The Late Permian to Late Triassic Great Bank of Guizhou: An isolated carbonate platform in the Nanpanjiang Basin of Guizhou Province, China

Brian M. Kelley, Daniel J. Lehrmann, Meiyi Yu, Marcello Minzoni, Paul Enos, Xiaowei Li, Kimberly V. Lau, and Jonathan L. Payne

ABSTRACT

The Late Permian to Late Triassic Great Bank of Guizhou (GBG) in southwest China is one of the few isolated carbonate platforms in the world that exposes an essentially complete record of initiation, development, and drowning across multiple platform-to-basin transects. The platform is exceptionally exposed in cross section at the surface by a faulted syncline that rotated strata to a dip angle of approximately 65°. Platform development spanned the end-Permian extinction and Triassic recovery that marks the transition from Paleozoic to Mesozoic styles of carbonate sediment production, providing a rare opportunity to assess the impact of global changes in carbonate factory types at a single locality. In addition, regional basin controls such as differential siliciclastic sediment input and varied antecedent topography provided mechanisms for lateral variability in platform morphology that can be investigated along exposures in several geographic sectors. Consequently, the GBG preserves a record of temporal and spatial variability in platform architecture that offers an unparalleled opportunity to investigate the controls on isolated carbonate platform morphology. A better understanding of these mechanisms is critical for improving predictive geologic models in exploration and field-development settings. The GBG also serves as a key outcrop analog for Early Triassic oolite reservoirs in the Middle East and China, the steep microbial-boundstone slopes of Carboniferous platforms in Kazakhstan, and the Permian platforms of Texas and New Mexico.

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AUTHORS

Brian M. Kelley ~ *ExxonMobil Upstream Research Company, 22777 Springwoods Village Parkway, Spring, Texas 77389; brian.m.kelley@exxonmobil.com*

Brian M. Kelley is currently a research scientist at the ExxonMobil Upstream Research Company. He received his Ph.D. at Stanford University.

Daniel J. Lehrmann ~ *Geoscience Department, Trinity University, One Trinity Place, San Antonio, Texas 78212; dlehrmann@trinity.edu*

Daniel J. Lehrmann is the Gertrude and Walter Pyron Professor in the Geosciences Department at Trinity University where he teaches courses in paleontology and sedimentary geology. He received his Ph.D. from the University of Kansas. His research focuses on the factors controlling the evolution of marine sedimentary basins and carbonate platforms.

Meiyi Yu ~ *Department of Resources and Environmental Engineering, Guizhou University, Caijiaguan, Guizhou Province, People's Republic of China; yuyouyi@163.com*

Meiyi Yu received his bachelor's degree in science from the Wuhan College of Geology. He worked as a geologist for the Regional Mapping Team of the Guizhou Bureau of Geology and Mineral Resources from 1985 to 2000. He is currently assistant professor at Guizhou University in Guiyang, Guizhou Province, China.

Marcello Minzoni ~ *Department of Geological Sciences, 201 7th Avenue, Room 2003 Bevill Building, Tuscaloosa, Alabama 35487; mminzoni@ua.edu*

Marcello Minzoni is an assistant professor at the University of Alabama. He received his B.S. and M.S. degrees from the University of Ferrara in Italy, and his Ph.D. in 2007 from the University of Kansas. From 2007 to 2016, he was a research scientist and a subject matter expert at Shell International Exploration and Production. His current research focus is on deciphering and modeling the various controls impacting the large-scale architecture and reservoir potential of carbonate systems using seismic, outcrop, and modern analogs.

PAUL ENOS ~ *Department of Geology, University of Kansas, 1425 Jayhawk Drive, Lawrence, Kansas 66045; enos@ku.edu*

Paul Enos is an emeritus distinguished professor at the University of Kansas, where he taught from 1982 to 2003 and also received a B.S. degree in geology in 1956. He earned an M.S. degree from Stanford University and a Ph.D. from Yale University. From 1964 to 1970, he was a research geologist at Shell Development Company and was a faculty member at State University of New York at Binghamton from 1970 to 1982.

XIAOWEI LI ~ *Department of Geological Sciences, Stanford University, 450 Serra Mall, Building 320, Stanford, California 94305; xwli@stanford.edu*

Xiaowei Li received his bachelor's degree from Guizhou University, China, and M.S. degree from the Institute of Tectonic Studies at the University of Texas at El Paso. He is currently a Ph.D. candidate in geological sciences at Stanford University.

KIMBERLY V. LAU ~ *Department of Earth Sciences, University of California, Riverside, 900 University Avenue, Riverside, California 92521; Kimberly.lau@ucr.edu*

Kimberly V. Lau received her B.S. in geology from Yale University and her Ph.D. in geological sciences from Stanford University. She is currently a postdoctoral fellow at the University of California, Riverside.

