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The Upper Permian Reefs in West Hubei, China

Oberpermische Riffe in West-Hubei, China

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INTERNATIONAL SYMPOSIUM
ON TRIASSIC REEFS

SCHLÜSSELWÖRTER: FAZIES - RIFF-MILIEU - SEDIMENTOLOGIE - KARBONATDIAGENESE - SÜD-CHINA - OBER-PERM

S U M M A R Y

Upper Permian reefs are widely distributed in the Lichuan district, West Hubei. The reefs occur within the Changxing Formation (zone with *Palaeofusulina*). Main frame-building organisms are sphinctozoan calcisponges, which together with various binding organisms (lamellar blue-green algae and *Tubiphytes*) form the organic framework of the reefs. In addition early diagenetic fibrous carbonate cements are important constructional elements.

Four stages can be recognized in the growth of the Jiantianba reef: The sediment of the first stage represents deep-water basinal facies (Wujiaping Formation; thin-bedded cherty limestones, siliceous rocks and shales), followed upwards successively by slope, fore-reef, and reef core facies, which in turn were overlain by a back-reef facies. This sequence indicates a shallowing-up sedimentation pattern and a gradual progradation of the carbonate platform basinwards. Slope facies and fore-reef facies are characterized by thick-bedded and massive sponge-skeletal limestones with intercalations of limestone breccias composed of reef-derived material. The reef core facies consists of non-bedded framestones with abundant sphinctozoan and inozoan calcisponges, hydrozoans, and encrusting and binding algae. *Tubiphytes* is found within quiet-water environments as well as in high-energy environments. The lagoonal deposits consist of dolomitized limestones with echinoderms, limestones with abundant gymnocodiacean algae, and coarse-grained calcidolomites.

Mixing of saline water with freshwater due to subaerial exposure of the reef resulted in dolomitization and dissolution. The reef dolomites are effective productive reservoir rocks.

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The composition of the frame-building fauna and also the depositional fabric of the reef framework can be compared with the Permian Capitan reef in North America and with Triassic reefs in the Alps.

ZUSAMMENFASSUNG

Oberpermische Riffe sind im Lichuan Distrikt, West Hubei, weit verbreitet. Die Riffe treten in der Changxing-Formation (Zone mit *Palaeofusulina*) auf. Hauptriffbildner sind segmentierte Kalkschwämme, die zusammen mit verschiedenen sedimentbindenden Organismen (lamellare Blau-Grün-Algen, *Tubiphytes*) das organische Gerüst der Riffe bilden. Hierzu treten als wichtige Bauelemente frühdiagenetische fibröse Karbonatzemente.

In der Entwicklung des Jiantianba-Riffes können vier Stadien unterschieden werden: Das erste Stadium wird durch eine Tiefwasser-Beckenfazies repräsentiert (Wujiaping-Formation; dünngebankte Kalke mit Hornsteinen, Kieselgesteine und Schiefer), die weiteren Stadien durch Hang-Fazies, Vorriff-Fazies und Riffkern-Fazies. Die Riffkern-Fazies wird durch Gesteine der Lagunen-Fazies überlagert. Die vertikale Faziesfolge deutet eine allmähliche Verflachung der Sedimentationsbasis und eine Verlagerung der Riffzone gegen das Becken an. Die Hang-Fazies und die Vorriff-Fazies sind durch dickgebankte und massive bioklastische Schwamm-Kalke mit Einschaltungen von Kalkbrekzien charakterisiert. Die Riffkern-Fazies besteht aus nichtgebankten Framestones mit sehr häufigen segmentierten und nichtsegmentierten Kalkschwämmen und Hydrozoen sowie mit inkrustierenden Algen. *Tubiphytes* tritt sowohl in Ruhigwasser-Bereichen als auch in hochenergetischen Zonen auf. Die Lagunen-Fazies ist durch dolomitisierte Kalke, Kalke mit massenhaft auftretenden Gymnocodiaceen und durch grobkörnige Dedolomite gekennzeichnet.

Dolomitisierung und die in den Riffkalken zu beobachtende starke sekundäre Lösung wird auf eine, mit einer subaerischen Exposition des Riffes verbundene Diagenese zurückgeführt. Die Riffkerngesteine sind produzierende Speichergesteine.

