of Tubiphytes &amp; arborescent corals; breccia</td>
<td>ZUMAN FM. (v. thick) Distal turbidites &amp; mudrock, + calcareous</td>
<td>QINGYAN FM. (basin margin)</td>
</tr>
<tr>
<td>OLENKIAN</td>
<td>YONGNINGZHEN FM.</td>
<td>ANSHUN FM.</td>
<td>UPPER LUOLOU (ZIYUN) FM.</td>
<td>ANSHUN FM.</td>
</tr>
<tr>
<td></td>
<td>Subtidal muddy limestone; evaporites in top</td>
<td>Cyclic peritidal dolostone, oolite.</td>
<td>Mudrock + calcareous</td>
<td>Cyclic peritidal dolostone, Tepees common</td>
</tr>
<tr>
<td>INDUAN</td>
<td>YELANG FM.</td>
<td>DAYE FM.</td>
<td>LUOLOU FM.</td>
<td>DAYE FM.</td>
</tr>
<tr>
<td></td>
<td>Limestone &amp; oolite; red weathering typical</td>
<td>Mid-ramp; interbedded laminated &amp; burrowed lime mudstone</td>
<td>Distal ramp; mudrock (base); laminated lime mudstone (top)</td>
<td>Mid-ramp; interbedded laminated &amp; burrowed lime mudstone</td>
</tr>
</tbody>
</table>


FEIXIANGUAN FM. (Induan, western Guizhou): sandstone & mudrock, fluvial and littoral deposits
BADONG FM. (Middle Triassic, eastern Guizhou): sandstone and red shale
in the Ladinian, although sands of bioclasts and grapestone formed the margin, whereas reefs were confined to small patches (Longtou Formation; table 2, fig. 5, 7). Peritidal cycles capped by tepee structures are ubiquitous and extend far into the platform interior, indicating a flat top to the platform. This package, around 1000 m thick, of limestone at the margin and dolostone in the interior forms the most prominent ridges in the landscape of southwestern Guizhou (Longtou and Yangliujing Formations; table 2, fig. 5). The Ladinian platform margin prograded at least 600 m over Anisian basinal deposits south of Guiyang (Xinyuan Formation, table 2, fig. 7), but backstepped and aggraded in the Zhenfeng area (fig. 5). The basin was eventually filled with flysch deposits, hemipelagic mudrock and fine-grained turbidite sandstones about 2000 m thick (Bianyang Formation; table 2; Enos et al., 1998). Carbonate deposition soon ceased, resulting in a condensed sequence characterized by black shale and marl with concentrations of manganese, iron and organic carbon (Wayao Formation; table 2). The Wayao Formation is gaining fame for its spectacular crinoid and marine reptile lagerstätte developed in the Guanling area (fig., 5; Yin et al., 2000). Accommodation space created during drowning was subsequently filled by up to 800 m of turbiditic sandstone and mudrock and 465 m of shallow-shelf sandstone during the Carnian (Laishike and Banan Formations; table 2). Thinning- and fining-upward cycles of conglomerate and cross-bedded sandstone of the Norian are interpreted as braided-stream deposits with interspersed paralic coals and mudrocks bearing fresh-water, brackish, or marine fossils (Huobachong Formation; table 2, fig. 7). Still coarser grained deposits of the Rhaetian indicate rejuvenation of braided streams to form a clastic wedge that thins and fines rapidly to the east and slowly to the north as it spread across a surface that beveled platform deposits as old as Anisian (Erqiao Formation; table 2, fig. 7). Thus, the...
long and impressive history of the Yangtze carbonate platform ended in the Carnian throughout Guizhou.

**Isolated carbonate platforms of the Nanpanjiang basin in Guizhou and Guangxi**

During the Triassic several isolated platforms developed within the Nanpanjiang basin including the Great Bank of Guizhou in southern Guizhou Province, and the Debao, Jinxi, Heshan and Chongzuo-Pingguo platforms in southern Guangxi (fig. 3). Each of the platforms is delineated from regional mapping of the distribution of shallow-marine carbonate platform facies and deep-water basinal carbonate and clastic facies. The Great Bank of Guizhou nucleated on antecedent topography inherited from the Late Permian Yangtze platform margin (fig. 2, 3). The isolated platforms in southern Guangxi may represent continued accumulation of shallow-marine carbonate sediments atop older isolated platforms that existed already in the Late Permian, although regional mapping in Guangxi does not differentiate facies sufficiently to delineate platform distribution (fig. 2). The southern margin of the Chongzuo-Pingguo platform was controlled by a regional fault for much of its length (fig. 2, 3). The north wall of the fault was elevated in the Late Permian.