JONATHAN L. PAYNE ~ *Department of Geological Sciences, Stanford University, 450 Serra Mall, Building 320, Stanford, California 94305; jlpayne@stanford.edu*

Jonathan Payne received his B.A. from Williams College and his Ph.D. from Harvard University. He is currently a professor of geological sciences at Stanford University.

INTRODUCTION

The Nanpanjiang Basin in the Guizhou Province of south China preserves exceptional exposures of several Late Permian to earliest Late Triassic carbonate platforms (Figure 1; Enos et al., 2006; Lehrmann et al., 2007). The distribution of platforms within the basin, their varied histories, and their depositional age provide a rare opportunity to evaluate the impacts of a broad range of controls on carbonate deposition and platform morphology for two key reasons. First, because isolated and land-attached carbonate platforms were broadly distributed across the tectonically active South China Block, it is possible to investigate the influence on platform geometry of spatial, basin-scale differences in subsidence rates, antecedent topography, and differential clastic sediment input to carbonate slopes. Consequently, the Nanpanjiang Basin provides an important opportunity to explore the effects of regional tectonics and differential clastic sediment input across both north-to-south and east-to-west gradients on a variety of carbonate buildups. Second, because carbonate deposition in the basin spans the end-Paleozoic extinction and early Mesozoic recovery, it is possible to examine the effects of temporal changes in ocean conditions and the resulting changes in carbonate factory types on buildup morphologies as the composition of carbonate-producing communities changed. The platforms initiated before the extinction of important carbonate-producing Paleozoic biota such as rugose corals and fusulinid foraminifera during the largest extinction of the Phanerozoic Era. The platforms subsequently developed during the Early Triassic interval of low-diversity, skeletal-poor seas when platform-margin reefs were absent and replaced by ooid shoals. Later, platform geometries were influenced by the return of diverse, platform-margin reefs with the advent of scleractinian corals during the Middle Triassic. It is rarely possible to see such a significant evolution of carbonate-factory types in a single platform. More commonly, significant changes in ocean chemical, biological, and physical environments and their resulting impacts on platform geometry are inferred from comparison among platforms from disparate temporal and geographic settings, leaving the causes of platform variability more difficult to reconcile.

The isolated platform with the longest depositional history in the basin is the Great Bank of Guizhou (GBG), which is the focus of this field guide. The GBG exhibits similarities to several important hydrocarbon-producing fields and outcrop analogs. The platform exhibits steep, microbial-boundstone slopes that bear strong similarities to those in significant carbonate fields in the Pricaspian Basin such as Tengiz and Kashagan, the Permian platform in the Guadalupe Mountains of Texas and New Mexico, and an outcrop analog at Sierra del Cuera in northern Spain. The giant ooid shoals of the Early