Die Zusammensetzung der Riffbildnerfauna und auch die Anlagerungsgefüge im Riffgerüst können mit dem permischen Capitan-Riff in Nordamerika und mit triadischen Riffen in den Alpen verglichen werden.

INTRODUCTION

Upper Permian reefs are widely distributed in the Lichuan district, West Hubei, where calcisponges and hydrozoans comprise the frame-building organisms of the typical reef. Their stratigraphical horizon corresponds to the Upper Permian Changxing formation. The outcrops of the reefs are well exposed in Jiantianba, Huangnitang and Jiannan, Lichuan County (Fig. 1). From the viewpoint of the complete exposure of the reef sequence, the abundance of frame-building organisms and the distinctness of reef textures and structures, the Upper Permian reefs in West Hubei can be regarded as the best developed Permian organic buildups in Southern China.

In the early 1960s, some preliminary investigations were carried out. By the beginning of the seventies, detailed research of the reefs exposed in Jiantianba and Huangnitang had been done by many people, resulting in the recognition of some general features of these reefs. During the field trip from May to August 1980, the authors had the opportunity to study the reefs and to collect a great number of fossils and rock samples. The investigation of the frame-building organisms, together with microfacies analysis

and the study of the geological situation support the conclusion that the Upper Permian reefs in West Hubei represent carbonate platform margin reefs.

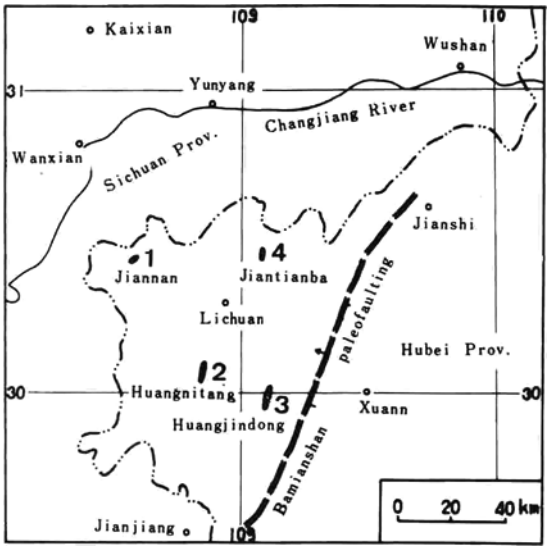

Fig. 1. Distribution of Upper Permian reefs (1-4) in West Hubei, South China. The Bamianshan paleofault separates areas with carbonate platforms and marginal reefs in East Sichuan and West Hubei from those with predominantly basinal sedimentation in Xuann and Nshi.

Verbreitung der oberpermischen Riffe (1-4) in West-Hubei, Süd-China. Durch die Bamianshan-Störung werden Gebiete mit Karbonatplattform-und Riffentwicklung (in Ost-Sichuan und in West-Hubei) von Räumen mit überwiegend Becken-Sedimentation (in Xuann und Nshi) getrennt.

1 STRATIGRAPHY (Fig. 2)

The Upper Permian of the Lichuan district is divided into two formations: Wujiaping formation and Changxing formation. The Wujiaping formation is mainly composed of thin-bedded cherty limestones, siliceous rocks and carbonaceous shales, containing *Codonofusiella*, *Waagenophyllum*, *Lophophyllidium*, *Tylopecta*, and others. The overlying Changxing formation, which is further subdivided into three members, consists mainly of dark-grey, thick-bedded bioclastic limestones with *Palaeofusulina*, *Lophocarinophyllum*, and *Pseudotirolites*. Equivalent to the Changxing formation is the Dalong formation, generally regarded as a lateral facies variation of the former. The Dalong formation is composed of thin-bedded siliceous rocks and cherty limestones, yielding abundant ammonites such as *Pseudotirolites* and *Pseudogastrioceras*.

