Field Excursion 2:
Permian-Triassic boundary and a Lower-Middle Triassic boundary sequence on the Great Bank of Guizhou, Nanpanjiang basin, southern Guizhou Province

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Introduction

The stratigraphic framework and Permian-Triassic depositional history of the Great Bank of Guizhou are presented in a preceding paper in this volume titled: Permian and Triassic depositional history of the Yangtze platform and Great Bank of Guizhou in the Nanpanjiang basin of Guizhou and Guangxi, south China. To avoid duplication, all figures referenced in this guide are found in the preceding paper (see pages 147-166, this volume). The following stop descriptions provide additional detailed information on the Permian-Triassic stratigraphy and record of the end-Permian extinction and biotic recovery in the Great Bank of Guizhou (GBG). The GBG is dissected by a NNW trending syncline (Bianyang syncline; fig. 8). The steeply dipping strata on the eastern limb of the syncline provide a two dimensional cross section through the platform permitting reconstruction of the depositional history and providing access to our field stops (fig. 9, 10).

Stops of the Excursion:

Stop-1 Overview Nanpanjiang basin and southern margin of Great Bank of Guizhou (southeast of Bangeng)

During the field excursion we will stay in the town of Luodian 10 km south of the Great Bank of Guizhou (fig. 8). Luodian is situated on an ENE trending anticline; Devonian, Carboniferous and Permian marine strata are exposed along its axis. As we drive northward we will cross Paleozoic strata on the anticline and then enter Triassic basinal strata. Most of the drive will be through Upper Triassic (Carnian) siliciclastic turbidites of the Bianyang Formation (fig. 5, 7). In satellite images the siliciclastic turbidites are distinguished from the platform by the sharp contrast in rounded stream-eroded topography of the siliciclastics versus the tower karst developed in the carbonate of the GBG (fig. 8).

The Bianyang Formation, exposed along much of the road between Luodian and Bangeng, is a typical flysch deposit (Chaikin, 2004). It has the sedimentologic attributes of great thickness (1000-3000 m), alternation of thin, matrix-rich clastic beds with hemipelagic background deposits, and abundant sole marks on the clastic beds. The spectrum of sedimentary structures (flute casts, groove casts, prod marks, load casts, climbing ripples, mud dippirs, dish structures, piping structures and flame structures) are diagnostic of turbidity-current deposition. The abundance and exquisite detail of the fluid-escape structures may reflect unusually rapid deposition, consistent with Lehrmann’s corollary of extremely rapid filling of the Nanpanjiang basin surrounding the Great Bank of Guizhou in the Early Carnian, rather than Ladinian as generally assumed (Lehrmann, 1993; Lehrmann et al., 1998).

The lower part of the Bianyang Formation (300-400 m) is characteristically dominated by sandstone with many thick, amalgamated beds, well exposed along the field trip route. The upper part, thicker than 1100 m, is dominated by mudstone. The sandstones are consistently very fine sand. They are matrix rich, with the average matrix content between 9% and 18%, depending on how much of the abundant calcite is calcitized matrix. The average QFL ratio is 74/10.5/16. Lithic components are claystone, siltstone, meta-siltstone and metaquartzite; igneous rock fragments are rare.

Paleocurrents within the Bianyang Formation in southern Guizhou are generally directed from east to west (Hou and Huang, 1984; Sun et al., 1989; Chaikin, 2004), with apparent local interaction with the carbonate platforms (Chaikin, 2004). Measurement of 57 paleocurrent vectors from the Luodian section gave a dominant mode of 317°, a southerly secondary mode (185°) and a mode of 265° from ripple marks. The mean of 79 lineations, mostly groove casts, is 325°, consistent with the vector mode. An obvious eastern source terrain would be the Jiangnan massif, which was largely exposed during Ladinian and Carnian times (fig. 5; Liu and Xu, 1994, p.158). It possibly merged with the Yunkai massif to the south to form the entire eastern border of the Nanpanjiang basin. Much
of the rock currently exposed in the Jiangnan massif consists of low-grade, siliciclastic metasedimentary rocks. Volcanoclastics, glacial-marine deposits and granitic intrusions are also well represented (Guizhou Bureau, 1987). The fine-grained quartz, siltstone clasts and feldspar could derive from such a source area. This vast terrain could have readily provided the voluminous deposits of the Bianyang Formation without necessitating extensive or rapid uplift. In order to deliver the sediment to the basin rapidly enough to fill it, however, whether during the entire Ladinian or only a part of the Carnian seems to require storing large quantities of fine-grained, unconsolidated sediment in large, mature drainage basins to be rapidly flushed out with rejuvenation. The upper part of the Bianyang Formation, well over half the total volume, consists of mudrock and siltstone, with virtually no sandstone. Thus, the source area ceased to deliver sand, but must then have supplied mud at a prodigious rate.

As we approach the GBG a large plateau of tower karst will be visible to the north. At stop 1, approximately 1 km south of the GBG (fig. 9) we will overview the siliciclastic turbidites of the Bianyang Formation and the southern margin of the GBG. The carbonate strata visible from the distance are primarily Ladinian in age. The abrupt Ladinian margins of the GBG are interpreted to have formed as an aggradational and erosional escarpment that developed approximately 1700 m of syndepositional relief above the adjacent basin margin and then was onlapped by the siliciclastic turbidites of the Bianyang Formation (fig. 9, 10D). Although the abrupt escarpment of the GBG is visible on the southern margin, the stratigraphic relationships are best demonstrated along the northern margin south of Bianyang (see at stop 3, fig. 8, 9). As the road approaches the base of the escarpment, east of the town of Bangeng, tongues and isolated pods of carbonate breccia are visible enclosed within the Upper Triassic siliciclastic strata of the Bianyang Formation (fig. 9). These breccias occur at the base of the Ladinian escarpment and are equivalent to the Carnian breccias interbedded with the Bianyang Formation exposed at the top of Guandao section at stop 6B (see below). The breccias contain a diverse reef fauna of *Tubiphytes*, scleractinian corals, sphinctozoan and inozoan sponges and solenoporacean algae and are interpreted to have been eroded from Ladinian patch reefs or a fringing reef developed along the high-relief escarpment (fig. 10D). When we reach the town of Bangeng the road turns north and enters Ladinian platform-interior strata along the axis of the Bianyang syncline (fig. 8, 9).

**Stop-2 Overview of Bianyang syncline and termination sequence of the GBG. Uppermost carbonates (Ladinian) followed by drowning and shale deposition (Carnian). Roadside stop 1.5 km north of Bangeng (fig. 9)**

As we drive from the town of Bangeng northward to stop 2, we traverse Ladinian carbonate strata from platform-marginal facies near Bangeng to peritidal, cyclic, platform-interior facies. The road crosses a zone of amalgamated tepee structures south of stop 2 (fig. 9). At Bangeng section, just west of the road, the tepee structures disrupt an interval of platform carbonates 300 m thick and provide abundant evidence of prolonged subaerial exposure (fig. 9). The tepee interval is interpreted to represent a zone of emergent islands restricted to the southern banktop (fig. 10D). Above the peritidal carbonate at Bangeng section is an interval of subtidal molluscan packstone 200 m thick followed by deepening-upward carbonate facies and a shift to marine shale (fig. 9). The marine shale in the axis of the syncline marks the termination of carbonate deposition on the GBG (fig. 9).

