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Benthic fossil assemblages and depositional facies of the Middle Triassic (Anisian) Yuqing Member of the Qingyan Formation, southern China

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Abstract. The Middle Triassic (Anisian) Yuqing Member of the Qingyan Formation crops out in Guizhou Province, southwestern China, and consists of storm-dominated inner and outer shelf deposits. It contains Tethyan benthic fossils that are grouped into two fossil assemblages. The allochthonous *Mentzelia multicostata-Mentzelia mentzeli* assemblage is characterized by brachiopods in the inner shelf facies. The parautochthonous and allochthonous *Posidonia wengensis* assemblages, composed mainly of epifaunal bivalves, dominate in the inner and outer shelf facies, although some species of *Posidonia* generally are characteristic of deep-sea environments or low-oxygen conditions.

Key words: bivalves, brachiopods, China, depositional environment, fossil assemblage, *Posidonia*, Triassic

Introduction

The Middle Triassic is considered to be the setting for the faunal turnover after the end-Permian mass extinction, and is an important time period for benthic ecology (Hallam and Wignall, 1997). Bivalves, in particular, substantially increased in generic diversity (McRoberts, 2001), and acquired new infaunal ways of life, including siphons and mucus-feeding (Stanley, 1968). Besides, abundant brachiopods are found in Triassic shallow-marine deposits. Especially in shallow-marine carbonate facies, brachiopods frequently predominate in benthic assemblages, although they are legacies of the Palaeozoic mass extinction and only minor members of marine benthic faunas in the Mesozoic (Hallam and Wignall, 1997). However, Anisian benthic assemblages and faunal compositions are hardly known because the record of shallow-marine fossils is relatively poor (Aberhan, 1994).

The Middle Triassic Yuqing Member of the Qingyan Formation is exposed in the Qingyan area, about 30 km south of Guiyang (provincial capital), Guizhou Province, China (Figures 1, 2). We collected abundant fossils and distinguished some benthic fossil assemblages in this member. In addition, depositional environments are reconstructed in detail based on facies analysis.

Geologic setting

The Qingyan Formation is equivalent to the Anisian (lower Middle Triassic). It is about 800 m thick, and is widely distributed in central Guizhou Province. It is mainly composed of platform limestone and basin mudstone, and was deposited in the Middle Triassic Nanpanjiang Basin (= Dian-Qian-Gui basin) (Wei *et al.*, 1996; Enos *et al.*, 1997, 1998; Stiller, 1997, 2001; Lehrmann *et al.*, 1998; Bao, 1998; Chen *et al.*, 1998) (Figure 3). The formation is subdivided into two subformations, i.e., the Xiaoshan and Yuqing subformations. The Yuqing Subformation consists of limestone and mudstone (about 400 m thick) and is subdivided into the Leidapo Member and the overlying Yuqing Member (Stiller, 1997). The Yuqing Member is composed of mudstones and marls (about 200 m thick) and consists of three parts (Figure 4). The lower part

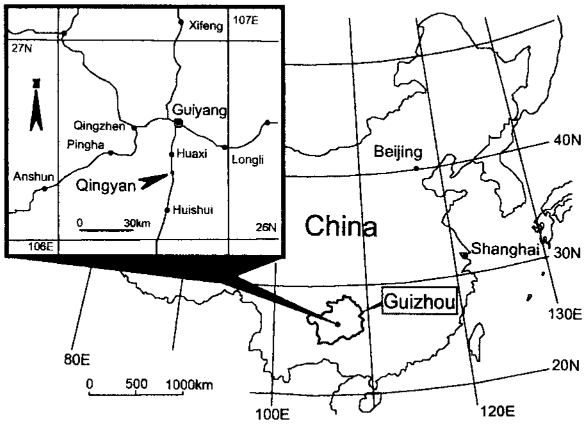

Figure 1. Location of the Qingyan area in the southern part of China.

Guiyang Formation		Shizishanjiao Member
Qingyan Formation	Yuqing Subformation	***Yuqing Member***
		Leidapo Member
	Xianshan Subformation	Yingshangpo Member
		Mafengpo Member
		Xiaoshan Member

Figure 2. Stratigraphic division of the Qingyan Formation.

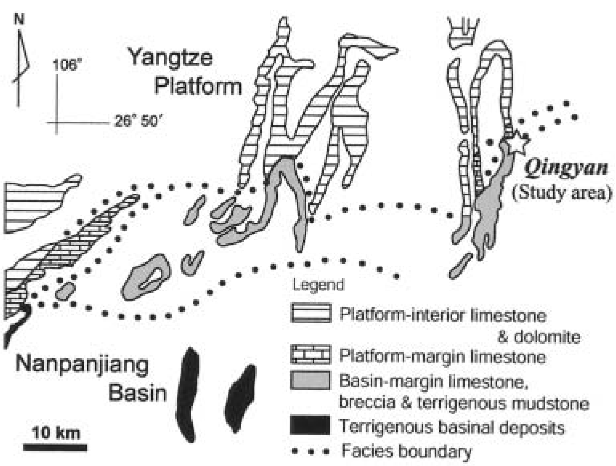

Figure 3. Anisian facies distribution in central Guizhou Province (modified from Enos *et al.*, 1997).