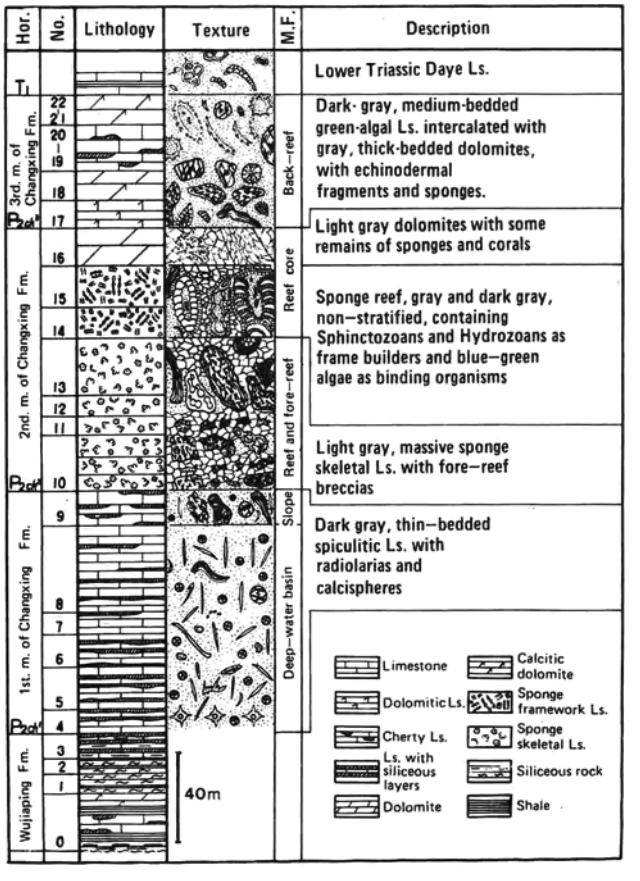

Fig. 2. Stratigraphy of the Upper Permian deposits in the area of Jiantianba, Lichuan district, West Hubei.

Stratigraphie des Oberperms im Gebiet von Jiantianba, Lichuan-District, West-Hubei.

2 Main Rock Types of the Reefs

According to the classification proposed by DUNHAM (1962) and EMBRY & KLOVAN (1971) five rock types can be distinguished for the reefs and related facies:

1. Framestone, composed mainly of frame-building organisms such as calcisponges, hydrozoans and stromatoporoids, often associated with many bioclasts and much limemud as interstitial filling material. This type represents the reef core facies. Three subtypes may be distinguished: sponge framestones (Plates 1/6, 2/1-3), hydrozoan framestones, and stromatoporoid framestones.

2. Boundstone (Plate 2/4), formed by binding and encrusting of lamellar blue-green algae and partially also *Tubiphytes* around other organisms such as calcisponges, bryozoans and various bioclasts. This type is often found in the initial stage of the reef development. Three subtypes can be distinguished: blue-green algal boundstones, blue-green algal bryozoan boundstones, and blue-green algal bioclast boundstones.

3. Grainstone and Rudstone (Plate 1/5), composed of angular breccias consisting of lithified spar-cemented reef material. These rocks are commonly found in the fore-reef facies.

4. Packstone, composed mainly of skeletal grains (e.g., green algae, gymnocodiacean algae and foraminifers) and micritic matrix. These rock types are commonly located in the back-reef facies. Three subtypes may be distinguished: micritic algal-foraminiferal limestones, micritic green-algal limestones, and micritic limestones with gymnocodiacean algae (Plate 2/6).

5. Wackestone, represented by argillaceous micrites rich in organic matter, and yielding many foraminifers, sponge spicula and calcispheres as well as radiolarians. This rock type often occurs in the deep-water basinal facies. Three subtypes are included: argillaceous micrites with radiolarians (Plate 1/1), spiculitic argillaceous micrites, and argillaceous micrites with calcispheres (Plate 1/2). Associated with these rocks are carbonaceous shales, mudstones and thin-bedded siliceous rocks.

3 Facies and Development of the Jiantianba Reef (Fig. 3)

Basin facies: Underlying the reef facies is a typical deeper-water basinal facies consisting of dark grey and black, thin- to medium-bedded micrites with spicula and calcispheres (Plate 1/2) intercalated with cherty layers and spiculitic siliceous rocks. In the lower part, some well-preserved radiolarians were found (Plate 1/1). On the top of the sequence a shallow-water benthic fauna (calcisponges, bryozoans, echinoderms) and calcareous algae occur, indicating a shallowing-up of the basin and perhaps the development of a carbonate platform.

Fore-reef and slope facies and the initial stage of reef growth: Upwards the overlying sediments represent the initial stage of reef growth. These sediments consist of light grey, brownish-grey, thick-bedded and massive sponge-skeletal limestones with the first frame-building organisms (sphinctozoans (Plate 1/3) and binding organisms (blue-green algae and *Tubiphytes* (Plate 1/4). Other organisms are foraminifers, brachiopods and gastropods. Within the sponge-skeletal limestones some thin-bedded and wedge-shaped fore-reef slump breccias can be seen interfingering with the reef limestone (Plate 1/5).