During the termination, the last carbonates to be deposited on top of the platform were oolitic-skeletal grainstone to packstone beds that grade upward to nodular-bedded, skeletal-oncolitic lime wackestone (fig. 16). Deepening is supported by a shift to diverse open-marine biota over the bank top and the nodular-bedded facies at the very top of the section. Included are Neogondolellid conodonts, representing deep-marine biofacies (fig. 15). Deepening conditions are inferred to have ended restricted shallow-subtidal conditions, beginning with wave-agitated conditions resulting in ooid grainstones which later pass upward to quieter, deeper, open-marine conditions represented by the nodular-bedded, skeletal-oncolitic wackestones (fig. 16). Oncoids within the nodular-bedded wackestone facies are encrusted by a consortium of cyanobacteria, serpulid worms and bryozoans. They probably formed as algal nodules in relatively deep-water environments similar to algal nodules found in deep environments adjacent to modern Carribean platforms (Reid and McIntyre, 1988). Similar algal nodules have also been reported from 135 foot water depths in Florida (Enos and Perkins, 1977).

**Stop-3 Overview of the northern high-relief escarpment of the GBG. Roadside south of Bianyang (fig. 9, 15)**

From stop 2 we continue to drive northward through Carnian shale in the axis of the Bianyang syncline. Eventually the road emerges on the northern margin of the GBG and winds its way northward and upward through siliciclastic turbidites of the Bianyang Formation (fig. 9). Stop 3, on a tall mountain in the Bianyang Formation, provides an ideal vantage point to look southeast and examine the Ladinian high-relief escarpment from a distance. At stop 3 we are approximately on structural strike (NNW-SSE) with the Ladinian carbonate of the GBG escarpment which dip 70° to the SW. The most conspicuous features are the extremely thick and well-beded Ladinian carbonates of the platform and the extremely sharp contact between the carbonates and basinal clastics in the foreground. From this vantage point the first impression is that the contact is a fault. However, a fault interpretation is ruled out because mapping demonstrates that there is no offset of underlying or overlying strata (fig. 9, 15). The sharp contact between the carbonates and clastics is
interpreted to have formed as a high-relief aggradational and erosional escarpment with 1700 m of syndepositional relief developed as the platform aggraded in the Ladinian (fig. 10D). After the platform was drowned during the Early Carnian (see stop 2) the siliciclastic turbidites onlapped the escarpment and buried the platform. The escarpment interpretation is supported by conodont biostratigraphy which demonstrates that the siliciclastic turbidites at the top of Guandao section (fig. 9) are Carnian and entirely younger than the uppermost platform carbonates (which are Ladinian). Further support comes from the lack of intertonguing of the carbonates and siliciclastics except for small tongues of breccia at the base of the escarpment at the top of Guandao section (fig. 9).

Stop-4a Permian-Triassic boundary and Lower Triassic platform-interior facies at Dajiang

Permian-Triassic boundary at Dajiang section (including a description from Heping section 1 km south of Dajiang)

Lithofacies and stratigraphy- Continuous Permian-Triassic boundary (PTB) successions are exposed in several sections in the interior of the GBG on the east limb of the Bianyang syncline (fig. 9). Stop 4A will examine the boundary at Dajiang section. Optional stop 4B will examine the PTB at Runghbao section (fig. 9, 10). From base to top the overall facies succession of the PTB in the GBG platform interior consists of: (1) cherty skeletal lime packstone with diverse normal-marine fossils in the uppermost Permian, overlain by a sharp contact with (2) calcimicrobial framestone in the basal Griesbachian with interbeds of (3) molluscan lime grainstone, followed by a thin interval of (4) microgastropod packstone and finally (5) platy, thin-bedded lime mudstone (fig. 11).

Upper Permian strata at Dajiang section are the Wujiaoping Formation and consist of thick, massive-bedded skeletal lime packstone with chert nodules. Fossils in the upper Wujiaoping Formation include crinoids, brachiopods, bryozoans, sphinctozoan sponges, rugose corals, dasycladacean algae, fusulinids, other foraminifera and Tubiphytes (fig. 11). The upper meter of the Wujiaoping Formation at Dajiang and Heping sections is composed of non-fusulinacean foraminifers and fragmented shell material. Palaeofusulina and the Changxingian foraminifers Colaniella and Nodosaria occur near the top of the Wujiaoping Formation at Heping section. Skeletal packstone of the Wujiaoping Formation is interpreted to represent a shallow-subtidal, open-marine platform environment with relatively low to moderately high current energy. The diverse normal-marine biota and presence of green algae indicate shallow photic-zone conditions and open-marine circulation. Mud-poor intervals with infiltrated lime mud indicate winnowing by wave action. Homogenous, mud-rich packstone intervals may have been thoroughly bioturbated.

The Wujiaoping Formation is overlain by an 8 to 16 m thick interval of calcimicrobial framestone that has a distinctive wavy, vaguely stromatolitic or thrombolitic appearance in outcrop (fig. 11). The calcimicrobial framestone is composed of irregular to dendritic black globular fossils similar to Renalcis that surround an interconnected network of irregular primary cavities filled with lime mud and skeletal debris. The calcimicrobial framestone lacks recognizable Permian macrofossils and overlies the Wujiaoping Formation across a sharp, planar contact, or an undulating seam stylolite contact (fig. 11). The contact and underlying strata contain no evidence of erosion or subaerial diagenesis. At Heping section the calcimicrobial framestone contains several interbeds of molluscan lime grainstone (fig. 11); the Dajiang section lacks the interbeds. The calcimicrobial framestone is overlain by a skeletal packstone interval a few meters thick that is composed mostly of minute (< 2 mm) gastropods (microgastropod packstone, fig. 11). It also contains bivalves, inarticulate brachiopods, small articulate brachiopods and rare echinoid spines. This interval is overlain by 60 m of monotonous, thin-bedded lime mudstone of the Lower Triassic Daye Formation (Figs. 10B, 11).

The calcimicrobial framestone extends continuously across the interior of the GBG (fig. 10A). Near the northern margin of the GBG, it gradually thins and pinches out. Near the pinchout, the calcimicrobial framestone overlies a thin interval of siliceous lutites of the Upper Permian Dalong Formation (fig. 10A). The Dalong Formation contains the Changxingian ammonoids Rotodiscoceras, Pseudotriolites and Pleuronodoceras as well as radiolarians (Guizhou Bureau of Geology and Mineral Resources, 1987).