of the Yuqing Member is mainly composed of massive and laminated mudstone and marl (up to 60 m thick), rarely containing *Posidonia*. The middle part is dominated by massive mudstone with intercalating marl, and yields abundant paper shells (*Posidonia* and *Daonella*) and ammonoids (about 110 m thick). The upper part is characterized by alternating beds of mudstone and marl (about 30 m thick), containing abundant brachiopods, bivalves, rare cephalopods, gastropods, corals, and disarticulated crinoid remains. It crops out at the foot of the Shizishan Mountain (Figures 4, 5.1).

Methods

We conducted a sedimentological study based on facies analysis in the field, and sectioned some blocks of sediment for detailed observations of the sedimentary structures, grain size, and fabric in the laboratory. The terminology for depositional environments and sedimentary structures follows Tucker and Wright (1990), Walker and Plint (1992), and Wright and Burchette (1996).

The fossils of the Yuqing Member are grouped into two assemblages based on faunal composition, modes of fossil occurrence, and shell preservation. Bulk rock samples from some horizons were broken up in the laboratory, and all fossils larger than 5 mm were counted. Modes of occurrence were mainly observed in the field. The life habits of the bivalves were reconstructed by analogy with related living taxa, and also by reference to previous studies (e.g., Fürsich and Wendt, 1977; Aberhan, 1994).

Depositional facies and interpretation

Two depositional facies can be distinguished in the Yuqing Member, based on grain size, lithology, and sedimentary structures. The upper and basal middle parts of the member are composed of facies 1, and the main portion of the middle and lower parts is dominated by facies 2.

Facies 1

Description.—Facies 1 is characterized by alternating beds of marl and gray mudstone (Figures 4, 5.2). The marl beds are 1–30 cm thick, and are composed of fine to coarse calcitic silt and massive siliciclastic mud. They are characterized by hummocky cross-stratification (HCS). The basal part of the HCS marl, 0.5–2 cm thick, shows massive and graded portions, and yields small bioclasts and poorly preserved shell remains (Figures 5.3, 5.5). The top part is com-