Reef core facies: The sediments mentioned above are overlain by the reef-core

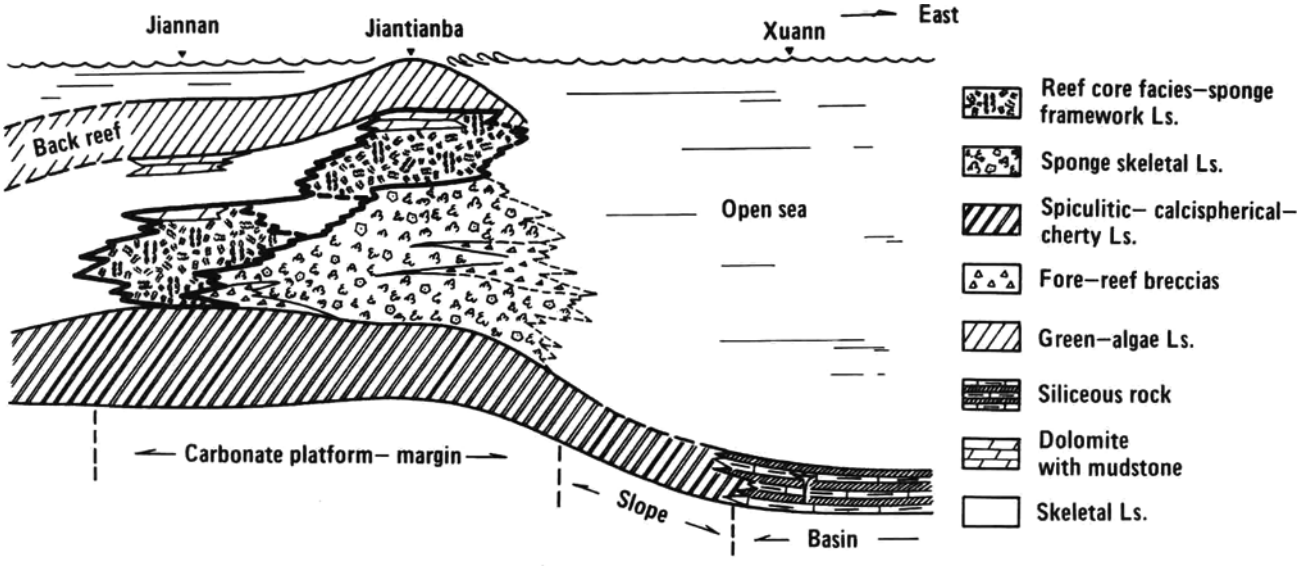

Fig. 3. Model of the reef development in the Upper Permian Changxing Formation, Lichuan District, West Hubei, South China.

Modell der Riff-Entwicklung innerhalb der oberpermischen Changxing Formation, Lichuan-Distrikt, Südchina.

facies, composed of grey to dark grey, non-bedded limestones. The four basic constituents of these limestones are: 1, frame-building organisms; 2, reef debris and lime mud as interstitial filling material; 3, fibrous, early diagenetic carbonate cements; 4, sparry calcites. Organisms of the reef can be classified into three groups: frame-builders (well-preserved sphinctozoans, inozoans, hydrozoans), binders (blue-green algae and *Tubiphytes*), and accessory organisms including echinoderms, brachiopods, gastropods, bryozoans and abundant foraminifers. Frame-building organisms are abundant and well-preserved, often in upright growth position. Binding organisms perform the function of securing individual elements of the reef into one reef mass, and through their encrusting habits provide strength to the frame-building elements. Here *Tubiphytes* plays an important role in encrusting and binding action in addition to laminar, blue-green algae. The prime function of *Tubiphytes* lies in its capacity as a framebuilder in calm-water zones as well as encrusting organism in areas of strongly agitated water.

In the reef core, the frame-building organisms or laminar blue-green algae are often surrounded by fibrous calcites (Plate 1/6), which represent the early cementation during filling of the pore space within the reefs. These cements might have originally been aragonite that was later converted into low-Mg calcite. In a low burial stage, hypersaline water from the lagoonal area could have seeped into the permeable reef to promote dolomitization, thus forming the euhedral dolomite crystals outside the fibrous calcite layers. The remaining reef cavities were later filled by sparry calcite.