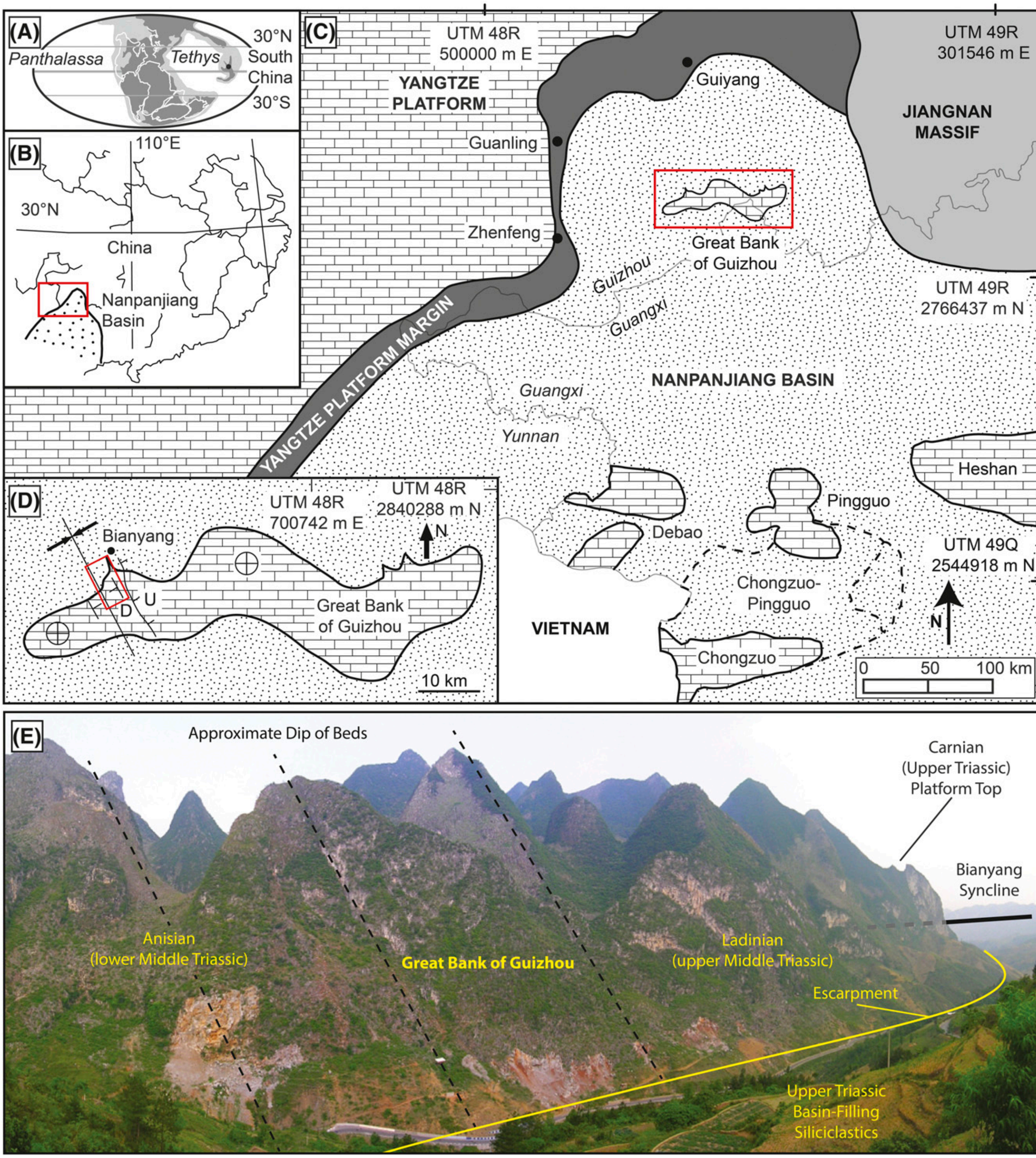

Figure 1. Geologic setting. (A) Paleogeographic map showing approximate location (in black) of the South China Block during the Late Permian to Triassic. Modified from Payne et al. (2006b). (B) Location of the Nanpanjiang Basin in south China (red box). (C) Detailed view of the Nanpanjiang Basin with the position of the Great Bank of Guizhou indicated. View is of the location enclosed by the red box in (B). (D) Detailed view of the Great Bank of Guizhou, with the location of Bianyang and the Bianyang Syncline indicated. View is of the location enclosed by the red box in (C). Red box near Bianyang indicates the location and geographic extent of the facies map in Figure 2. (E) Escarpment of the Great Bank of Guizhou. Stratigraphic top is to right; structural dip of approximately 65°. The platform margin erosional escarpment is represented by the sharp contact between platform carbonates and siliciclastic turbidites of the Bianyang Formation (foreground). UTM = Universal Transverse Mercator.

Triassic are an important analog for the Feixianguan Formation of the Sichuan Basin and the Khuff and Kangan formations of the Middle East (Alsharhan, 2006; Lehrmann et al., 2012).

GENERAL ACCESS AND SAFETY

Access is provided by domestic flights to Guiyang in Guizhou Province from Beijing, Shanghai, and Hong Kong. Travel from Guiyang to Bianyang or Luodian requires approximately two to three hours by car, depending on road conditions, closures, and construction. Suitable accommodations can be found in either Bianyang or Luodian. For geological field trips or research in China, a work permit must be acquired by collaboration with an academic institution or the geological survey. The GBG is preserved in a subtropical climate with rugged karst terrain in a remote location requiring careful attention to safety. The most significant safety issues involve travel by car and the remote location relative to the closest well-equipped hospital in Guiyang.

GEOLOGICAL BACKGROUND

The Yangtze Craton separated from the northeast margin of Gondwana during the Devonian, migrated northward across the eastern Paleotethys throughout the late Paleozoic and early Mesozoic, and eventually accreted to the North China Block during the Late Triassic Indosinian orogeny (Şengör, 1987; Enos, 1995; Meng and Zhang, 1999). For much of the late Paleozoic and early Mesozoic, the Yangtze Craton was the site of significant shallow-water carbonate deposition (Enos, 1995) as it migrated through the tropical eastern Paleotethys. Along the southern edge of the craton, a narrow marine embayment formed the Nanpanjiang Basin (Figure 1C; Enos et al., 2006). The Nanpanjiang Basin was surrounded on three sides by the shallow-marine carbonate Yangtze Platform.