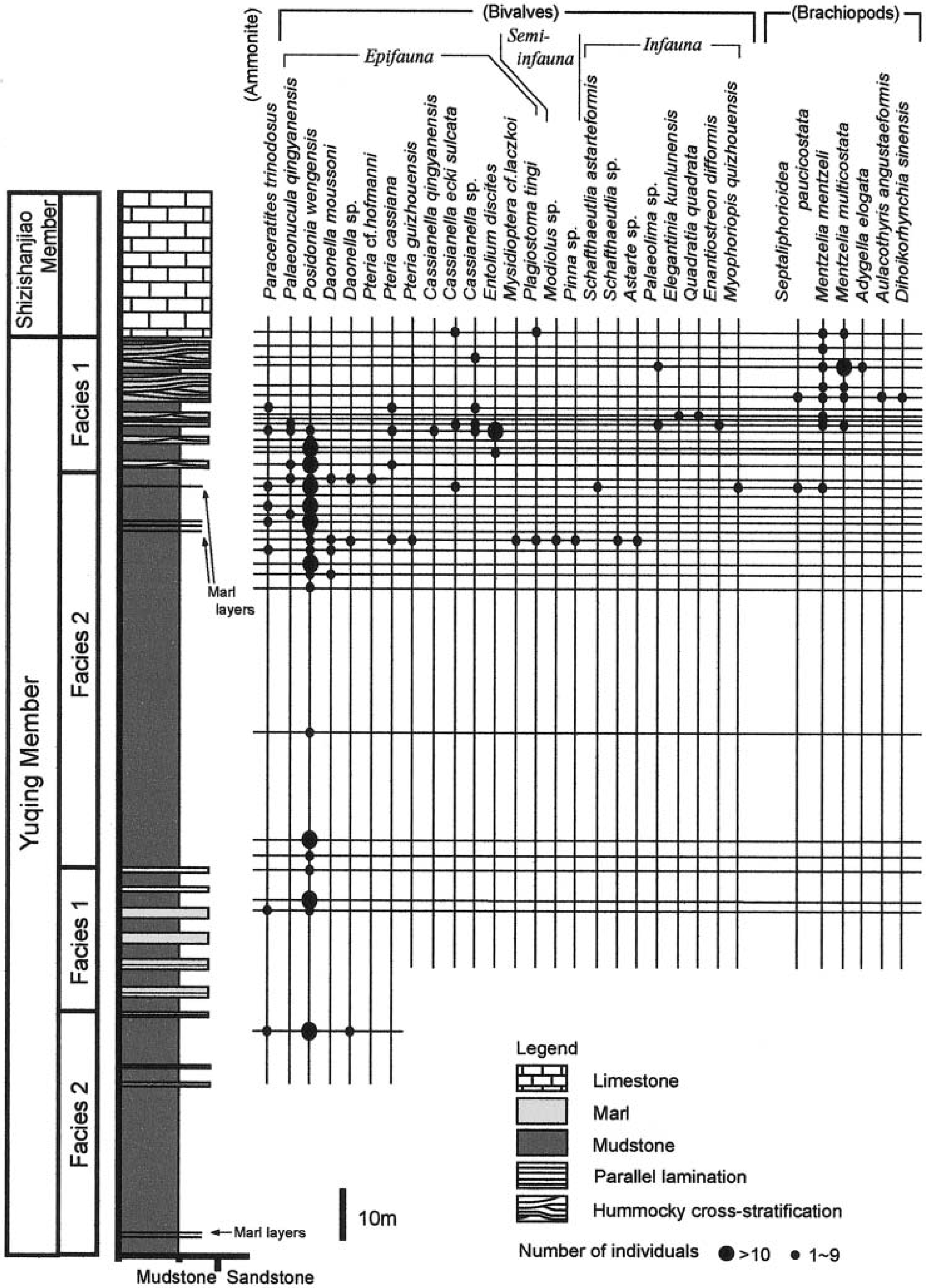

Figure 4. Summarized columnar section of the Yuqing Member, showing stratigraphic occurrences of bivalve and brachiopod species.