Conodont Biostratigraphy- Closely spaced samples from the Heping section yielded abundant conodonts. The Upper Wujiaoping Formation at Heping yielded only Hindeodus typicalis (fig. 11) and lacked H. parvus. Although diagnostic Late Permian conodonts were not recovered from this section, the presence of Palaeofusulina and Colaniella indicate a Late Permian, Changxingian age. Fragments of Neogondolella changxingensis were recovered from the upper Wujiaoping Formation at Dajiang and Guandao sections (fig. 11). The lowermost sample from the calcimicrobial framestone at Heping section was collected 65 cm above the base of the unit and contains Hindeodus parvus (fig. 11). Hindeodus parvus occurs up-section through the calcimicrobial framestone and into the lime mudstone of the Daye Formation (fig. 11). The first occurrence of H. parvus is widely used to define the base of the lowermost Triassic, Griesbachian stage (Paull and Paull, 1994; Orchard et al., 1994; Yin et al., 1996). Thus, the conformable biostratigraphic PTB is interpreted to occur within the basal 65 cm of the calcimicrobial framestone at Heping (fig. 11). Imsarcicella isarcica occurs in the microgastropod packstone immediately overlying the calcimicrobial framestone. The consecutive appearances of H. parvus followed by I. isarcica thus place the microbialite in the H. parvus zone (fig. 11).

Depositional environments- Calcimicrobial framestone
Figure 11: Permian-Triassic boundary section at Heping (1 km south of Dajiang) with biostratigraphic and carbon isotope data. The PTB event horizon is marked by the last occurrence of diverse Permian fossils at the top of skeletal packstone of the Wujiaoping Formation. The biostratigraphic Permian-Triassic boundary is defined by the first appearance of Hindeodus parvus slightly higher, in the lower part of the calcimicrobial framestone. See figures 9 and 10 for location.
of the Lower Triassic Griesbachian is interpreted to represent shallow-subtidal, open-marine environments similar to the environment of deposition of the underlying Permian skeletal packstone. The framework is composed of equant to lunate, globular fossils with micrite walls that form irregular, tufted, and dendritic aggregates surrounding irregular internal cavities. These structures are interpreted as calcified, coccolid cyanobacteria similar to Renalcis (Lehrmann, 1999). The environment of deposition is interpreted in the context of the interbedded skeletal grainstone and metazoan fossils contained within the framework. Cyanobacteria flourish in a great variety of environments, including saline lagoons (Playford and Cockbain, 1976), open-marine platforms (Gebelein, 1976) and even in anaerobic or acidic environments (Schopf, 1992). The calcimicrobial framestone lacks sedimentary, biotic, or diagenetic evidence for hypersalinity or tidal-flat conditions. The occurrence of interbedded molluscan grainstone with normal-marine fauna indicates wave agitation and free exchange of seawater across the area during the deposition of the calcimicrobial framestone. The occurrence of echinoderms and articulate brachiopods within the framestone further supports open-marine conditions.

Grainstone and packstone beds, composed mainly of fragmented bivalves, are intercalated with the calcimicrobial framestone at Heping (fig. 11). The presence of articulate brachiopods and echinoderms provides evidence for an environment with normal-marine salinity. The grainy texture and fragmented fossils indicate a shallow-marine environment subject to wave action and possibly storm events exchanging marine water across the platform interior. Shell fragments may be randomly oriented or aligned parallel to bedding. Rarely, the packstone contains infiltrated lime mud and peloids perched on shell fragments. The low-diversity biota is interpreted to reflect the drop in biodiversity in the immediate aftermath of the end-Permian extinction rather than restricted marine circulation. Grainstone beds within the calcimicrobial framestone are broadly lenticular as they are discontinuous between sections. Grainstone interbeds are abundant in Dawen and Heping sections but pinch out laterally and are absent in the Dajiang section (fig. 10). The lenticular geometry of the grainstone beds and fact that these two facies were deposited in adjacent coeval, shallow-subtidal environments.

Overlying the microbialite is microgastropod packstone followed by thin-beded lime mudstone of the Daye Formation (fig. 11). The microgastropod packstone is in places composed almost entirely of minute gastropods 1-2 mm in diameter. The muddy texture of this facies and the absence of open-marine biota, except for a few small, articulate brachiopods, suggest a change to a low-energy, lagoonal environment with restricted circulation. The thin-beded lime mudstone of the Daye Formation overlies the microgastropod packstone and contains a few scattered bivalves and gastropods and contains extremely rare thin beds of oolite packstone. The low-diversity fauna suggests a shallow, restricted lagoonal environment. The homogenous structure of the lime mudstone suggests extensive bioturbation, but the paucity of discrete burrows, burrow mottling and bedding-plane traces is puzzling.

**Carbon isotope and TOC data**- Organic and carbonate carbon isotopes were measured across the PTB in Heping section approximately 1 km south of Dajiang (Krull et al., 2004). Negative excursions across the Permian-Triassic boundary in δ13Corg and δ13Ccarb occur immediately above the PTB “event horizon”, marked by the onset of the calcimicrobial framestone, and immediately below the first occurrence of H. parvus (fig. 11). The carbon isotope shifts are associated with a drop in average total organic carbon (TOC) and the depleted values in both δ13Corg and δ13Ccarb, together with low TOC content persist throughout the Griesbachian H. parvus zone. These data document a negative shift of δ13Corg, δ13Ccarb and TOC correlate with the base of the Griesbachian H. parvus zone and the onset of growth of calcimicrobial framestone following the extinction. Correlation of the δ13C excursion with the GSSP at Meishan shows that calcimicrobial framestones and H. parvus zone (8 to 16 m thick) have exceptionally high sediment accumulation rates relative to the correlative zone at Meishan, which is only 18 cm thick (beds 25-27c).

**Lower Olenekian (Smithian) peritidal cyclic limestone of the platform interior**

**General lithofacies and depositional environments**- Lower Triassic strata in the interior of the GBG are approximately 400 meters thick. They begin with calcimicrobial framestone biostromes 8-16 m thick in the Lower Griesbachian, 50 m of thin-beded lime mudstone in the Griesbachian and Dienerian, overlain by 100 m of oolite dolo-grainstone and oolitic microbial laminites in the Dienerian, 180 m of peritidal cyclic limestone in the Lower Olenekian (Smithian) and finally massive peritidal dolomite in the Upper Olenekian (Spational; fig. 9, 10B). The Olenekian-Anisian boundary in the platform interior occurs within the massive peritidal dolomite. The age of the peritidal cyclic limestone is constrained by the occurrence of the conodont Lonchodina nevadensis and by correlation of carbon isotope profiles to the biostratigraphically constrained Guandao section at the basin margin (Payne et al, 2004; fig. 18).