Regional maps delineate the Great Bank of Guizhou to be composed of shallow-marine carbonate platform facies of the Lower Triassic Daye and Anshun Formations, and the Middle Triassic Poduan and Longtou Formations surrounded by basinal facies of the Lower Triassic Luolou Formation and the Middle Triassic Xinyuan and Bianyang Formations (fig. 3, 4, 5, 7). Like the Yangtze platform, the Great Bank of Guizhou evolved from a ramp (or low relief bank) profile in the Early Triassic through a progressively steepening reef-rimmed profile in the Middle Triassic and was terminated and buried with clastics in the Late Triassic Carnian (fig. 7). Details of the lithofacies and depositional environments of the Great Bank of Guizhou are provided in the following section.

The Debao, Jinxi, Heshan and Chongzuo-Pingguo platforms in Guangxi are delineated in regional geological maps as shallow-marine carbonate facies of the Majiaoling and Beisi Formations surrounded by basinal carbonates and clastics of the Luolou and Nanhong Formations respectively (fig. 3). The Majiaoling Formation consists of thin-bedded and burrowed lime mudstone with thin lenses of oolite. The Beisi Formation, in contrast, contains a number of thick beds of oolite grainstone, and contains restricted molluscan biota, supratidal fabrics and dolostone in its upper part. In the Chongzuo-Pingguo platform the Majiaoling and Beisi Formations are 140 m and 750 m thick respectively. Oolite intervals in the Beisi Formation at Chongzuo are typically cross-bedded and occur in mas-
sive ridge forming units up to 50 m thick (Pei Donghong, unpublished data). The Luolou Formation consists of dark-gray to black, ammonoid bearing, thin-bedded and laminated lime mudstone with shale interbeds. Some intervals contain bedding parallel burrows and the unit contains debris-flow breccias adjacent to carbonate-platform margins. The Nanhong Formation occurs south of the Chongzuo-Pingguo platform and consists of ammonoid bearing sandstone, shale and siliciclastic mudstone. During the Early Anisian much of the area of the southernly isolated carbonate platforms was terminated (drowned) during a deepening event and the platforms were subsequently overlain by siliciclastic turbidites of the Banna and Baifeng Formations (fig. 4). Just prior to carbonate platform drowning and shift to basin-clastics a thick pile of felsic pyroclastic volcanics and lava flows were deposited on top of the southern part of the Chongzuo-Pingguo platform (Guangxi Bureau, 1985). Although the volcanism effectively buried the platform, shallow-marine carbonate sedimentation resumed briefly following the cessation of volcanic activity. Deepening then resulted in a shift to pelagic carbonates and siliciclastics as the platform drowned in the Early Anisian. The northern part of the Pingguo-Chongzuo platform (Pingguo area) as well as the Heshan platform to the east also suffered drowning in the Early Anisian (fig. 3-4; Kessel and Gross, 2002). During the regional drowning of shallow-marine carbonate sedimentation in southern Guangxi, small areas of carbonate sedimentation accumulated to produce Anisian pinnacle platforms within the Pingguo area (fig. 4). The pinnacle platforms are represented by the Guohua Formation and are composed of peritidal dolomite and limestone containing Tubiphytes reefs. The pinnacle platforms accumulated 1700 m of shallow-marine carbonate in the Anisian prior to termination and burial with siliciclastic turbidites in the Ladinian (fig. 4, 5). The overall pattern of earlier termination, greater thickness of shallow-marine carbonate, step-back and pinnacle development in southern Guangxi in contrast to later termination in the Great Bank of Guizhou in the northern Nanpanjiang basin (fig. 3, 4, 5) is interpreted to be controlled by higher rates of tectonic subsidence in the southern basin (fig. 6).