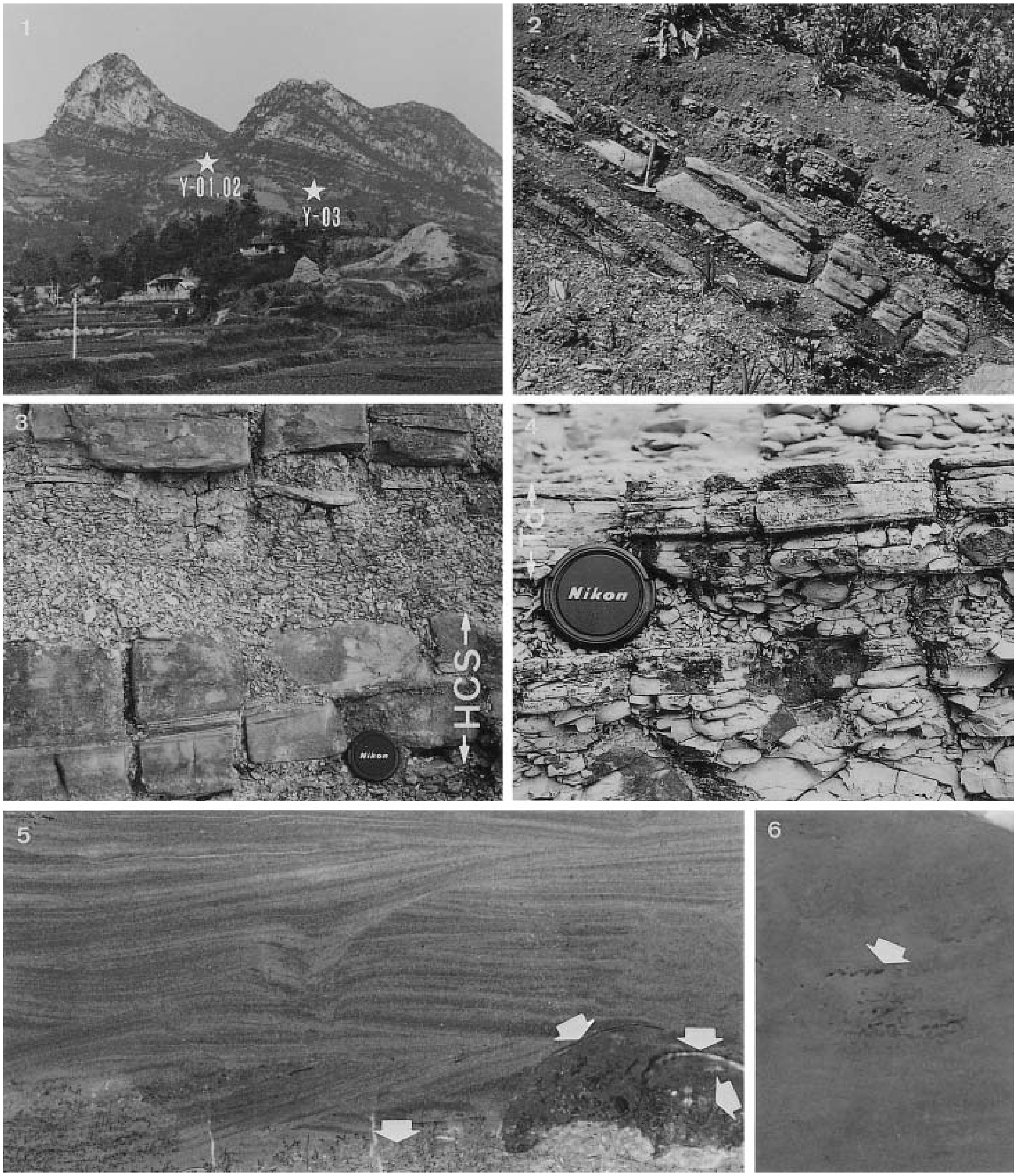

Figure 5. Photographs showing outcrops and sedimentary structures. 1. Fossil localities (Y-01-03) of the Yuqing Member at Shizishan Mountain. 2. Alternating beds of marl and mudstone (lower part of Yuqing Member). 3. Alternating beds of HCS marl and massive mudstone at Y-01 (upper part of Yuqing Member). 4. Alternating beds of parallel-laminated mudstone and massive mudstone (lower part of Yuqing Member); parallel-laminated mudstone represents Td division of Bouma sequence. 5. Vertical section of HCS marl (lower part of Yuqing Member); note disarticulated shell remains (arrowed) preserved in the basal part. 6. Vertical section of massive mudstone containing tiny trace fossils *Phycosiphon* isp. (arrowed) (middle part of Yuqing Member).

monly obscured by bioturbation. Symmetrically combined flow ripples rarely are preserved at the top of HCS. The mudstone is composed of clay and 10–20% calcareous fine-silt grains, and commonly shows bioturbation consisting of rather large (0.5–2.0 cm in diameter), three-dimensional burrows and small two-dimensional curved burrows.

Interpretation.—These alternating beds of facies 1 with their discrete hummocky cross-stratification were deposited in inner shelf environments between the fair-weather wave-base and the storm wave-base (Walker and Plint, 1992; Cheel and Leckie, 1993). The bioturbated mudstone provides evidence of benthic activity and relatively high oxygen levels during fair-weather conditions. The poorly preserved shell remains were probably transported from shallow-marine environments or were reworked by storms in inner shelf environments. Although shallow sea areas in the Nanpanjiang Basin generally were dominated by carbonates (Enos *et al.*, 1997), some siliceous deposits were present as well.

Facies 2

Description.—Facies 2 is characterized by massive mudstone. This mudstone is composed of calcitic silt (5–10%) and clay, and contains small two-dimensional burrows (*Phycosiphon* isp.) (Figure 5.6). Thin, silty marl layers (about 0.5–2 cm thick) and parallel-laminated siltstone (about 0.5–01 cm thick) are rarely found (Figure 5.4). Occasionally, the basal parts of marl layers contain small and thin graded shell lenses containing shell fragments of brachiopods and bivalves, overlain by parallel lamination. The marl layers are lithologically similar to the thin HCS beds of facies 1, and laterally change into the latter. Parallel-laminated siltstone also is intercalated with small shell lenses (several cm wide) that contain paper shells (*Posidonia* and *Daonella*). Facies 2 comprises the upper and basal middle parts of the Yuqing Member, and laterally changes into facies 1, which is interpreted to represent inner shelf environments.

Interpretation.—Facies 2 probably was accumulated in outer shelf environments, because this facies is characterized by mudstone that laterally changes into deposits of the inner shelf facies. Small two-dimensional burrows are common in less-oxygenated areas (Bromley, 1996). The laminated marl layers are probably distal storm deposits, comparable to the Td interval in Bouma's turbidites (Bouma, 1962). The laminated mudstone also may have formed during the latest stage of turbidity currents and partly during the calm conditions after the passage of turbidity currents.

Fossil assemblages

Abundant bivalves and brachiopods as well as rare cephalopods (ammonoids), gastropods, and corals were collected from the Yuqing Member at the foot of Shizishan Mountain (Figures 5.1, 6, 7). Twenty-three species of Bivalvia belonging to 17 genera and some cephalopods were mainly found in the mudstone of all parts of the Yuqing Member. Six brachiopod species and corals are restricted to the HCS marl of the alternating beds (facies 1) in the upper part of the Yuqing Member. Poorly preserved gastropods rarely occur in the HCS marl and mudstone of facies 1. These modes of occurrence and of shell preservation are variable within each depositional facies. Two fossil assemblages are distinguished, based on faunal composition, mode of fossil occurrence, and shell preservation.

Mentzelia multicostata-Mentzelia mentzeli assemblage

Composition—The *Mentzelia multicostata-Mentzelia mentzeli* assemblage is composed mainly of the following brachiopods: *Mentzelia multicostata*, *Mentzelia mentzeli*, *Septaliphorioidea paucicostata*, and *Adygella elongata*. *Mentzelia multicostata* and *M. mentzeli* constitute over 50% of this assemblage. Epifaunal bivalves, such as *Cassianella ecki sulcata*, *C. qingyanensis*, *Plagiostoma tingi*, *Pteria cassiana*, *P. guizhouensis*, *P.* cf. *hofmanni*, *Praechlamys* sp., *Modiolus* sp., as well as infaunal bivalves such as *Palaeoneilo distincta*, *Elegantinia elegans*, *Quadratia quadrata* and *Schafhaeutlia* sp., are rarely found in this assemblage. Disarticulated crinoid stem remains are abundant. Stiller (2001) reported *Diholkorhynchia sinensis*, *Mentzelia subspherica* and *Angustothyris angustaeformis* (brachiopods), *Parallelodon beyrichi*, *Neoschizodus laevigatus* and *Plagiostome* sp. (bivalves) and a few gastropods.