A large amount of the interstitial material is composed of micrite, probably formed by the break-down of skeletal elements or by the bioactivity of blue-green algae.

Main framebuilding calcisponges are: *Amblysiphonella, Girtycoelia* (Plate 2/2), *Waagenella, Colospongia, Sollasia, Follicatena, Cystothalamia, Uvanella, Hartmanina, Peronidella*. Four new genera *Lichuanospongia, Polycystocoelia, Sinocoelia, Stromatocoelia*) have been found and will be described elsewhere. Hydrozoans include *Rhabdactinia* (which may be a calci-

sponge), *Palaeoaplysina* and *Spongiomorpha*.

Mixing of saline water with freshwater due to the subaerial exposure of the reef resulted in dolomitization and strong leaching. The medium crystalline, white grey, massive dolomites contain remains of echinoderm fragments and other bioclasts. Intercrystalline porosity combined with solution porosity is well developed (Plate 2/5); the dolomites are effective productive reservoir rocks for oil and gas.

Back-reef facies: The lagoonal deposits consist of an intercalation of dark grey, medium- to thick-bedded micritic and calcisiltitic echinodermal-algal limstones with light grey and grey, medium- to thick-bedded dolomites and calcidolomites. The lagoonal sediments overlie the reef core facies, indicating a progradation of the carbonate platform towards the open sea.

The lowermost part of the lagoonal sediments is represented by strongly dolomitized limstones with abundant echinoderms and some calcisponges and pelecypods. Fine-grained calcidolomites with echinoderms, forominifers and brachiopods are found in the lower part of the section. The middle part is composed of limestones with some cherts; the limestones contain abundant gymnocodiacean algae (Plate 2/6) and rare fusulinid foraminifera (*Colaniella* and *Palaeofusulina*). The upper part of the lagoonal section consists of inequigranular crystalline calcidolomites with rare fossils (some echinoderms and pelecypods). At the top of the section beds with arenitic intraclasts occur, perhaps being Triassic in age.

The reefs exposed in Huangnitang, Lichuan county, are very similar to those of Jiantianba, differing only in the larger quantity of lime mud and in the scarceness of fibrous calcite cements.

4 DIAGENESIS (Fig. 4)

Diagenetic modifications of the reef rocks include cementation, dolomitization and dissolution:

Cementation: Three generations of cements can be distinguished: fibrous calcite, euhedral dolomite rims, and void-filling blocky cement. Fibrous calcite cements exhibit two subtypes. The earliest formed cements on the surface of frame-building organisms and bioclasts are uniform fringes of short fibrous calcite. These cements are subsequently followed by fringes composed of long fibrous calcite. Primary intergranular and inter-framework porosity has been strongly reduced by these submarine fibrous cements. Euhedral dolomite crystals form rimmed bands on the top of the fibrous cement layers, indicating suabaerial exposure. Blocky sparry calcites represent the latest stage of cementation.

Dolomitization: Subaerial exposure is also indicated by the dolomite found at the top of the reef section. The dolomite is characterized by rather large (300-500 um) euhedral crystals. In addition to these dolomites, some very clean euhedral dolomite crystals are scattered at random in the reef rocks. These dolomites reveal undulose extinction and curved crystal faces, indicating formation by replacement.

Dissolution: Irregularly distributed secondary porosity within the reef rocks is due to freshwater dissolution in the vadose zone during subaerial exposure.