The Great Bank of Guizhou (GBG) is an isolated Triassic carbonate platform, extending approximately 70 km east-west and 20 km north-south in southern Guizhou Province (fig. 3, 8). The stark contrast in topography between the rugged, high-relief karst terrain of the carbonate platform and the lower stream-eroded siliciclastic turbidites in the basin spectacularly reveals the abrupt platform margins as one approaches the area on the ground (e.g.
Much of the GBG is nearly undeformed except for a NNW-trending asymmetric, faulted syncline that splits the platform perpendicular to its long dimension (Bianyang syncline; fig. 8, 9). The east limb of the syncline exposes a continuous cross section through the interior and margins of the platform and contains a complete record of the initiation of the GBG as an isolated platform in the Late Permian, progressive steepening of the platform from low-relief bank stage in the Early Triassic, aggrading reef-rimmed stage in the Anisian, high-relief escarpment development in the Ladinian, and finally drowning and burial by turbidites in the Carnian termination stage (fig. 10).

The following provides a summary of the evolution of the GBG interpreted from mapping of the architecture and facies in the Bianyang syncline (Lehrmann, 1993).

Late Permian to earliest Triassic: Initiation stage

The GBG was initiated in the latest Permian and earliest Triassic, during expansion of the Nanpanjiang basin, as a local area of shallow-marine carbonate accumulation (fig. 2, 3). Expansion of the basin drowned much of the shallow-marine carbonates in the eastern Yangtze platform north of the GBG beneath black, siliceous lutite of the Dalong Formation (fig. 2, 9). The siliceous lutite contains pelagic fossils such as radiolarians and ammonoids. The combination of the black color, pelagic fossils and bioturbation suggests a dysaerobic environment.

In the latest Permian, north of Luodian in the Bangeng-Bianyang area, shallow-marine skeletal grainstone-packstone and patch reefs of sponge boundstone formed the initial accumulation of the GBG (fig. 9, 10A). These shallow-marine strata extend across the base of the platform and across its adjacent basin margins. The strata extend horizontally into the basin with no indication of Permian faults or uplift, indicating that the GBG did not nucleate on a tectonic structure (fig. 9, 10A). The plat-
form nucleated on depositional topography near the margin of the former Yangtze platform (fig. 2, 3).

Upper Permian skeletal grainstone-packstone in the interior of the GBG (at the base of Dawen, Dajiang, Heping and Rungbao sections; fig. 10A, 11) contains diverse normal-marine fossils, which are extensively fragmented. The diverse fauna, fragmented fossils and grainstone texture indicate an open marine, shallow-subtidal environment occasionally winnowed by wave action. Sponge boundstones at the margins also contain diverse open-marine faunas (fig. 10A), but, in contrast, have muddy fabrics suggesting somewhat deeper, subtidal environments below normal wave-base. The sponge boundstone passes basinward into the siliceous lutite of the Dalong Formation (fig. 9, 10A).

During the earliest Triassic the GBG maintained a similar morphology despite the end-Permian mass extinction (fig. 10A). The end-Permian extinction is recorded across a conformable Permian-Triassic boundary at Dawen, Dajiang, Heping and Rungbao sections, which is marked by an abrupt shift in marine biota, but with no indication of a significant hiatus or an overall change in depositional environments (fig. 11). In the earliest Triassic, calcimicrobial framestone was deposited across the platform interior and the basin-margin shifted to the deposition of marine shale containing the bivalve *Claraia* at Guandao section (fig. 9, 10A, 13). PTB sections will be examined at Dajiang, Rungbao and Guandao sections: stops 4A, 4B, 5.

**Early Triassic: Low-relief bank stage**

After deposition of calcimicrobial framestone in the earliest Triassic, relative rise in sea-level caused the margins of the GBG to step back ~700 m as the GBG developed a low-relief bank profile with a shallow subtidal to peritidal interior, oolite-grainstone margins and basin-margin flanks composed of pelagic lime mudstone, debris-flow breccia and turbidite grainstone-packstone (fig. 9, 10B). Deepening and step back of the margins, at the beginning of the low-relief bank stage, are supported by the fact that the pelagic, debris-flow and turbidite facies overlie the former platform-margins of the initiation stage (fig. 10B). The basin-margin strata of the low-relief bank stage dip gently (~1.5°) away from the platform, which is interpreted to have developed 50 to 100 m of relief based on differences in thickness of platform and basin-margin strata.