During the latest Permian and earliest Triassic, a deepening event expanded the size of the Nanpanjiang Basin and drowned part of the Yangtze Platform, causing the platform margin to migrate approximately 100 km (~60 mi) to the north (Lehrmann et al., 1998; Enos et al., 2006). Topographically higher areas of the drowning Yangtze Platform became sites of isolated carbonate platform development as the basin subsided. Some of these platforms may have initiated on the structural grain created by horst and graben development during Devonian extension and rifting (cf., Xie et al., 1984; Qing et al., 1991). The GBG (Figure 1C–E) is the northernmost of the isolated platforms, coinciding with the remnant Yangtze Platform reef margin of the Late Permian, suggesting that it initiated on the antecedent topography of the former elevated rim (Lehrmann et al., 1998). During the Early and Middle Triassic, the Nanpanjiang Basin rapidly subsided, with the fastest rates of subsidence in the southern part of the basin (Lehrmann et al., 2007). The isolated platforms progressively drowned and were buried beneath siliciclastic turbidites along a south-to-north gradient from the Middle Triassic to Late Triassic (Lehrmann et al., 2007, 2015) in association with convergence primarily along the Songma suture zone during the Indosinian orogeny (Enos, 1995; Enos et al., 2006; Lehrmann et al., 2007, 2015).

The GBG preserves a relatively continuous record of carbonate sedimentation from the latest Permian to the earliest Late Triassic, when it finally drowned and was buried by siliciclastic turbidites (Lehrmann et al., 1998). The western part of the GBG is dissected by a syncline (Figure 1D) that cuts across the platform from the northwest to the southeast. Strata on the eastern limb dip at approximately 65° to the southwest. At the intersection of the syncline and the northern platform margin, deformation and subsequent erosion expose the platform margin in cross sectional profile (Figure 2). Because the depositional profile is exposed at the surface, this locality offers a rare opportunity to examine the developmental history of an isolated platform throughout its history and across a range of paleoenvironmental conditions from the platform interior to the basin margin.

DEPOSITIONAL FACIES MODEL AND EVOLUTION

The GBG initiated during the latest Permian on a topographic high of the remnant Yangtze Platform reef margin (Figure 3A; Lehrmann et al., 1998). The topographically lower area of the Yangtze Platform