The entire Lower Triassic platform-interior succession of the GBG contains facies consistent with shallow subtidal to peritidal conditions and lacks evidence of major deepening events. Furthermore, the underlying Upper Permian strata and overlying Middle Triassic strata represent open-marine shallow-subtidal and restricted-marine, tidal flat environments, respectively (Lehrmann et al., 1998). Reef mounds of calcimicrobial framestone occur in the platform-interior, peritidal cyclic limestone, but are absent from the platform margin, suggesting that these features formed only in relatively low-energy environments of the platform interior. Thus, the facies succession and strati-
Lithofacies and depositional cycles- The Olenekian peritidal cyclic limestone extends across the interior of the GBG (fig. 9, 10B). It is 145 m thick and contains 66 shallowing-upward parasequences in the Dajiang section (fig. 12). Individual parasequences range from 0.2-7.4 m in thickness. The parasequences are composed of five shallow-subtidal to supratidal facies: skeletal packstone, oolitic packstone and grainstone, calcimicrobial biostromes and reef mounds, flaser-bedded and horizontally burrowed ribbon rock, and microbial laminate. A typical parasequence has a skeletal packstone or oolite base followed by calcimicrobial mounds, and capped by flaser-bedded ribbon rock (fig. 12). Variations include parasequences with calcimicrobial facies at the base, those lacking calcimicrobial mounds, or those capped by a microbial laminate rather than ribbon rock.

Skeletal packstones are typically massive or contain horizontally-oriented bivalve fragments with perched infiltrated sediment. Skeletal grains include thin-shelled bivalves, gastropods, ostracodes, foraminifers, minor echinoderm fragments and sparse lingulid brachiopods and worm tubes. The skeletal packstone is interpreted to represent open to restricted, shallow-subtidal environments with relatively low current energy. Most of the skeletal grains probably represent restricted marine circulation; the presence of echiinoderms, however, suggests occasional open-marine circulation. Abundance of mud indicates low-energy conditions. The massive fabric suggests bioturbation.

Oolitic packstone and grainstone beds, at the base or in the middle of parasequences, are thin to medium bedded. No lamination or cross-bedding was observed. Grainstone is rare; much of the oolite is mud-poor packstone with infiltrated internal sediment. Peloids, bivalve fragments and imbricated flat-pebble conglomerates are locally abundant. The oolitic packstone and grainstone represent subtidal shoals. Grainstone fabrics and imbricated interclasts indicate a current-swept shoal environment. Infiltrated mud fabrics suggest shoal stabilization and shift to lower energy conditions in the upper parts oolitic beds.

Biostromes and bioherms composed of calcimicrobial framestone occur in the middle and base of parasequences immediately below parasequence cap facies. Bioherms include small domal mounds as well as inverted conical mounds up to 1.5 m tall. Individual bioherms range from 10 cm to 1.5 m thick and have diameters of one to two times their height. Bioherms within individual beds are generally of similar size and have a lateral spacing of one to several meters. Where they form syndepositional relief, skeletal packstone inter fingers with the lower mound and flaser-bedded ribbon rock onlaps and overlaps the upper mound. The calcimicrobial framestone fabrics are identical to those described from the basal Griesbachian of Dajiang section.

Flaser-bedded ribbon rock most commonly caps the shallowing-upward cycles. It consists of laminated interlayers of lime mudstone and flaser-bedded grainstone. The ribbon appearance results from flaser bedding produced by the interlayering of grainstone lenses with continuous lime mudstone drapes. Grainstone lenses contain ripple cross laminae and isolated starved ripple forms. Scoured surfaces are commonly overlain by imbricated intraclasts. Opposed current indicators suggest reversing currents. Rare interlayers of lime mudstone and grainstone contain tidal bundling (spring/neap packages) with progressive upward thinning of grainstone-mudstone couples. In some parasequence caps, near the top of Dajiang section, the ribbon rock contains water-escape structures - fissures that disrupt lamination into small antiformal structures. The ribbon rock represents muddy tidal flats dominated by intertidal conditions. Reversing-current indicators, scours, grainstone lenses and starved ripples formed during flood and ebb tides. Lime mud drapes were deposited from suspension during submergence and slack tide. Minor burrowing occurred during submergence of the tidal flat. Autoclastic brecciation and v-shaped cracks associated with water-escape structures suggest these features formed by desiccation during subaerial exposure of the tidal flat. The dominance of hydrodynamic structures indicates low intensity of bioturbation. Microbial laminate occurs in parasequence caps within the upper parts of Dajiang section (fig. 12). A few of the layers contain evidence for significant subaerial exposure such as prism cracks, autoclastic breccia with reddened clasts and calcareous soil concretions. This facies represents rare supratidal conditions and prolonged exposure of the tidal flats.

The Lower Triassic platform-interior sequence of the Great Bank of Guizhou is notable for its extremely low biodiversity and predominance of unusual microbialite precipitates and ribbon rock facies dominated by physical sedimentary structures. The low biodiversity corresponds to a period of pronounced instability of the carbon cycle, suggesting that environmental perturbations may have prevented rediversification of life during the Early Triassic (Payne et al., 2004; fig. 18). Notably, two of the large negative carbon excursions coincide with the onset of major packages of microbialite deposition in the platform interior (fig. 18). These observations suggest that microbialite genesis may be linked with environmental disturbances also reflected in the carbon isotope record.

Milankovitch cyclicity- Parasequence thickness and facies stacking patterns in the peritidal cyclic limestone display three orders of cyclicity, suggesting hierarchical stratigraphic packaging (fig. 12). Yang and Lehrmann (2003) performed spectral analysis on the strata in Dawen and Dajiang sections (fig. 9) using the gamma analysis technique. Spectral analysis of the time series displayed multiple statistically significant spectral peaks, suggesting a quasi-periodic nature of the record. Prominent short-eccentricity, short-obliquity, and long-precessional index peaks, and minor long-eccentricity, long-obliquity, short-precessional index, and constructional-tone peaks were
Figure 12: Lower Triassic peritidal cyclic limestone in Dawen and Dajiang sections. The locations of the sections are keyed to figures 9 and 10. Numbered arrows to the left of sections indicate 4th order parasequence sets. Unnumbered arrows immediately left of the columns denote 5th order parasequences. Systems tracts and 3rd order sequence boundary are indicated to the left of Dawen section. TST = transgressive systems tract, HST = highstand systems tract, SB = sequence boundary. The typical or most common parasequence type ("ideal cycle") is indicated on the lower right.
calibrated on the gamma-corrected spectra. Thus, Milankovitch climatic forcing probably greatly influenced sedimentation. On the basis of the calibration, the subtidal facies has sedimentation rates of 24.6 to 30.7 cm/ky and the intertidal-supratidal facies has rates of 2.7 to 6.0 cm/ky. The estimated duration of deposition of the interval in the two sections is 1139 to 1423 ky, corresponding to a stratigraphic completeness of 60 to 75%. The high level of stratigraphic completeness was attributed to low amplitude sea level oscillation in a greenhouse climate of the Early Triassic.

**Stop-4b Optional stop at Permian-Triassic boundary at Rungbao section**

The Permian-Triassic boundary succession at Rungbao section is essentially identical to that described for Dajiang section (see description in stop 4A and fig. 11). The section is, however, easily accessible from the road and contains well-developed microbial fabrics and undulatory bedding superficially resembling stromatolites, cherty Upper Permian carbonates and a volcanic ash layer within the uppermost Permian carbonate. Geochemistry and petrography demonstrate that the claystone is indeed volcanic ash and has a rhyolitic composition (Newkirk et al., 2002).