Mode of occurrence—This assemblage was obtained from basal parts of HCS marl beds (facies 1), covering erosional bases with coarse calcareous sand grains. These shell concentrations form thin shell-supported lenses, 2–10 m wide and 1–3 cm thick, and are discontinuously distributed in the same horizon. Almost all shells are preserved as disarticulated valves and fragments (Figures 5.5, 6.9–10), and their surfaces show abrasion and breakage. The mode of occurrence and the shell preservation are typically allochthonous. Infaunal shells, such as *Quadratia quadrata* and *Elegantinia* sp., are occasionally encrusted by epifaunal shells (Figure 6.7). Probably some shells had been exposed postmortally on the sea floor. Occasionally,

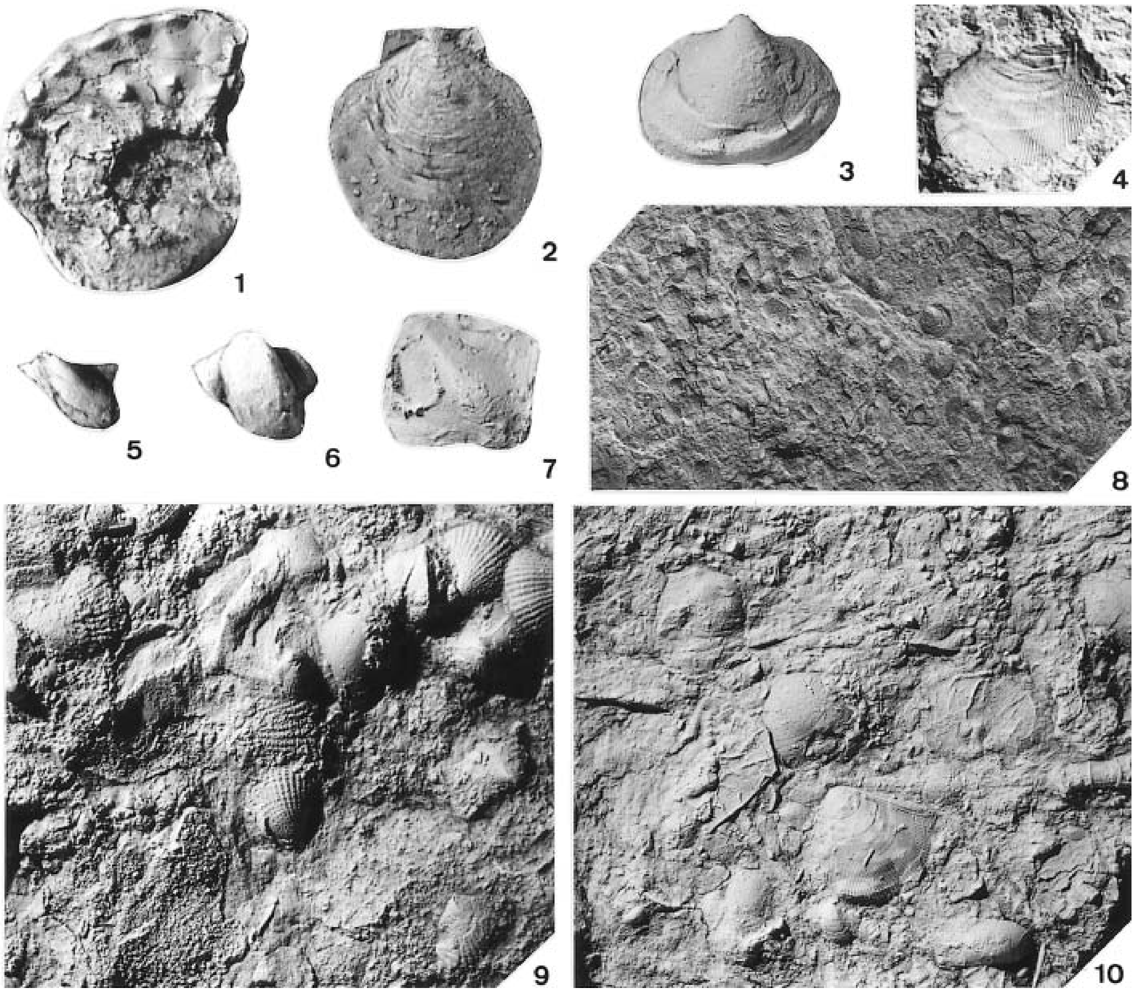

Figure 6. Fossils from the upper part of the Yuqing Member. 1. *Paraceratites trinodosus* Mojsisovics, lateral view, ×1.0. 2. *Entolium discites* (Schlotheim); right valve, ×1.0. 3. *Mentzelia mentzeli* Dunker; ventral valve, ×1.0. 4. *Mysidioptera* sp.; right external cast, ×1.0. 5. *Pteria cassiana* Bittner; left valve, ×1.0. 6. *Cassianella qingyanensis* Chen, Ma and Zhang; left valve, ×1.0. 7. *Quadratia quadrata* Yin; left valve, ×2.0. 8. Shell concentration composed of *Posidonia* sp. overlying parallel-laminated mudstone, ×1.2. 9. Shell concentration of *Mentzelia multicostata* Yang and Xu in the basal part of HCS marl, ×1.0. 10. Shell concentration composed of disarticulated bivalves and brachiopods in the basal part of HCS marl, ×1.0.