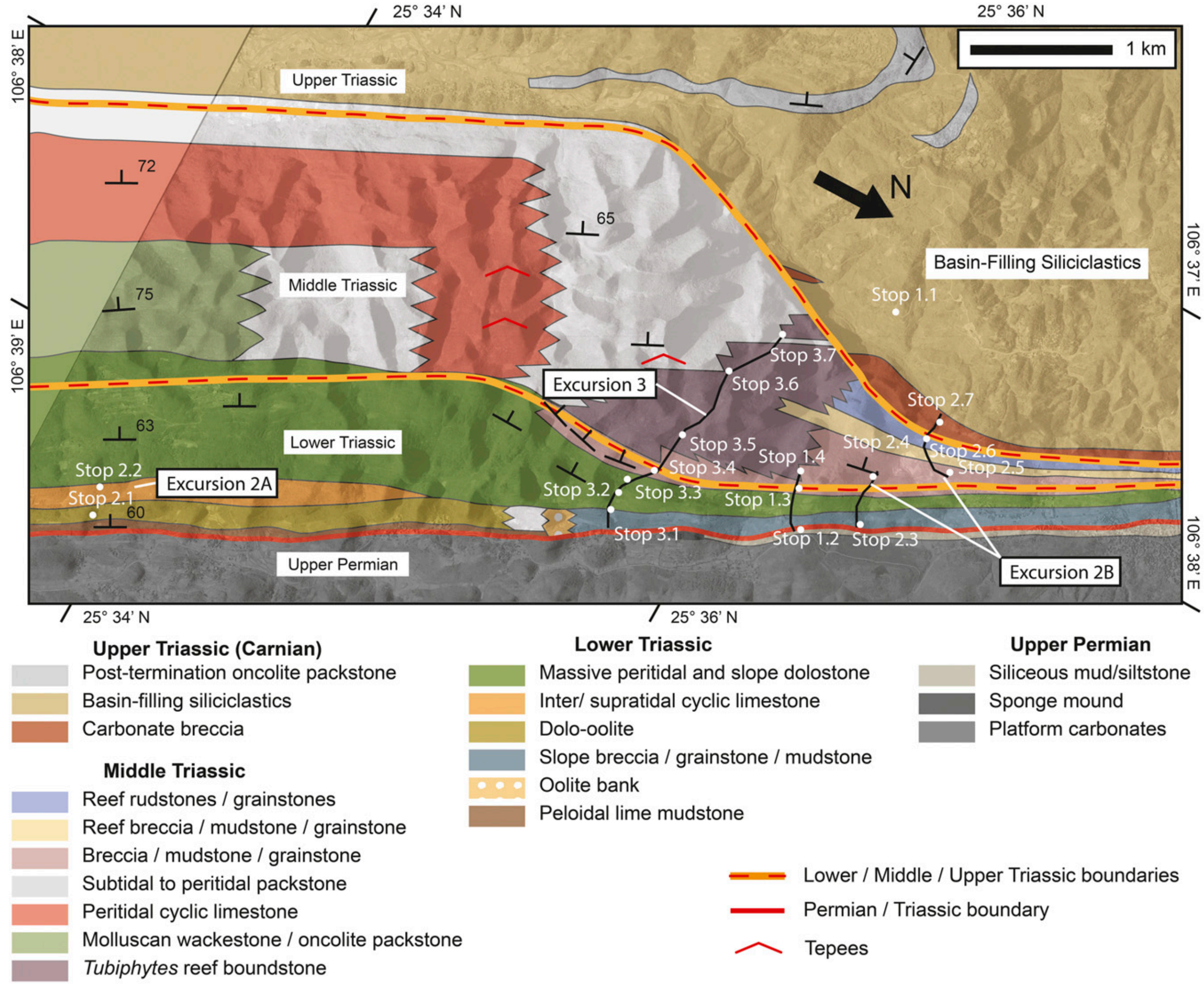

Figure 2. Facies distribution map. The platform is exposed in relatively uncomplicated cross section at the surface by the dip of the platform strata (~65° to the southwest, on average) and subsequent erosion. Top of the map is the approximate location of the syncline axis. Map is overlain on a Worldview-1 satellite image (modified from Lehrmann, 1993; Lehrmann et al., 1998; Kelley, 2014).

interior to the north of the GBG drowned as accommodation increased and the GBG aggraded. The drowning area of the shallow-marine carbonate Yangtze Platform interior was overlain by dark, fine-grained, siliceous sediments, regionally mapped as the Dalong Formation (Lehrmann et al., 1998). This Permian formation contains pelagic fossils such as ammonoids and radiolarians and includes evidence of bioturbation. The initial accumulation of the GBG itself is represented by patch reefs of sponge and rugose coral boundstone along with skeletal grainstone and packstone, regionally mapped as the Permian Wujiaping Formation. A diverse fossil assemblage that also includes bryozoans, fusulinids, other foraminifera, brachiopods, calcareous algae, echinoderms, bivalves, and gastropods indicates a normal, open-marine environment (Figure 4A). Chert nodules are also abundant and possibly reflect the abundance of siliceous sponges. Near the northern margin of the GBG, a sponge bioherm marks the transition from platform to basin, as depositional fabrics indicate a gradation from a wave-winnowed, mud-poor environment with fragmented fossils to a muddier, subtidal environment below normal wave base (Lehrmann et al., 1998).

The end-Permian extinction is recorded on the GBG as a sharp contact between the diverse skeletal grainstone and packstone of the Wujiaping Formation and a thrombolitic, microbial framestone containing a low-diversity assemblage of fossils including