On the platform interior, the calcimicrobial framestone is overlain conformably by thin-bedded lime mudstone followed by dolo-oolite grainstone, oolitic cryptagal-laminitite and peritidal cyclic-limestone (fig. 9, 10B). The lime mudstone is light gray, thin bedded and contains a depauperate fauna of small bivalves and gastropods (fig. 11) suggesting restricted conditions in the interior at the beginning of the low-relief bank stage. The lime mudstone is overlain by cross-bedded dolo-oolite grainstone (fig. 9, 10B). The shift to oolite deposition indicates that high-energy shoal environments spread across the platform interior. Overlying the dolo-oolite is oolitic, cryptagal-laminitite which consists of alternating cryptalgal laminae (horizontal stromatolite layers) and ooid packstone layers (fig. 10B). The oolitic cryptagal-laminitite contains fenestral pores, meniscus cements and leached-oolid fabrics indicating subaerial exposure in a supratidal environment.

During the later part of the low-relief bank stage, oolite shoals continued on the margins while a peritidal cyclic-limestone facies was deposited on the platform interior (fig. 10B). The peritidal cyclic-limestone is made up of meter-scale cycles with skeletal packstone, oolitic packstone or calcimicrobial framestone bases and caps of laminated “ribbon-rock” mudstone to packstone (fig. 12).
Figure 9: Geological map of the eastern limb of the Bianyang syncline (from Lehrmann, 1993). Location of map area is the eastern limb of the syncline shown in figure 8. Stops for the field excursion and stratigraphic sections discussed in the text are shown.
Dajiang section contains more than 60 such cycles. The peritidal cyclic-limestone is interpreted to have formed as shallowing-upward cycles in open-marine to restricted, subtidal and intertidal environments. We will have an opportunity to examine each of the Lower Triassic platform interior facies (thin bedded lime mudstone, doloolite grainstone, oolitic cryptagal-laminitie and peritidal cyclic-limestone) as we hike through the Lower Triassic platform interior succession at Dajiang Section – stop 4A.

Middle Triassic Anisian-Early Ladinian: Aggrading reef-rimmed stage

During the Middle Triassic (Anisian-Early Ladinian) aggrading reef-rimmed stage, *Tubiphytes* boundstones developed at the platform margin and cyclic tidal-flats formed on the platform interior (fig. 9, 10C). Basin-margin deposition began with pelagic lime-mudstone, debris-flow breccia and turbidite grainstone-packstone and later shifted to mud-free talus breccia as the platform progressively steepened (fig. 9, 10C). At the beginning of the reef-rimmed stage the platform expanded in width as the platform margin prograded over the basin-margin strata of the low-relief bank stage (fig. 9). Later the platform aggraded and prograded slightly (fig. 9). The platform-interior, peritidal cyclic dolomite is composed of meter-scale, shallowing-upward cycles with burrowed molluscan-peloidal packstone and domal stomatolite bases and fenestral-laminitie caps (fig. 10C). The unit is pervasively dolomitized and is locally coarsely crystalline, obliterating depositional fabrics.

The *Tubiphytes* boundstone forms extensive, unbedded deposits at the platform margin. The boundstone was found at all localities of the platform margin indicating that it forms a continuous rim, up to 1.5 km wide, around the GBG. The boundstone is composed of branching *Tubiphytes* frameworks with isopachous and botryoidal marine cements. The *Tubiphytes* frameworks are reinforced by micrite crusts, *Bacinella* and cement. In some areas marine cement makes up the majority of the volume of the boundstone. Locally the boundstone contains subsidiary frameworks of phaceloid scleractinian corals and sphinctozoan sponges. The *Tubiphytes* boundstone is interpreted to represent shallow-marine environments along the platform margin; fig. 9) and 4) the siliciclastic turbidites in the basin were deposited after the platform was terminated, and thus onlap the escarpment (fig. 9, 10E).