exceptionally well preserved, articulated *Mentzelia multicostata* are randomly arranged in shell lenses, forming peculiar monospecific occurrences (Figure 6.9).

Posidonia wengensis assemblage

Composition—This assemblage is dominated by the paper shells *Posidonia wengensis*, *Posidonia* sp., *Daonella moussoni*, and *Daonella* sp. These species lived epifaunally; however, the mode of life of these Triassic species is still under discussion (Kobayashi and Tokuyama, 1959; Jefferies and Minton, 1965; Fürsich and Wendt, 1977). *Posidonia wengensis* and *Posidonia* sp. generally form over 90% of this assemblage (Figure 7).

Section Y-03, exceptionally, yielded the following bivalves: epifaunal *Entolium discites*, *Cassianella ecki sulcata*, *C. qingyanensis*, *Pteria cassiana* and the infaunal *Palaeonucula qingyanensis* (Figure 7). *Entolium discites* is especially abundant in these beds.

Mode of occurrence—Two modes of occurrence have been observed in *Posidonia wengensis*, *Posidonia* sp., and *Daonella moussoni*. The first type consists of shell-supported, lenticular and patchy shell concentrations (3–5 cm wide) in shelf mudstone (facies 1, 2) and in the top part of storm-generated thin marl layers in outer shelf mudstone (facies 2) (Figures 6.8, 8). For example, five small, approximately circular shell con-