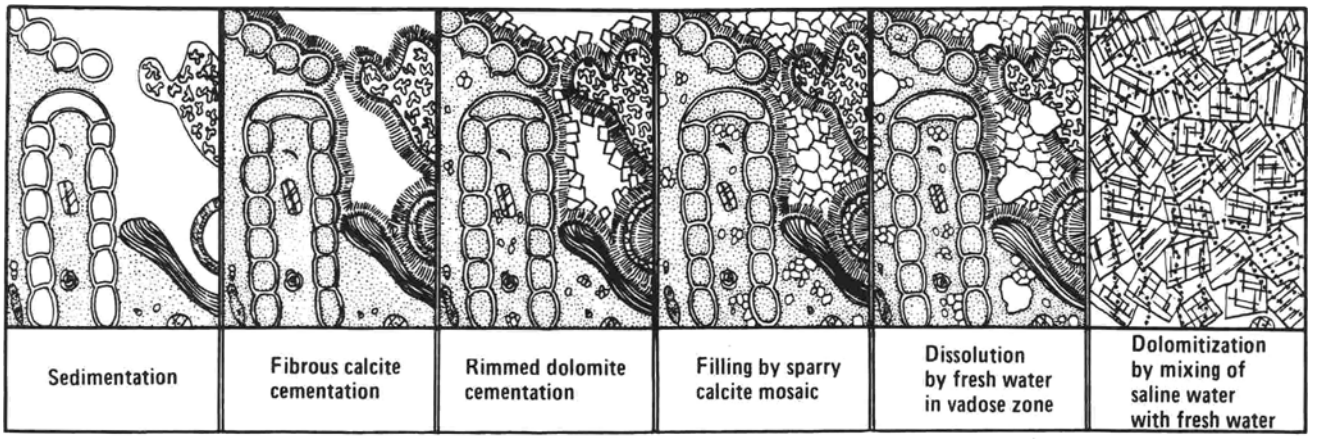

Fig. 4. Diagenetic events within the carbonate sediments of the Upper Permian Changxing Formation, Lichuan district, South China.

Ablauf der diagenetischen Veränderungen in den Riff-Karbonaten der oberpermischen Changxing-Formation, Lichuan-Distrikt, Südchina.

5 Distribution of Upper Permian Reefs in West Hubei

The sedimentation base in the Jiantianba area gradually became shallower during Changxing time following the deep-water basin sedimentation during Wujiaping time, and probably was transformed into shallow-water carbonate platform sedimentation. This sedimentation model can be postulated from the facies patterns developed in the Upper Permian of West Hubei and East Sichuan, and also from the correlation of reef outcrops with subsurface data.

Two major depositional regions, caused by Bamianshan paleofaulting, were formed: Uplift was predominant on the northwestern side, forming a carbonate platform in East Sichuan and West Hubei. A discontinuous barrier reef oriented in a NNE direction developed along the margin of the carbonate platform (Huangnitang and Jiantianbareefs). The horizons with a reef-core facies tend to rise gradually eastwards with the shallowing of the sea, thus indicating a gradual progradation of the carbonate platform basinwards. On the south-eastern side, in Xuann and Nshi, a deep-water basin evolved. Here the sediments are thinner; they are mainly composed of black, thin-bedded siliceous rocks, micrites and shales, containing some ammonites, radiolarias and sponge spicula.

6 Tentative Comparison with Permian Reefs in North America and Triassic Reefs in the Northern Alps

Frame-building and binding organisms as well as the microfacies of Upper Permian reefs in West Hubei are very similar to the Permian Capitan reef in West Texas, North America. The frame-building organisms of these reefs are dominated by sphinctozoan sponges (see NEWELL et al. 1953; RIGBY 1971), which also occur with just a few genera in the Upper Permian reefs of West Hubei. The same holds true for *Tubiphytes* and laminar blue-green algae, which are important binding organisms in North American Permian reefs as well as Chinese reefs. The depositional fabrics in the Permian reef limestones seem to be similar in the Capitan reef-complex

and in the Hubei reefs.

The Upper Permian frame-building organisms in West Hubei can be also compared with the biota of the Ladinian and Cordevolian Wetterstein reefs in the Northern Alps (OTT 1967; BRANDNER & RESCH 1981) and reefs of the same age in the Southern Alps (FOIS & GAETANI 1981). Common features are as follows: Sphinctozoans predominate and some are congeneric; *Tubiphytes* is abundant; the most important encrusting and binding organisms are blue-green algae.

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P l a t e 1 Microfacies of Upper Permian Reefs in West Hubei: Basin, Slope, Fore-reef and Reef

Mikrofazies oberpermischer Riffe in West-Hubei: Becken, Hang, Vorriff und Riff

Fig. 1. Deep-water basin (First Member of the Changxing Formation): Argillaceous radiolarian micrite, rich in organic matter. Compacted, calcitized radiolarians, some with well-preserved microstructures. x 100.

Fig. 2. Deep-water basin (same horizon as Fig. 1): Argillaceous spiculitic micrite with calcispheres. Monoaxial spicula accumulated in a reducing, quiet deep-water environment, rich in organic matter. x 100.