**Stop-5 Lower-Middle Triassic (Olenekian-Anisian) boundary section in basin-margin facies at Guandao section**

Guandao section occurs on the east limb of the Biaoyang syncline at the basin margin immediately north of the GBG (fig. 8, 9). Several aspects make this one of the most important sections in the Nanpanjiang basin for chronostratigraphy. The section: (1) is approximately 750 m thick and has continuous exposure of Upper Permian through Upper Triassic (Carnian) strata, (2) is composed primarily of deep-marine, pelagic, carbonate strata that contain abundant conodonts, (3) apparently records continuous sedimentation without significant unconformities, (4) preserves primary magnetic signature and several volcanic horizons, (5) occurs adjacent to a carbonate platform with preserved paleobathymetry allowing physical correlation between shallow-marine platform strata with deep-marine strata at the basin margin and (6) is easily accessible from the nearby town of Biaoyang (figs. 9, 10, 15). Furthermore, although Guandao section has the disadvantage of lacking abundant ammonoid faunas, the section should provide useful constraints on the global geologic time scale as it contains a long, continuous record of Triassic sedimentation in contrast to the numerous short marine sections that have commonly been used in composite for reconstructing Triassic chronostratigraphy.

**Lithofacies and record of Triassic biotic recovery**

Guandao section was measured in two overlapping segments: lower Guandao, which spans the Upper Permian through the Middle Triassic Anisian (Pelsonian) (fig. 9, 13) and upper Guandao section, which spans the Lower Triassic, Upper Olenekian (Spathian) through the Upper Triassic Carnian (fig. 9, 15). The sections are offset and correlated along an interval with volcanic ash horizons that straddles the Lower-Middle Triassic (Olenekian-Anisian) boundary (fig. 17).

**Lower Guandao Section**—The base of lower Guandao section was measured in cherty skeletal packstone of the Upper Permian Wujiaoping Formation. The Wujiaoping Formation represents sedimentation prior to the initiation of the GBG as an isolated platform and was deposited near the southern margin of the Upper Permian Yangtze platform (fig. 2, 3, 9). It contains a diverse assemblage of shallow-marine benthic fossils including articulate brachiopods, mollusks, echinoderms, bryozoans and foraminifers.

Overlying the Wujiaoping Formation is the Upper Permian Dalong Formation that represents the initial “drowning” of a large area of the Yangtze platform north of the area of the GBG (fig. 2, 13). The Dalong Formation adjacent to the GBG is 10-15 m thick and is composed of deeply weathered, dark brown to black, nodular-bedded siliceous lutite (chert), cherty nodular-bedded lime mudstone and shale. One of the “shaly” interbeds near the top of the Dalong Formation at Guandao section may be a volcanic ash.

The Dalong Formation contains radiolarians and the ammonoids Rotodiscoceras, Pseudotirolites and Pleurondoceras. The combination of dark color and pelagic fauna with minor bioturbation and presence of small articulate brachiopods suggests a dysaerobic environment. The Dalong Formation reaches a maximum thickness of 78 m in southern Guizhou (Guizhou Bureau, 1987). Further work is needed to determine the depositional environments of the Dalong Formation and the conditions that led to the termination and step back of a vast area of the Yangtze platform in southern Guizhou (fig. 2). Two observations suggest that the “drowning” cannot be explained simply as the result of eustatic sea level rise: 1) the Yangtze platform was terminated in the eastern sector only (fig. 2), and 2) paleobathymetry adjacent to the Upper Permian reef mound on the north margin of the GBG (fig. 9; Lehrmann, 1993) suggests water depths of approximately 30 meters for Dalong Formation deposition.

The Permian-Triassic boundary occurs between the Dalong Formation and the overlying shale containing the bivalve Claridia (fig. 13). The shale is 18 m thick, deeply weathered and has a brown-tan color and is laminated. Overlying the Griesbachian shale, the Induan succession is dominated by hemipelagic lime mudstone, allogedic lime packstone and grainstone, submarine debris-flow breccia beds and shale interbeds (fig. 13). These facies correlate biostratigraphically with the Luolou Formation that has been mapped regionally in the Nanpanjiang basin of southern Guizhou and Guangxi (fig. 3, 7).

The Induan lime mudstone is thin-bedded, dark gray to black and commonly laminated, rarely it is burrowed. At the base of debris-flow breccia beds lime mudstone is
Figure 13: Upper Permian through Middle Triassic (Anisian) strata at lower Guandao section. Facies are from the basin-margin slope succession on the northern margin of the GBG. See figures 9 and 10 for location. Dominant carbonate grain types (ooloids, intraclasts, and various skeletal grains) are indicated immediately right of the lithofacies column. Conodont biostratigraphy and volcanic-ash horizons are also indicated. U-Pb dates of volcanic ash layers are shown in fig. 17.
commonly contorted by soft-sediment deformation into wavy or overturned folds. Allodapic packstone and grainstone beds are dominantly composed of oolite, peloids and intraclasts of lime mud or oolite packstone. Debris-flow breccias are matrix-rich and contain a mix of oolite clasts derived from the platform margin and lime-mudstone clasts derived from the slope. The Induan succession at Guandao section is notable for extremely low skeletal content and dominance of non-skeletal grains (ooloids, intraclasts, peloids; fig. 13). Thin-section point counts indicate skeletal abundance near zero (J. Payne, unpublished data). Allodapic packstones and breccia clasts contain a few bivalve fragments.

Facies types and depositional environments are similar in the Olenekian of southern China. Allodapic packstone and grainstone, debris-flow breccia beds and shale. The Olenekian strata at Guandao section are biostratigraphically correlated with the upper Luolou Formation in southern Guizhou (fig. 3, 13). Near the base of Olenekian succession are two dolomitized breccia intervals, each greater than 1 m thick, that form a prominent ridge in the landscape (fig. 9, 13). The strata overlying the dolomitized breccia beds contain more conspicuous fossils (bivalves, crinoids and Tubiphytes, indicating the beginning of benthic recovery near the end of the Olenekian (Upper Spathian; fig. 13). Thin-section point counts indicate that abundance and diversity of skeletal grains increased only in the Upper Olenekian (5% skeletal abundance in the Upper Spathian) after remaining low throughout the preceding Lower Triassic (J. Payne, unpublished data). Thin sections reveal the presence of bivalves, crinoids, cephalopods, foraminifers, brachiopods, ostracods and Tubiphytes fragments. Volcanic-ash horizons occur in the Upper Olenekian and Anisian (fig. 13). Notably the pelagic lime mudstone and packstone beds near the Olenekian and Anisian boundary at Guandao section contain chert nodules. In southern China, chert nodules are commonly found in Upper Permian carbonates but are almost entirely absent from Triassic strata. The occurrence of chert nodules at this level may reflect either increased abundance of biogenic silica from radiolarians or siliceous sponges or mobilization of silica from the volcanic ashes.