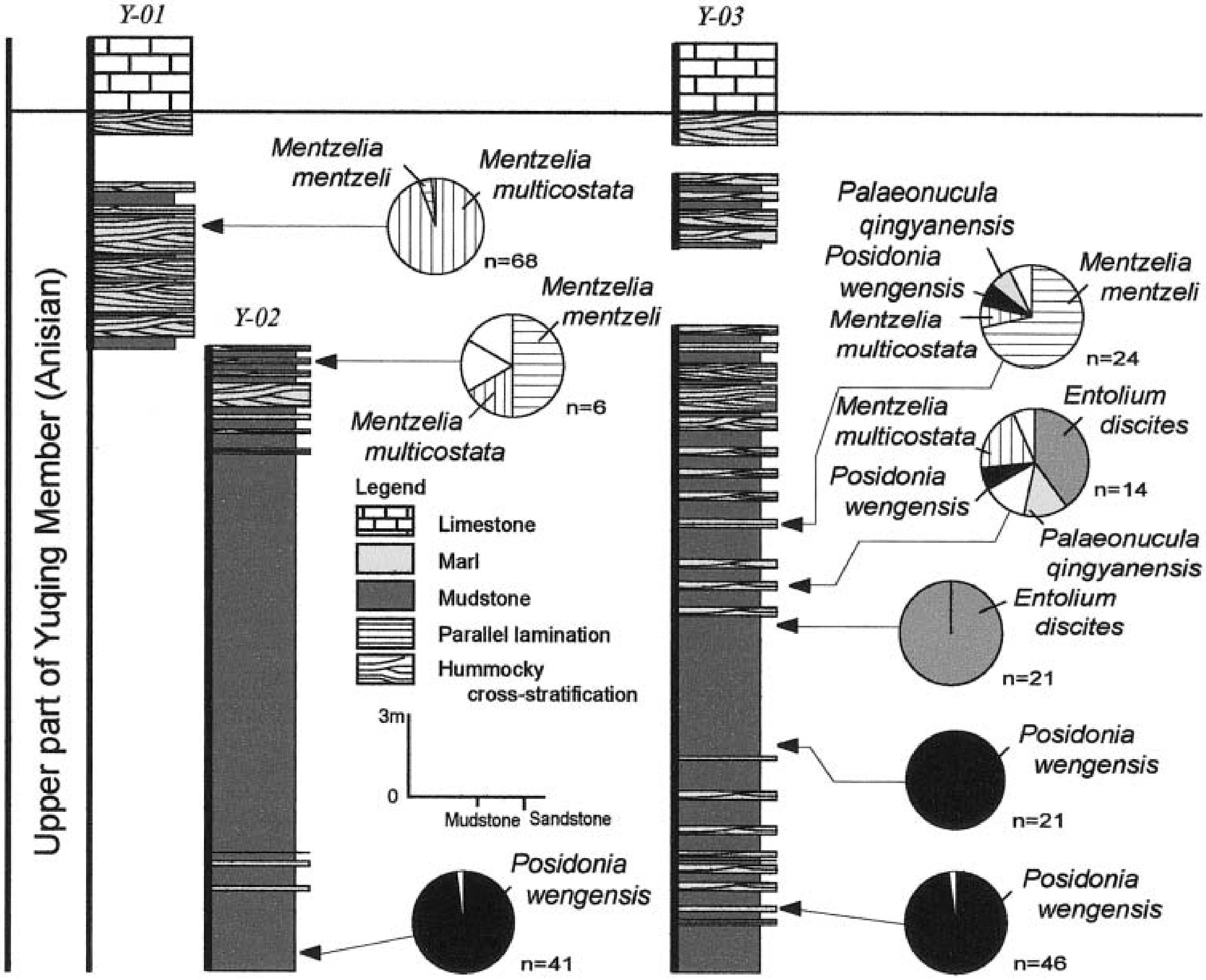

Figure 7. Columnar sections of the upper part of the Yuqing Member and fossil compositions.

centrations are found within 100 cm^2 on the horizontal plane of a marl layer, and further shell fragments are scattered between them. The shells commonly are preserved as disarticulated valves and fragments, only rarely as articulated valves (5–10%). These occurrences are interpreted to be allochthonous.

The second type is represented by sporadic occurrences (0–2 individuals/2500 m^2) in shelf mudstone. Most of the shells are preserved with their valves articulated. There are no signs of abrasion or breakage, even though the valves are extremely thin. Judging from the mode of occurrence and preservation, these shells probably are preserved within or near the original habitat. This type represents parautochthonous occurrences.

At Y-03, *Entolium discites* is commonly preserved in articulated form or else commonly with the right and left valves of the same individual overlapping. The infaunal *Palaeonucula qingyanensis* is preserved in articulated form, although not in life position. Generally these taxa are found sporadically in the mudstone-dominated alternating beds characterized by discrete HCS marl (facies 1) with *Posidonia wengensis* and *Posidonia* sp., and do not form shell concentrations. These modes of occurrence and of shell preservation probably represent parautochthonous conditions. However, *Cassianella ecki sulcata*, *C. qingyanensis*, *Pteria cassiana*, *P. guizhouensis*, and *P.* cf. *hofmanni* probably were more or less transported, because all specimens of these taxa are poorly preserved as disarticulated valves.

Depositional environments

The basal middle and the upper part of the Yuqing Member are composed of storm-dominated inner shelf

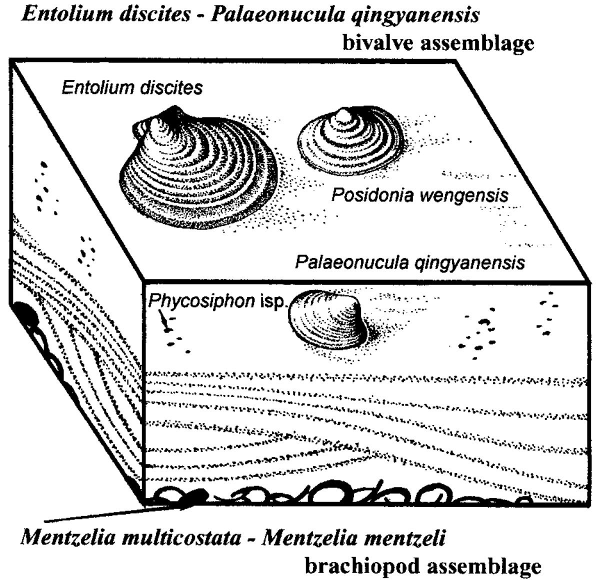

Figure 8. Reconstructed benthic fossil assemblage of the inner shelf of the Yuqing Member.

deposits. The lower and middle parts are dominated by outer shelf deposits that formed below the storm wave base. The inner shelf deposits of the middle part are covered by a thick outer shelf succession of mudstone containing abundant *Posidonia* shells. Laterally and vertically, the outer shelf deposits gradually change into inner shelf deposits. Thick inner shelf deposits are distributed in the western part of the study area. Finally, these shelf deposits are overlain by the limestone of the Shizishanjiao Member of the Guiyang Formation. The latter contains abundant well preserved shallow-marine fossils, e.g., brachiopods, bivalves, gastropods, corals, and articulated portions of crinoid stems (up to over 20 cm long). This limestone formed on the carbonate platform in the northern part of the Nanpanjiang Basin. Therefore, this entire sequence roughly records two regressions and one transgression during the late Anisian.

Sediments of the Yangtze Platform, an isolated platform (“Great Bank of Guizhou”), and the adjoining Nanpanjiang Basin (= Dian-Qian-Gui Basin) are widely exposed in Guizhou Province (Wei *et al.*, 1996; Enos *et al.*, 1997, 1998; Stiller, 1997; Lehrmann *et al.*, 1998; Bao, 1998; Chen *et al.*, 1998) (Figure 3). The Middle Triassic of this platform is characterized by cyclic subtidal to supratidal deposits, and by reefs formed by *Tubiphytes* boundstone at the platform margin (Enos *et al.*, 1998; Lehrmann *et al.*, 1998). These shallow marine environments were influenced by tidal currents. However, the depositional environments in our study area were dominated by wave and storm energy processes. Therefore, tide-influenced carbonate facies and wave-influenced siliciclastic facies are distributed around the Yangtze Platform.