Adjacent to the *Tubiphytes* reef complex, the basin-margin slope succession is exposed at Guandao section (fig. 9, 13-14). Basin-margin sedimentation consisted of pelagic shale and hemipelagic lime mudstone to wackestone with thin-shelled bivalves, alloplastic carbonate turbidites and debris flows containing debris shed from the platform (polymict breccia). Lower Guandao section will be examined at stop 5; conodont biostratigraphy, magnetostratigraphy and radioisotope ages of volcanic ash layers provide a geochronology for the GBG. Allochthonous material shed from the platform also provides a “sampling” of sediment transported from the platform margin. At the Olenekian-Anisian boundary there is an abrupt shift from alloplastic units dominated by oolite clasts to *Tubiphytes* boundstone clasts signaling the onset of *Tubiphytes* reef development in the uppermost Spathian and Early Anisian (fig. 10B, C, 17).

Preserved architecture allows evaluation of depositional slope and relief. During the early part of the aggrading reef-rimmed stage (Anisian), basin-margin strata had slopes of approximately 5° and were composed of pelagic lime-mudstone with interbeds of muddy, debris-flow breccia and carbonate turbidite grainstone-packstone at Guandao section. During the later part (Early Ladinian) the platform developed up to 400 m of relief, the basin-margin progressively steepened up to 30° and slope sedimentation shifted to mud-free breccias and lithoclastic grainstones interpreted as avalanche deposits (fig. 9, 10C).

Ladinian: High-relief escarpment stage

During the later part of the Middle Triassic (Ladinian) the basin margins starved and the GBG accumulated vertically forming an erosional escarpment-margin with up to 1700 m of relief (fig. 9, 10D). The escarpment interpretation implies that the GBG developed a tremendous amount of relief during the Ladinian and was subsequently overlain by a thick succession of siliciclastic turbidites (fig. 10E). We will view the escarpment margin at stops 1 and 3. The high-relief escarpment interpretation is supported by four lines of evidence: 1) the contact between the platform carbonates and the siliciclastic turbidites is extremely sharp (fig. 9, 15), 2) the platform strata contain no siliciclastic interbeds, 3) the siliciclastic turbidites flanking the margin lack carbonate beds or carbonate debris except for a few small wedges of breccia immediately adjacent to the escarpment (extending <200 m from margin; fig. 9) and 4) the siliciclastic turbidites in the basin are younger than the platform carbonates as determined by conodont biostratigraphy (Lehrmann 1993). In other words the GBG grew to over 1700 m high and was bounded by an erosional escarpment. The siliciclastic turbidites in the basin were deposited after the platform was terminated, and thus onlap the escarpment (fig. 9, 10E).

Platform-margin strata exposed along the escarpment are skeletal-peloid packstone and grainstone with local boundstone (fig. 9). The facies is thick bedded with beds extending from the platform interior to the edge of the escarpment. The facies contains a mixture of peloids, bivalves, gastropods, dasycladacean algae and miliolids from most likely from restricted, platform interior environments and fragmented *Tubiphytes*, *Bacinella*, corals and echinoderms most likely representing open-marine environments along the platform margin. A few scleractinian bioherms are interbedded with the packstones and grainstones. This facies is interpreted to have been deposited as a mosaic of wave-winnowed shoals, local patch reefs and low-energy restricted areas between shoals and patch reefs. The facies could also represent such a mosaic of environments deposited in a back-reef setting, if reefs formerly occurred along the margin, but were sub-
The possibility that a reef rim existed along the escarpment, and was later removed by erosion, is suggested by diverse boundstone lithologies found in breccias at the base of the escarpment at the top of Guandao section (fig. 9). These breccias will be examined at the top of Guandao section (optional stop 6B). Boundstone clasts within the breccias have a biota with a greater diversity than the patch reefs interbedded in the platform margin. The boundstone clasts contain scleractinian corals, Tubiphytes, sphinctozoan sponges, bryozoans, Ladinella porata, solenoporacean algae, and inozoan sponges.