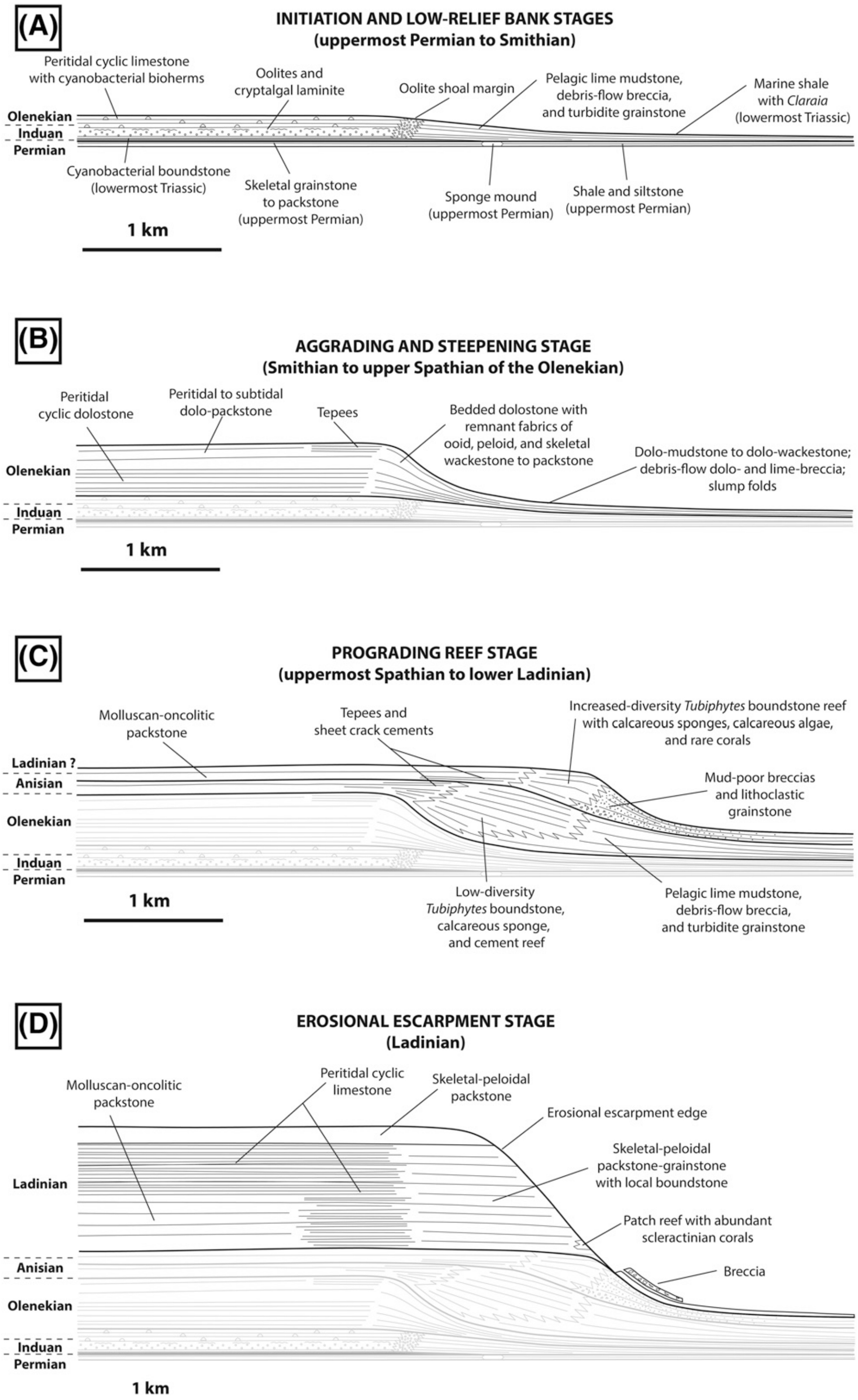

Figure 3. Reconstruction of key development stages of the Great Bank of Guizhou at Bianyang with vertical exaggeration removed. Modified from Kelley (2014). (A) Initiation and low-relief bank stages. (B) Aggrading and steepening stage. (C) Prograding reef stage. (D) High-relief escarpment stage.