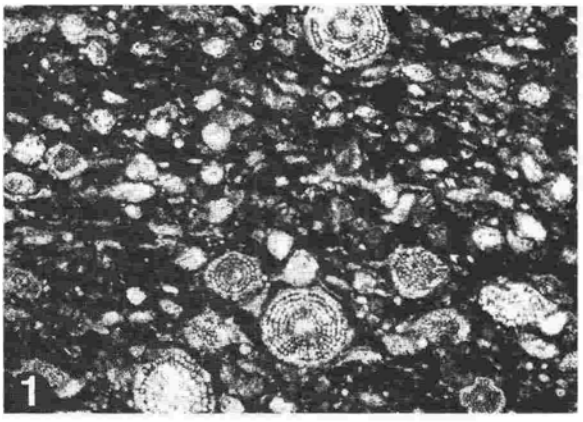
Fig. 3. Slope (same horizon as Fig. 1): Blue-green algal-sponge boundstone. Transverse section of *Amblysiphonella* sp., showing vesiculae. The calcisponge is overgrown by blue-green algae and by *Tubiphytes* (at the top of the Figure). x 4.

Fig. 4. Slope (same horizon as Fig. 1): Blue-green algal boundstone, consisting of black algal crusts and recrystallized bioclasts. x 25.

Fig. 5. Fore-reef (Second Member of the Changxing Formation): Sparry limestone breccia, composed of angular limestone clasts and of bioclasts (sponge, left side). Different types of sparry calcite cements. x 4.

Fig. 6. Reef core (same horizon as Fig. 5): Calcisponge framestone. Sponges are overgrown by fibrous cement crusts. Inter-framework voids have been filled with large white calcite crystals, which partly destroy the fibrous fabric. x 4.

All samples are from Jiantianba, Lichuan district, West Hubei, China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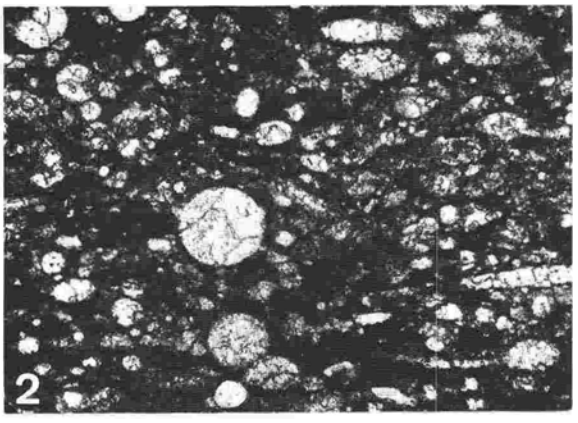
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P l a t e 2 Microfacies of Upper Permian Reefs in West Hubei: Reef and Back-reef

Mikrofazies oberpermischer Riffe in West-Hubei: Riff und Lagune

Fig. 1. Reef core (Second Member of the Changxing Formation): Calcisponge framestone. The sponge (right) is encrusted by blue-green algae which were subsequently filled with coarse-grained calcite. x 20.

Fig. 2. Reef core (same horizon as Fig. 1): Calcisponge framestone. The interstitial material between the calcisponges consists of micrite and various small bioclasts (algae, ostracods, etc.). At the lower right: *Girtycoelia* sp. x 4.

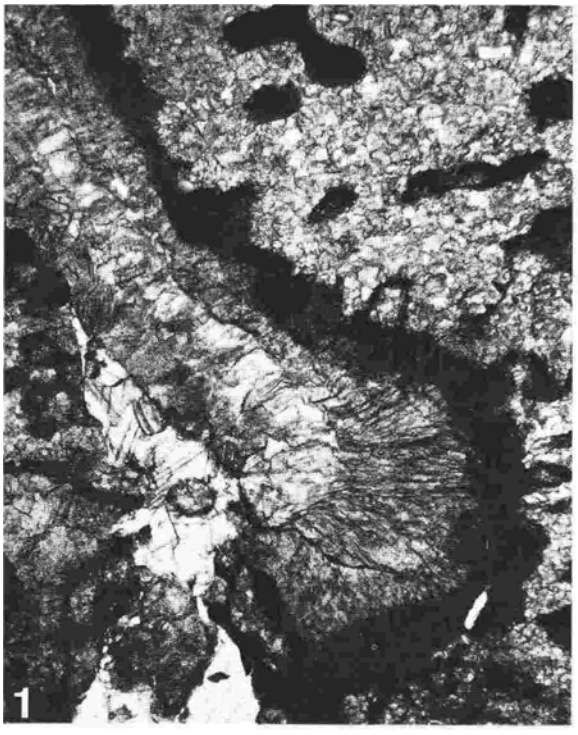
Fig. 3. Reef core (same horizon as Fig. 1): Calcisponge framestone. Distinct secondary porosity (white voids) caused by late dissolution. x 25.