At the beginning of the high-relief escarpment stage, the platform developed an atoll-like profile with an interior lagoon composed of molluscan-oncolite packstone-wackestone that is bounded outboard by peritidal cyclic-limestone (fig. 9, 10D). The unit is composed of extensively burrowed skeletal-peloidal wackestone with bivalves, gastropods and dasycladacean algae, punctuated by oncolite packstone beds. The unit also contains rare domal stromatolites. This facies is interpreted to have been deposited in a restricted subtidal lagoon with water depths ranging from shallow-subtidal to occasionally intertidal.

Later, a flat-topped profile was restored as tidal flats spread across the former lagoon, depositing peritidal cyclic-limestone across the platform interior (fig. 10D). On the southern interior of the platform, the unit contains a thick interval disrupted by tepee structures (fig. 10D). The tepees disrupt an interval 300 m thick restricted to the southern bank-top, suggesting that they formed along a crest of islands.

Near the end of the high-relief escarpment stage, deepening resulted in a shift to subtidal conditions across the platform interior. This deepening is represented by a shift from peritidal cyclic limestone to skeletal-peloidal packstone (fig. 10D). The skeletal-peloidal packstone is an extensively burrowed facies with bivalves, gastropods and calcareous algae. The unit lacks any evidence of peritidal facies such as fenestral lamination. The biota indicates restricted, quiet, subtidal environments.

**Late Triassic Carnian: Termination (drowning)**

At the beginning of the Late Triassic (Carnian) the GBG was terminated as water depths increased over the platform top and the platform was buried by a thick pile of siliciclastic turbidites and marine shales (fig. 7, 10D). The platform was terminated by drowning as indicated by an upward shift from shallow-subtidal carbonates to deep-marine, nodular-bedded carbonates with deep-water conodont bioclasts (fig. 16). We will view the termination horizon from the distance at stop 2.

**Record of end-Perman extinction and Early-Middle Triassic recovery**

The GBG contains one of the most continuous and expanded known records of the end-Permian mass extinction and the subsequent Early and Middle Triassic recovery interval. In particular, the exposure of a two-dimensional cross section from platform-interior to platform-margin and basin-margin environments provides the opportunity to separate the effects of local environment from those of regional to global biotic recovery (fig. 8, 9). Although extracting macrofossils from the platform limestones for genus- and species-level identification is hindered by the small size of the fossils and their preservation in clean limestones, analyses of thin sections and polished slabs provide the opportunity to track broad changes in faunal composition and abundance that complement more detailed taxonomic studies in areas where environmental and stratigraphic controls are not as well developed. Decreases in fossil abundance and size are readily apparent in the field across the Permian-Triassic boundary in both platform and basin settings, as is the shift from a fauna dominated by crinoids, sponges and brachiopods to one dominated by mollusks. Faunal recovery occurs on the GBG through the Spathian and Middle Triassic, consistent with the timing of diversity and size increase observed elsewhere in the marine record (e.g., Schubert and Bottjer, 1995; Payne et al., 2004; Payne, in press).

**End-Permian mass extinction**

The end-Permian extinction horizon is distinct and well exposed in the platform interior sections at Dawen, Heping, Rungbao and Dajiang (fig. 9, 10). We will have the opportunity to examine the extinction horizon in detail at the Dajiang section (stop 4A) and another opportunity at Rungbao (stop 4B). Upper Permian (Changxingian) strata at Dajiang consist of fossiliferous packstones and grainstones containing a diverse fauna of sphinctozoan and inozoan sponges, crinoids, echinoids, brachiopods, bivalves, gastropods, diverse foraminifera (including fusulinids), *Tubiphytes* and dasycladacean algae (fig. 11). Many of these fossil grains are visible to the naked eye on weathered surfaces or with the aid of a hand lens. In particular, it is easy to find large and abundant crinoid ossicles and inozoan sponges.