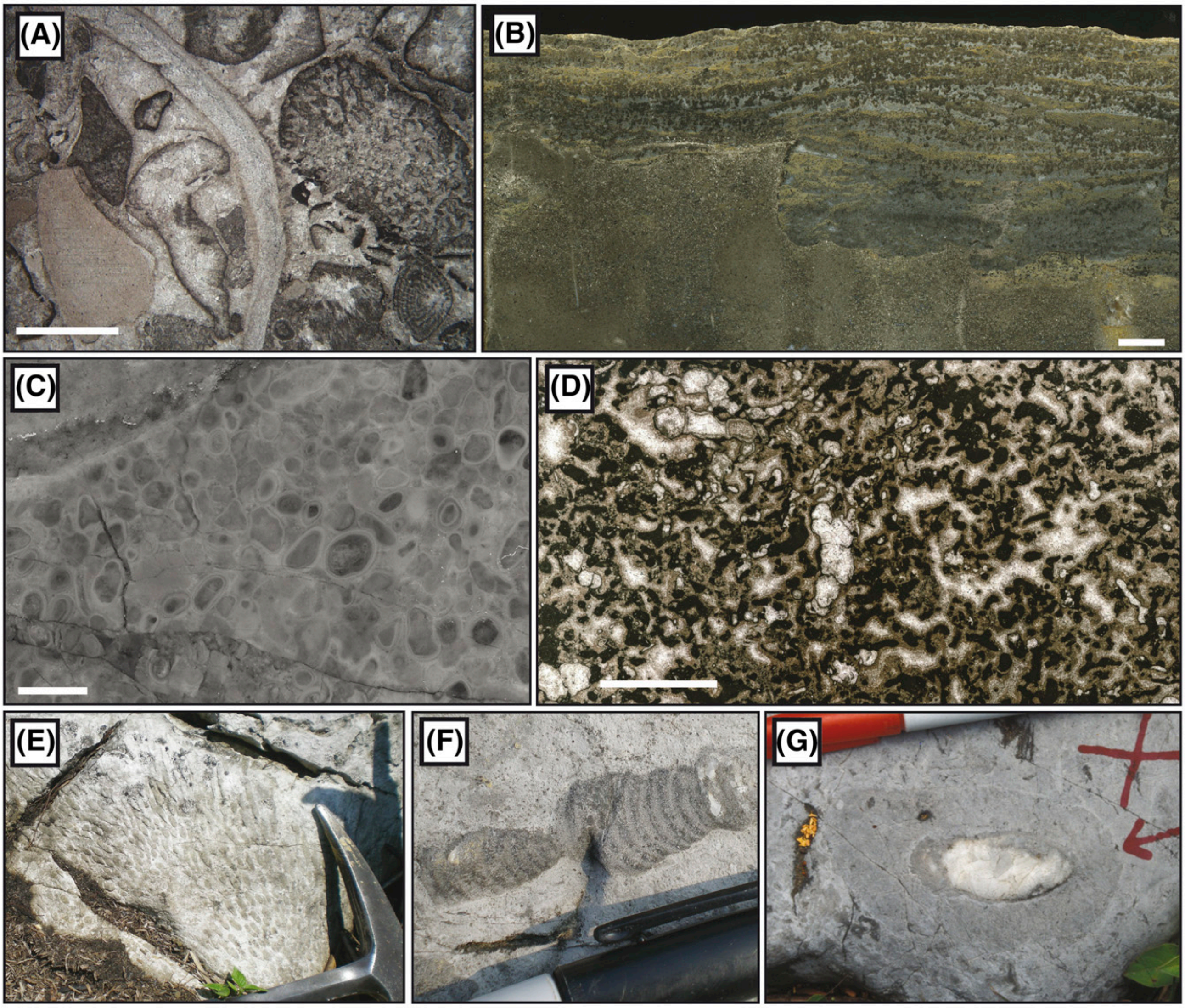

Figure 4. Representative images. (A) Photomicrograph of uppermost Permian, diverse-biota grainstone from the Wujiaping Formation. The diversity and abundance of skeletal fossils in the uppermost Permian contrast with the low skeletal abundance and diversity of the Lower Triassic strata. Scale bar = 5 mm (0.20 in.). (B) Polished slab of the lithostratigraphic boundary surface between the uppermost Permian and lowermost Triassic. Permian at bottom. Thrombolitic fabric of calcimicrobial framestone at top of slab. Scale bar = 1 cm (0.39 in.). (C) Typical Lower Triassic giant ooids and other coated grains. Scale bar = 1 cm (0.39 in.). (D) Thin-section photo of *Tubiphytes* and calcareous sphinctozoan sponge boundstone from the lower reef section. Dark masses are the micritic envelope of *Tubiphytes*. Light areas are sparry calcite. Sponges are small and generally less than 7 mm (0.27 in.) in maximum dimension. Multiple generations of early marine peloidal-micritic, brownish-fibrous, and isopachous cements are visible surrounding the *Tubiphytes* envelopes. Scale bar = 1 cm (0.39 in.). (E) Branching scleractinian coral. Hammer for scale. (F) Solenoporacean red alga from Upper Guandao section. Marker for scale. (G) Inozoan sponge from Upper Guandao section. Marker for scale.

gastropods, bivalves, brachiopods, and echinoderms (Figure 4B; Lehrmann, 1999). The microbial framestone (Permian–Triassic boundary microbialite) contains globular and tufted masses similar to *Bacinella* and *Renalcis*. The microbialite extends across the GBG in an expansive biostrome as much as 15 m (50 ft) in stratigraphic thickness. At the adjacent basin margin, earliest Triassic sediments are marine shales containing the bivalve *Claraia* (Lehrmann et al., 1998).

The margins of the GBG subsequently stepped back approximately 700 m (~2300 ft) during an Induan transgression that resulted in a significant rise of relative sea level (Figure 3A), indicated by the presence of lower-slope facies overlying the former platform margin (Lehrmann et al., 1998). The platform-interior facies contain thin-bedded lime mudstone, dolo-oolite grainstone, oolitic cryptmicrobial laminite, and cyclic peritidal limestone, suggesting a subtidal, open-marine to restricted-marine environment (Lehrmann et al., 1998). The platform margin was composed of ooid shoals (Figure 4C). The slopes exhibit hemipelagic lime mudstone, debris-flow breccia, extensive slump folds, and carbonate turbidite grainstones and packstones. Later, during the Olenekian, the platform aggraded and the slopes steepened (Figure 3B; Kelley, 2014). In the interior and margin of the platform, massive dolostone largely obscures lithofacies and fossil composition, but local areas of limestone preservation provide evidence for the composition of the facies. Interior environments reflect subtidal-to-intertidal cyclic sedimentation. Margin and slope limestones are commonly thin- to medium-bedded packstones containing bivalve shoals and, increasingly in the Spathian (Payne et al., 2006b), an abundance of skeletal fragments including crinoids. The presence of oolite shoals on the margin is suggested by the occurrence of ooids in coeval slope and basin-margin strata. Analysis of satellite imagery and field investigation implies the presence of an atoll-like morphology despite the absence of platform-margin reefs.