**Upper Guandao section** - Upper Guandao section was measured in the valley and up the hillside approximately 200 meters north (basinward) of lower Guandao section. The base of the section is in Upper Olenekian (Spathian) strata containing volcanic-ash horizons (fig. 14). The volcanic units thicken and apparently amalgamate basinward away from the platform (fig. 17). The section continues up through the Anisian and Ladinian. It represents the basin-margin slope succession deposited north of the massive, aggrading Tubiphytes reef (fig. 9, 10). Biostratigraphically the Anisian succession correlates with the Xinyuan Formation of southern Guizhou (fig. 4, 7). The siliciclastic turbidites of the Bianyang Formation at the top of upper Guandao section (fig. 9, 10) are Carnian in age whereas in other areas of Guizhou this unit is considered largely Ladinian (fig. 5).

The lithofacies consist of pelagic lime mudstone, allodapic skeletal and intraclastic lime packstone or grainstone and debris-flow breccia beds with clasts derived from the platform-margin Tubiphytes reef. Skeletal abundance and diversity is greater in the Anisian-Ladinian succession than in the uppermost Olenekian. Thin-section point counts record 8 to 9% skeletal grains averaged over all lithologies (J. Payne, unpublished data). Whereas the increase in skeletal abundance from near zero to approximately 5% in the upper Olenekian reflects an increase in the abundance of animal skeletal grains, the additional increase in the Anisian and Ladinian records the additional input of Tubiphytes grains at this time. Thin-bedded lime mudstone and wackestone contains thin-shelled pelagic bivalves, radiolarians, echinoderms and rarely ammonoids. Skeletal packstone and grainstone and clasts within breccias contain Tubiphytes fragments, crinoids, echinoids, foraminifers, calcareous algae, mollusks, brachiopods, ostracodes, calcisponge fragments and a few scleractinian corals. Notably, the skeletal abundance and diversity remains relatively constant throughout the Anisian and Ladinian succession (J. Payne, unpublished data).

**Conodont biostratigraphy – the Olenekian-Anisian boundary**

A total of 603 samples, each 3-5 kg., were collected from lower and upper Guandao sections. Sample spacing ranging from about 2 meters to 20 cm, with more closely spaced samples near important boundaries such as the Olenekian-Anisian boundary. Most of the samples contained abundant conodonts, many with hundreds or thousands of elements. From the entire stratigraphic succession we have identified 56 conodont species, enabling a substage zonation of the Upper Permian through Carnian (ranges of important species are shown in fig. 13, 14).

The Olenekian-Anisian boundary is especially well constrained by conodont biostratigraphy, providing a high-resolution record of this critical interval of biotic recovery (fig. 14). The Olenekian-Anisian boundary is placed at the first occurrence of Chiosella timorensis. Cs. timorensis has been recognized as a key index fossil for definition of the boundary as it has a narrow stratigraphic range and global distribution (Orchard, 1995; Orchard and Tozer, 1997). Further, the International Commission on Stratigraphy has reported agreement that the first occurrence of Cs. timorensis will define the O-A boundary in the global stratotype to be designated at the Desli Caira section in Dolobrogea, Romania (Ogg, 2004). At Desli Caira the first occurrence of Cs. timorensis closely corresponds with the occurrence of biostratigraphically important ammonoids Japonites, Paradanubites and Paracrochordiceras (Gradinaru, 2001).

Additional constraints on placement of the Olenekian-Anisian boundary at Guandao section include: the last occurrences of Neospadodus abruptus and Ns. triangularis (Orchard, 1995) well below the boundary, the occurrence of Ns. symmetricus and Ns. homeri below and
Figure 14: Lower Triassic (Spathian) through Middle Triassic (Ladinian) strata at upper Guandao section. Facies are from the basin-margin slope succession on the northern margin of the GBG. See figures 9 and 10 for location. Lithology and grain type symbols are the same as those shown in figures 13. Conodont biostratigraphy and volcanic ash horizons are indicated. U-Pb dates of volcanic ash layers are shown in fig. 17.

extending slightly above the boundary and the first occurrence of *Gladiogondolella tethydis*, *Nicoraella germanicus* and *Ni. kockeli* above the boundary (fig. 14).

**Volcanic ash layers- preliminary U-Pb dates**

Several volcanic ash horizons straddle the boundary (fig. 17). Preliminary age dates are as follows. We emphasize that these age dates are preliminary and should not be cited as certain boundary ages until the data are sufficiently refined. The lowest dated horizon occurs 4.5 m above the O-A boundary in the lower *Cs. timorensis* biozone and is age dated to be 247.8 MA. The highest dated horizon occurs in the uppermost *Cs. timorensis* biozone and is age dated at 246.5 MA. These preliminary data indicate an age of > 247.8 MA (probably around 248 MA) for the O-A boundary. Given that age dates for the end-Permian extinction horizon from independent labs appear to be converging near 252 MA (see Bowring et al., 1998; Mundil et al., 2004), the duration of the Early Triassic Epoch and the interval of delayed recovery was approximately 4 million years.
Magnetostratigraphic data collected (total of 322 paleomagnetic samples from lower and upper Guandao sections) defined a series of ten normal and ten reversed magnetozones in lower Guandao section that characterize a geomagnetic polarity record for the Lower Triassic and basal Anisian. Detailed demagnetization experiments have resulted in the isolation of a Lower Triassic paleomagnetic directional data. Magnetostratigraphic data from Guandao were subjected to the reversal test and passed at a grade ‘B’ level (Paul Montgomery, personal communication). Comparison with predicted Lower Triassic paleomagnetic directions for the Guandao area show good agreement (Enkin et al 1992; Van der Voo, 1993). Based on this evidence a primary paleomagnetic signal is interpreted.

Magnetic reversal stratigraphy from Guandao section correlates with the reversal zonation of the O-A boundary in western Tethyan sections (Muttoni et al., 2000). In both areas normal polarity occurs in the Lower Spathian followed by a predominantly reversed zone with a few thin reversals in the upper half of the Spathian and straddling the Olenekian-Anisian boundary (fig. 14). This is followed by a zone of normal polarity in the Bithynian to Lower Pelsonian (fig. 14).

Samples were collected for carbon-isotopic analyses from the lower Guandao and upper Guandao sections with an average spacing of approximately one meter where exposure permitted. The results provide a detailed and relatively continuous record of large fluctuations in the global carbon cycle that continued through the Early Triassic and into the Middle Triassic before stabilization occurred rapidly in the Anisian (fig. 18). Unfortunately, heavily weathered shales across the P-Tr boundary at the Guandao section reduce the quality of the record near the extinction event itself. This part of the record is well recorded in the platform-interior sections (fig. 18). The Smithian-Carnian record from the lower Guandao and upper Guandao sections, on the other hand, is excellent. In particular, two large cycles are apparent with positive peaks near the Smithian-Spathian boundary and within the base of the Anisian. The Anisian peak is followed by a trend to lighter values and subsequent stabilization at values around 1.5‰. From the Anisian through the Carnian values do not vary by more than approximately 1‰.