The extinction horizon consists of a sharp but irregular surface upon which the calcimicrobial framestone developed. The surface is stylolitized in many locations, but analysis in thin section demonstrates that the boundary between diverse Upper Permian packstones and the calcimicrobial framestone is conformable where it is not stylolitized and lacks evidence of subaerial diagenesis. The calcimicrobial framestone contains a low-diversity fauna of ostracods, gastropods and bivalves that occur within the micrite matrix filling many of the voids in the microbialite (fig. 11). Small gastropods (<1 cm) can often be identified in the field within hand samples of the microbialite. Immediately overlying the 15 meters of calcimicrobial framestone at Dajiang are several packstone beds containing abundant small (<1 mm) gastropods and bivalves with subordinate articulate brachiopods and rare echinoid spines (fig. 11). Many of these grains form the nuclei of small oncoids. Above this fossiliferous inter-
Fossil abundance decreases and remains low (<< 1%) through several tens of meters of lime mudstone (fig. 11).

The most salient features to note at the Dajiang section are: 1) the thickness (>40 m) and diversity of Upper Permian packstone and grainstone, 2) the dominance of the Late Permian fauna by taxa with low metabolic rates and heavy calcification (e.g., sponges, brachiopods, crinoids) and 3) the small size of Early Triassic fossils and the dominance of mollusks.

**Early-Middle Triassic recovery:**

The abundance, diversity and size of fossil grains on the GBG did not change significantly from the Griesbachian through the Smithian. The low abundance and low diversity of Upper Permian packstone and grainstone, 2) the dominance of the Late Permian fauna by taxa with low metabolic rates and heavy calcification (e.g., sponges, brachiopods, crinoids) and 3) the small size of Early Triassic fossils and the dominance of mollusks.

![Figure 10: Restored cross-sections of the GBG illustrating Late Permian through Late Triassic evolution. Sections are from the Binyang syncline and correspond to field trip localities (see figure 9). A) Upper Permian to basal Triassic: Initiation stage, B) Lower Triassic: Low-relief bank stage, C) Middle Triassic Anisian-Early Ladinian: Aggrading reef-rimmed stage, D) Ladinian: High-relief escarpment stage, E) Late Triassic Carnian: Termination (drowning stage).](image-url)

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**Early-Middle Triassic recovery:**

The abundance, diversity and size of fossil grains on the GBG did not change significantly from the Griesbachian through the Smithian. The low abundance and low diversity of fossil grains in all environments, from the platform interior through the platform margin and into the basin margin, suggest that the pattern reflects more than merely local environmental controls on fossil abundance and diversity. The first evidence of biotic recovery locally is an increase in the abundance and diversity of fossils in Spathian basin-margin strata (fig. 13). We will have an opportunity to observe the increase in fossil abundance from the Smithian through the Anisian at the Guandao section during stop 5. Fossil abundance increased gradually through the Spathian, primarily due to an increase in the abundance of crinoid grains. This increase does not appear to result solely from increasingly effective transport of grains from the platform margin at this time because older Lower Triassic turbidites contain micritic grains of similar sizes but do not contain abundant crinoid ossicles. Anisian packstones and grainstones on the basin margin contain similarly abundant, but larger, crinoid ossicles as well as abundant Tubiphytes grains, gastropods, bivalves and rare ammonoids (fig. 13, 14). The first occurrence of Tubiphytes grains in the uppermost five meters of the Spathian indicates that the platform-margin reef complex was initiated by this time (fig.10C, 13). Growth of the reef complex from the latest Early Triassic and earliest Middle Triassic makes it significantly older than preserved Anisian reefs in the Dolomites and suggests that it was among the first platform-margin reefs to form after the end-Permian mass extinction. Large, framework-building metazoans are absent from the Anisian reef complex, however, which was constructed primarily by Tubiphytes, a problematic micritic tube that appears, at least locally, to reflect micritic cementation around a siphonous alga. Scleractinian cor-

![Figure 10: Restored cross-sections of the GBG illustrating Late Permian through Late Triassic evolution. Sections are from the Binyang syncline and correspond to field trip localities (see figure 9). A) Upper Permian to basal Triassic: Initiation stage, B) Lower Triassic: Low-relief bank stage, C) Middle Triassic Anisian-Early Ladinian: Aggrading reef-rimmed stage, D) Ladinian: High-relief escarpment stage, E) Late Triassic Carnian: Termination (drowning stage).](image-url)
Acknowledgements

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