Near the end of the Early Triassic, the appearance of a *Tubiphytes* and cement reef (Figures 3C, 4D) on the margin (Lehrmann et al., 1998; Payne et al., 2006a) and slope (Kelley, 2014) marked the return of platform-margin reefs following the end-Permian extinction and their earliest appearance worldwide during the Mesozoic. The appearance of the reef coincided with an interval of higher relative progradation, reflecting either higher sedimentation and cementation rates on the slope reef, a decrease in the rate of accommodation increase, or a combination of the two processes. The *Tubiphytes* reef persisted in situ during the Anisian (early Middle Triassic). During the Ladinian, accelerated basin subsidence (Lehrmann et al., 2007) limited the progradation potential of the GBG (Minzoni et al., 2014; Lehrmann et al., 2015;) and the platform aggraded, forming a high-relief escarpment profile (Figure 3D; Lehrmann et al., 1998). Outer platform bedding extends to the escarpment edge where it was truncated by submarine erosion.

During the earliest Late Triassic, the rate of carbonate deposition slowed relative to accommodation increase, and the GBG drowned as increasing water depths limited the growth potential of the platform top. The stratigraphic succession on the uppermost platform exhibits a transition from shallow subtidal carbonate facies to deeper marine carbonates. The deeper-water facies fines upward through an approximately 40-m (~130-ft) interval of skeletal-oncolitic grainstones, packstones, and nodular wackestones that contain pelagic bivalves and Neogondolellid conodont fossils, suggesting increasing water depths (Lehrmann et al., 1998). The interpretation of increasing water depths is supported by the reappearance of an open-marine assemblage of fossils after being absent from the platform interior since the Early Triassic stages of platform development. Above the carbonate strata, the platform top is covered by more than 150 m (192 ft) of laminated, calcareous shale. Although an increasing water depth was likely a significant contributor to platform drowning, an increase in siliciclastic input, as evidenced by an up to 8% greater clay content in upper platform carbonates (Lehrmann et al., 1998) and apparently rapid siliciclastic filling of the adjacent basin (Minzoni et al., 2014), could have also been a factor.

In the basin, siliciclastic turbidites of the Bianyang Formation, exhibiting alternations of fissile shale with more massive sandstone beds, fill the approximately 1700 m (5577 ft) of accommodation surrounding the high-relief platform (Lehrmann et al., 1998). Adjacent to the platform, wedges of carbonate breccia are preserved at the base of the siliciclastic turbidite sequence and interbedded with the turbidites, indicating episodes of platform-top erosion during the Carnian. The carbonate beds contain a diverse assemblage of large metazoan and algal fossils including scleractinian corals, solenoporacean algae, serpulid worm tubes, and both sphinctozoan and inozoan sponges (Figure 4E–G). The abundance of large skeletal fossils implies either that marginal reefs were present near the edge of the escarpment, but were eroded, or that significant patch reefs were present near the margin.

GREAT BANK OF GUIZHOU FIELD ITINERARY

The field itinerary is designed to fit within three days. During the trip, participants will get an overview of the spectacular platform escarpment, the initiation of the platform within uppermost Permian strata, evidence of the end-Permian extinction and Triassic recovery, a broad range of facies and depositional environments, and the ultimate termination of the platform in Upper Triassic strata. Excursion 1 provides an overview of the platform escarpment, the termination sequence within the syncline, and a slope transect from the uppermost Permian to the initiation of the Middle Triassic reef. The platform escarpment overview reveals the extreme relief between the platform top and basin floor during the Late Triassic. It also allows participants to view the relationship between carbonate strata and the surrounding clastic basin fill. Excursion 2 provides an opportunity to see biostratigraphic and lithostratigraphic evidence of the end-Permian extinction, Lower Triassic microbialite, extensive platform-interior dolomitization, and a slope transect comprising Upper Permian to Upper Triassic strata that covers the entire interval of platform deposition. The excursion allows participants to compare in sequence the diversity and abundance of the uppermost Permian fossil assemblage with lowermost Triassic microbialites and the extended interval of low skeletal diversity within Lower Triassic strata. Excursion 3 provides an opportunity to walk across the initiation of the oldest-known platform-margin reef facies of the Mesozoic Era. Participants will see the stratigraphic evolution of the Middle Triassic reef from its early composition, when it was dominated by marine cements and *Tubiphytes*, to the increasing occurrence of framework-contributing algae and skeletal metazoans, and finally to the appearance of some of the earliest scleractinian corals.

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