Evidence is strong that the pattern of carbon-isotopic fluctuations through the Early Triassic reflects global changes in the carbon cycle. The magnitude and timing of the fluctuations through the Early Triassic reflects global changes in the carbon cycle. The magnitude and timing of the
Permian-Triassic boundary excursion is well known from localities around the globe (e.g., Magaritz et al., 1988; Baud et al., 1989). The Smithian-Spathian and Early Anisian positive peaks have been observed at other localities around the Tethys (e.g., Atudorei, 1999; Baud et al., 1996), and the large positive excursion near the Dienerian-Smithian boundary is found in the Dolomites and elsewhere (Horacek et al., 2001; J. Payne, unpublished data; S. Richoz, pers. comm.). Only the second negative excursion in the platform interior, near the Griesbachian-Dienerian boundary, has yet to be observed within other marine carbonate sections.

The instability of the carbon cycle during the Early Triassic is remarkable both for its magnitude and for its contrast with Middle Triassic stability. The cause of Early Triassic carbon-cycle instability is poorly understood. Suggestions of a role for methane hydrate destabilization at the end of the Permian (e.g., Krull et al., 2004; Krull and Retallack 2000) could account for the negative excursion at the PTB, but cannot explain continuing carbon-cycle instability because the time scale involved in repeated excursions is too short to allow replenishment of the clathrate reservoir. A more conventional explanation of the repeated excursions, reflecting changing ratios of carbon burial as organic matter versus carbonate rocks, is challenged by the magnitude of the excursions. Generating such large and rapid excursions requires an extraordinarily high fraction of organic carbon burial (>0.5 vs. carbonate burial) given any reasonable isotopic fractionation between organic and inorganic carbon. If the excursions do represent changes in the fraction of organic burial, it will be essential to determine the conditions (such as episodes of shallow-shelf anoxia) that were capable of producing such elevated levels of organic carbon burial, as well as the reasons why such conditions did not persist beyond the Early Triassic.

Stop-6a Anisian-Ladinian platform-margin Tubiphytes reef traverse. Rigorous traverse on trail through karst terrain south of Guandao (fig. 9)

Extensive Anisian and Ladinian reef complexes are preserved in the Nanpanjiang basin of Guizhou, Guangxi and Yunnan of southern China. Reefs occur on the edge of the extensive Yangtze platform that fringed the basin and along the margins of isolated platforms within the basin (Poduan and Guohua Formations, fig. 4; see also Enos et al., 1997; Lehrmann et al., 1998; Lehrmann et al., 2003). These reef complexes add greatly to the geographic distribution of known Anisian reefs (see review in Flügel, 2002). Furthermore, they are among the oldest Triassic reefs in the world and, unlike many of their counterparts in western Tethys, they are preserved in situ as limestone. The Great Bank of Guizhou (GBG) contains the best-exposed reef complex among the isolated platforms because a faulted syncline provides a two-dimensional cross-section of the platform, including the reef margin (fig. 9). Exposure of a cross-section from the platform interior to the basin margin allows the physical stratigraphic corre-

Figure 16: Stratigraphic section of the Ladinian-Carnian platform termination succession at the top of Bangeng section, in the axis of the Bianyang syncline. See figure 9 for location. See text and stop 2 of the field guide for further details.

Stop-6a Anisian-Ladinian platform-margin Tubiphytes reef traverse. Rigorous traverse on trail through karst terrain south of Guandao (fig. 9)

Extensive Anisian and Ladinian reef complexes are preserved in the Nanpanjiang basin of Guizhou, Guangxi and Yunnan of southern China. Reefs occur on the edge of the extensive Yangtze platform that fringed the basin and along the margins of isolated platforms within the basin (Poduan and Guohua Formations, fig. 4; see also Enos et al., 1997; Lehrmann et al., 1998; Lehrmann et al., 2003). These reef complexes add greatly to the geographic distribution of known Anisian reefs (see review in Flügel, 2002). Furthermore, they are among the oldest Triassic reefs in the world and, unlike many of their counterparts in western Tethys, they are preserved in situ as limestone. The Great Bank of Guizhou (GBG) contains the best-exposed reef complex among the isolated platforms because a faulted syncline provides a two-dimensional cross-section of the platform, including the reef margin (fig. 9). Exposure of a cross-section from the platform interior to the basin margin allows the physical stratigraphic corre-
Figure 17: Olenekian-Anisian boundary section in basin margin facies in Lower Guandao and Upper Guandao sections (see figures 9 and 10 for locations). Lithology and grain type symbols are the same as those shown in figures 13 and 14. Magnetic reversal stratigraphy (black is normal polarity) is shown at left of Lower Guandao section. Conodont biostratigraphy and preliminary U-Pb age dates of volcanic ash layers are shown for both sections. We emphasize that the U-Pb age dates are still preliminary and should not be cited as certain boundary ages until the data is sufficiently refined. Further discussion of the biostratigraphy, geochronology, and magnetostratigraphy is provided in the stop descriptions of the field guide in this volume.
The abundance of siphonous alga (J. Payne, unpublished data; Lehrmann, at least locally, to reflect micritic cementation around a siphonous alga. The presence of abundant Tubiphytes grains and blocks of Tubiphytes boundstone in Anisian through basal Carnian strata on the basin-margin provide evidence for the persistence of a reef or patch reefs also on the high-relief escarpment margin into the Ladinian. Apparently the Ladinian reefs along the high-relief escarpment were largely stripped away by erosion and their remnants are largely preserved in clasts in breccias found at the foot of the escarpment (fig. 9; see description for stop 6B).

Much of the volume of the reef complex is composed of discontinuous units of Tubiphytes boundstone, Tubiphytes grainstone and breccia cemented by large volumes of isopachous marine cement. Although sampling reveals the spectrum of lithologies and alternation of boundstone and grainstone can be detected in outcrop, the reef facies is generally massive, without distinct bedding.

A variety of free-living organisms are also found within the reef complex. The reef-dwelling fauna includes crinoids, gastropods, bivalves, ostracodes and brachiopods. Among the reef dwellers, crinoid grains are the most abundant, with subordinate bivalves and gastropods. Benthic foraminifers and dasyclad algae are also present in low abundance. Fossils of free-living organisms generally occur within grainstones and are rare within Tubiphytes boundstone, suggesting that much of the reef-dwelling fauna lived near, but not within, the Tubiphytes framework.

Several generations of marine cements contribute significantly to the reef framework, often contributing the majority of the total rock volume. Cements include: 1) peloidal microcrystalline cement; 2) brownish fibrous cement; 3) botryoidal cement; and 4) isopachous fibrous marine cement. What little void space remained within the reef after marine cementation was occluded by equant sparry calcite after burial.