Fig. 4. Reef core (same horizon as Fig.1): *Tubiphytes*-Calcisponge boundstone. *Tubiphytes*, encrusting shells and other bioclasts. The fibrous structure at the top is similar to *Radiomura*, a microproblematicum from the Upper Triassic of the Alps. x 25.

Fig. 5. Reef core: Medium-grained crystalline dolomite with well-developed intercrystalline porosity and large dolomite crystals (size 300-500 µm). x 40.

Fig. 6. Back-reef (Third Member of the Changxing Formation): Micritic gymnocodiacean packstone with abundant fragments of *Gymnocodium* sp. x 25.

All samples are from Jiantianba,Lichuan district, West Hubei, China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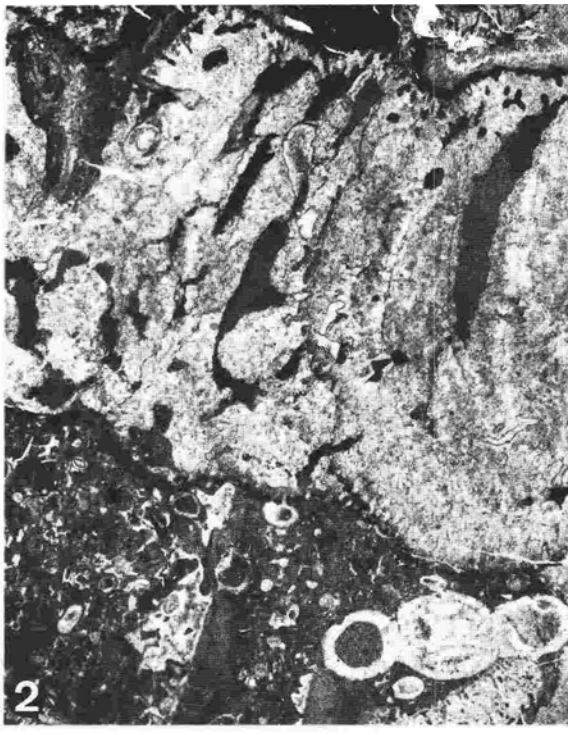
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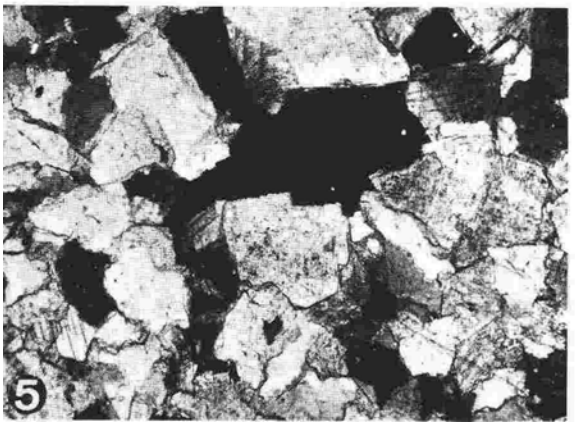
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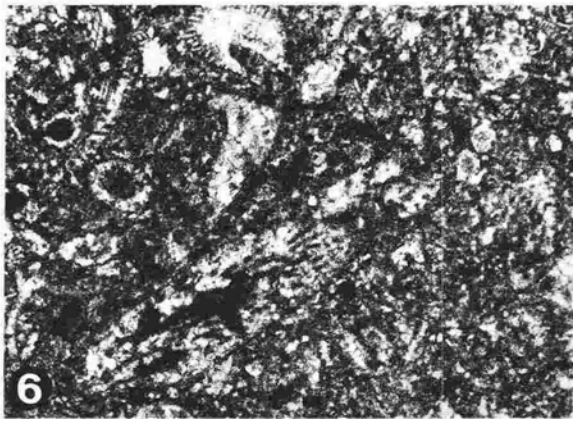
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