Habitat of *Posidonia wengensis*

Assemblage of *Posidonia* and related genera (ex. *Bositra*) have been reported from Triassic to Jurassic deposits all over the world. They frequently form monospecific shell concentrations in laminated, organic-rich shales and mudstones in deep-marine environments (Kobayashi and Tokuyama, 1959; Fürsich and Wendt, 1977; Morris, 1979; Aberhan, 1994; Etter and Tang, 2002). In general, *Posidonia* is a characteristic element in hemipelagic and pelagic facies (Kobayashi and Tokuyama, 1959) and in oxygen-controlled environments (Aberhan, 1994); especially in the Jurassic, it is found under low-oxygen conditions (Jenkyns, 1988; Aberhan, 1994; Etter and Tang, 2002).

However, in the Yuqing Member, storm-dominated inner and outer shelf deposits abundantly yield parautochthonous *Posidonia wengensis* in the form of monospecific occurrences. Articulated *P. wengensis* occurs with parautochthonous *Entolium discites* and *Palaeonucula qingyanensis* from inner shelf muddy deposits. The shelf deposits commonly contain various large burrows, which suggest oxygen had been fully supplied within the sediments and the bottom of the sea. Besides, *P. wengensis* is commonly found in the slope and basin deposits of the underlying Leidapo Member (Stiller, 2001). Probably *Posidonia wengensis* thus not only inhabited deep marine habitats, but also shallow marine environments above the storm wave base.

Age of the Yuqing Member and problems of geologic age of the Tethyan fauna from Japan

Paraceratites trinodosus, *Judicarites* sp., and *Acrochordiceras*? sp. (ammonoids) rarely occur in the Yuqing Member (Stiller, 2001). *Paraceratites trinodosus* was collected from the mudstone of the middle and upper parts of the member (Figures 4, 6.1). *Paraceratites trinodosus* is reported from the Dont Formation and the Prezzo Limestone in the southern Alps, Europe, the *P. trinodosus* Subzone characterizing the upper Anisian in the Tethyan realm (Mietto and Manfrin, 1995).

The bivalve *Daonella moussoni* was obtained from the upper part of the Yuqing Member. This paper shell is found in the *Frechites occidentalis* Zone in the

Prida Formation, Nevada, U.S.A., indicating a late Anisian age (Silberling and Nichols, 1982). A late Anisian *Daonella moussoni* Zone is also known in the Baifeng Formation, Guangxi Province, China (Chen *et al.*, 1992). *Daonella luganensis* and *D. pseudomoussoni* have also been reported from other localities in the Yuqing Member (Stiller, 2001).

On the genus level, the bivalve fossils of the Yuqing Member are very similar to those of the underlying Leidapo Member, to those of the Anisian Junzihe Formation, western China, and to those of the Carnian Cassian Formation in the southern Alps (Fürsich and Wendt, 1977; Yang *et al.*, 1983; Stiller, 2001). Some bivalves of the Leidapo Member and the Cassian Formation even are conspecific (Chen, 2003), although those of the Cassian Formation are believed to have diversified during the Upper Triassic Carnian in Europe (Hallam and Wignall, 1997). Besides, in Japan, "St. Cassian-type bivalve assemblages" mainly composed of Myophoriidae have been reported from the Konose Group, Kumamoto Prefecture, the Buko Limestone Formation, Saitama Prefecture, and some other areas (Tamura, 1972, 1981, 1992). The ages of these formations generally were estimated as Carnian by comparison with "St. Cassian-type bivalves" (Tamura, 1992). However, "St. Cassian-type bivalves", such as *Cassianella*, *Cultriopsis*, and *Myophoriidae*, had already been diversified during the Anisian in southern China (Chen, 2003). Therefore, these deposits are probably not limited to the Carnian. Consequently, the age of these Tethyan faunas in Japan must be examined further.

Conclusions

1. The Yuqing Member is composed of storm-dominated inner and outer shelf deposits, and represents two regressions and one transgression.

2. Two benthic assemblages are recognized in the Yuqing Member. The *Posidonia wengensis* assemblage occurs widely in shelf deposits and is parautochthonous and allochthonous. *Posidonia wengensis* inhabits shallow-marine inner shelf conditions, although *Posidonia* generally is a characteristic element in hemipelagic and pelagic facies or oxygen-controlled environments. The *Mentzelia multicostata-Mentzelia mentzeli* assemblage is composed of typical allochthonous brachiopods and rare bivalves; it occurs in inner shelf environments.

3. The age of "Upper Triassic" Japanese Tethyan faunas must be reexamined. It is highly likely that these faunas correlate to Chinese Middle to Upper Triassic Tethyan faunas.

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