We interpret the history of cementation of the Tubiphytes reef complex as follows. The earliest generation of carbonate precipitation occurred around a soft-bodied siphonous alga to form the Tubiphytes framework. This generation of cement must have formed during the life of the alga, for the substrate for nucleation likely consisted of mucopolysaccharides excreted by the living alga. The second generation of cement consisted of clotted micrite surrounding the Tubiphytes framework. It seems likely that this micrite, like the micrite forming the tube of Tubiphytes, reflects biotically mediated carbonate precipitation in open contact with seawater. The subsequent generation of brownish fibrous marine cement shows no evidence for dissolution prior to precipitation and is found surrounding Tubiphytes in grains transported to the basin margin in turbidity currents. These two pieces of evidence indicate that even the brownish fibrous cement was precipitated in open contact with seawater prior to any significant burial. Given the generally high depositional rates, approximately 200 m/Ma in the reef complex, open contact with seawater must have lasted on the order of 10^3 years. Evidence for dissolution prior to the precipitation of isopachous fibrous cements suggests possible exposure or burial of the reef boundstone prior to this episode of cementation. On the other hand, the deposition of micrite between layers of isopachous cement in some cavities suggests that, at least in some cases, the isopachous cement was also precipitated in contact with shallow-marine water. Botryoidal cements appear to postdate isopachous cements in several samples, but are generally interpreted as shallow-marine cements. Finally, the remaining voids were completely occluded by sparry calcite after burial.

Despite the extent of the reef complex and the fact that the reef aggraded to produce at least 400 m of relief above the adjacent basin floor (fig. 9, 11C), there is little evidence that the framework elements — primarily Tubiphytes and marine cements — attained any significant local relief above the seafloor. In the field, local relief of less than one meter was observed where hemispherical Tubiphytes boundstones are in contact with grainstones. Karst topography and locally thick vegetation, however, preclude the determination of detailed stratigraphic relationships within the reef complex over distances greater than a few tens of meters.

Stop-6b Optional stop examine the Anisian through Carnian basin-margin succession at upper Guandao section (fig. 9, 14)

Upper Guandao section- Upper Guandao section was measured in the valley and up the hillside approximately 200 meters north (basinward) of lower Guandao section. The base of the section was measured in Upper Olenekian (Spathian) strata containing volcanic-ash horizons. The section continues up through the Anisian and Ladinian and represents the basin-margin slope succession deposited north of the massive, aggrading Tubiphytes reef complex (fig. 9, 10). The silicilastic turbidites of the Bianyang Formation at the top of upper Guandao section (fig. 9, 10) are Carnian in age.

Lithostratigraphically the Anisian-Ladinian strata in upper Guandao section can be subdivided into 3 major units (fig. 14). 1) The Aegean-Lower Pelsonian succession consists of thin-bedded, pelagic lime mudstone and wackestone, containing thin-shelled bivalve debris; allogenic skeletal packstone and grainstone, composed primarily of fragmental Tubiphytes debris and crinoid
ossicles; and thin, polymict debris-flow breccia beds (each no more than a few meters thick). 2) The Upper Pelsonian-Illlyrian succession also contains pelagic lime mudstone, allodapic skeletal packstone and grainstone and polymict, debris-flow breccia, but in this interval breccia tongues range from about 10 m to more than 50 m thick. Soft-sediment deformation of the beds underlying the breccia tongues is spectacularly exposed near the path. 3) The Ladinian through the Carnian succession is composed of lithoclastic grainstone breccias and skeletal grainstone composed of Tubiphytes boundstone clasts, fragmented Tubiphytes debris, crinoid ossicles and other subordinate skeletal grains (fig. 14). The three units are mapped in figure 9. The upward change records progressive steepening of the basin-margin slope (from $5^\circ$ in the Early Anisian to $>30^\circ$ with ~400 m of relief in the Early Ladinian) as the platform-margin reef complex aggraded. Steepening slopes yielded thicker debris-flow breccia units and more abundant slumping of pelagic lime mudstones in the Upper Pelsonian and Illlyrian. Eventually slope deposition shifted to lithoclastic grainstone in the Ladinian as the slope reached the angle of repose and transport shifted from subaqueous debris flow to subaqueous debris fall and grain flow (fig. 10). Grains in the allodapic packstone and grainstone beds of upper Guandao section are dominantly derived from the platform-margin reef complex and are dominated by Tubiphytes fragments. Skeletal grains are dominated by crinoids, with subordinate bivalves, gastropods, echinoids and brachiopods. Clasts in the breccias include lime mudstone, or packstone and grainstone derived from the slope and Tubiphytes boundstone derived from the platform-margin reef. No platform-interior lithologies are found in the breccia clasts, indicating that allodapic sediment was derived primarily from the margin and that no major subaerial erosion events occurred to transport material eroded from the platform interior. The lack of definitive exposure fabrics in debris-flow breccia clasts suggests deliv-
er primarily by high-stand shedding. Skeletal abundance and diversity is greater in the Anisian-Ladinian succession than in the uppermost Olenekian. Thin-section point counts record 8 to 9% skeletal grains averaged over all lithologies (J. Payne, unpublished data). Skeletal packstone and grainstone beds and breccia clasts contain Tubiphytes fragments, crinoids, echinoids, foraminifers, calcareous algae, mollusks, brachiopods, ostracodes, calcisponge fragments and a few scleractinian corals. Skeletal abundance and diversity remains relatively constant throughout the Anisian-Ladinian succession (J. Payne, unpublished data).

Breccia clasts derived from the platform margin provide an indirect sampling of the platform-margin reef complex through the Middle Triassic. The broad evolution of the platform-margin biota is apparent in the changing biotic content of the breccia tongues. The thick Anisian breccia tongues contain only clasts of Tubiphytes boundstone along with slope lithologies. The large extent of the Anisian reef, despite the lack of framework elements other than cements and Tubiphytes, suggests controls beyond the recovery and evolution of framework-building metazoans in the re-establishment of platform-margin reefs in the Middle Triassic. A better understanding of the origin of Tubiphytes and of the biological and geochemical controls on early marine cementation of the Middle Triassic platform margin should provide new insights into the recovery of reefs during the Middle Triassic.

In contrast, the Carnian breccia tongues (interbedded with siliciclastic turbidites at the top of upper Guandao section, fig. 9) contain reef blocks with a much greater biotic diversity than the Tubiphytes reef complex. This reef material, which was derived from patch reefs or narrow fringing reefs along the high-relief Ladinian escarpment (fig. 9, 10C), contains solitary and colonial scleractinian corals, with colonies reaching 50 cm or more in diameter. (fig. 9, 10C), contains solitary and colonial scleractinian corals, with colonies reaching 50 cm or more in diameter. The thick Anisian breccia tongues contain only clasts of Tubiphytes boundstone along with slope lithologies. The large extent of the Anisian reef, despite the lack of framework elements other than cements and Tubiphytes, suggests controls beyond the recovery and evolution of framework-building metazoans in the re-establishment of platform-margin reefs in the Middle Triassic. A better understanding of the origin of Tubiphytes and of the biological and geochemical controls on early marine cementation of the Middle Triassic platform margin should provide new insights into the recovery of reefs during the Middle Triassic.

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