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桂林北郊岩山中泥盆世吉维期珊瑚-层孔虫礁*

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内 容 提 要

桂林北郊灵川县岩山大村剖面和乌龟山剖面为中泥盆世吉维期沉积，其沉积构造、生物组成、微相序列反映出生物礁的特点，大量层孔虫为造礁的主要生物，其生长形式为：(1)厚板状；(2)半球状和穹窿状；(3)大型柱状和不规则状；(4)披覆状或薄板状。珊瑚有3层，或作为礁基，或参加造礁，前者为单体珊瑚，后者为复体珊瑚。刺毛虫主要为根茎状，常被层孔虫包绕，也是造礁的主要生物。藻类生物很少。横向上可以分出礁核相，礁后相和礁前斜坡相。主要的微相类型有13种，纵向上可以识别出两个造礁旋回，从礁基—珊瑚、层孔虫礁—礁后外带—礁后内带，两个造礁旋回之上为礁坪所覆。根据礁的规模、礁体与上下沉积物的关系、礁生物组成的变化和古地理位置的讨论推测为一岸礁体系。

关键词　珊瑚-层孔虫礁　吉维期　岩山　桂林

MIDDLE DEVONIAN (GIVETIAN) CORAL-STROMATOPOROID REEF AT YANSHAN, NORTH OF GUILIN, GUANGXI, SOUTH CHINA**

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1 INTRODUCTION

Reefs are well developed in the upper Middle and lower Upper Devonian of Guilin; with stromatoporoids, tabular, rugose corals and *Chaetetes* as the most important reef builders, and often highly diverse, which is in sharp contrast to the algal mounds of the Famennian age. In some cases, algae and receptaculites constitute the Frasnian reefs.

Accurate interpretations and studies on the reefs and mounds in Guilin require both proper "classification" of the reef and understanding of the active sedimentologic and bio-

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logic processes during the forming of the reefs. Classifications of reefs based on organisms (coral reef, stromatoporoid reef, etc.), or shape of the reef in map view (barrier reef, fringing reef, atoll, etc.) is used here as a basis for the topic being discussed. The characteristics and distribution of lithofacies also should be studied and discussed. The term of reef complex is used for the specific type of reef having a significant rigid organic framework which generally forms in moderate to high wave energy, shallow-water environments, as well as the genetically related facies associated with the framework (Longman, 1981). Two terms, bioherm and biostrome, are commonly used to designate biogenically constructed geological structure. Here bioherm is used for a lens-shaped reef or mound, while biostrome describes a tabular rock body, usually a single bed of similar composition. Fringing reefs are those growing on board; patch reefs are usually growing across the platform, while barrier reefs include those growing and distributed intermittently to continuously along platform margins.

2 REEF SECTION

The reef is located at Yanshan of Lingchuan county, north of Guilin city, sitting on the axis of the Yanshan anticline. The reef-bearing strata are considered as Givetian deposits based on the brachiopod *Stringocephalus* in abundance. The basement of the Yanshan reef is composed of mudstone, shale and sandstone of the Xindu Formation. The reef carbonates are surrounded by clastic neritic facies. The reef outcrop extends for 2km in length from south to north and 1.6km in width from east to west (pl. I, fig. 1). It can be recognized as fore-reef facies with reefal breccia deposits in the west and reef core facies in the east (pl. I, fig. 1). The Yanshan reef should be referred to fringing reef because of its palaeogeographical situation in the near-shore setting.

Tangjiawan Formation

Bed 23　Dark grey, thin to medium bedded blue algae-bearing wackestone and stromatoporoid limestone with chert, yielding *Stachyodes*, *Chaetetes*, solitary corals, brachiopods and crinoid stem. 5.1m

Bed 22　Dark grey to black medium-bedded wackestone, with bioclasts including brachiopods and crinoid stem. 8.0m

Bed 21　Light grey to grey thick-bedded packstone, yielding stromatoporoids, *Chaetetes* and solitary rugose corals. 8.8m

Bed 20　Grey to dark grey medium to thick-bedded wackestone and packstone, yielding fewer brachiopods. 11.8m

Bed 19　Grey, medium to thick-bedded packstone, with bioclasts mostly of brachiopod shells and crinoid fragments, yielding fewer solitary corals, gastropods and ostracods. 11m

Bed 18　Dark grey, medium-bedded to massive wackestone, yielding *Amphipora*, *Stachyodes*, *Stringocephalus* and solitary corals. 9.5m

Bed 17　Dark grey, medium-bedded wackestone, yielding brachiopods, gastropods, *Thamno-*

pora, crinoids, ostracods, tentaculites and siliceous sponge spinule. 8.6m

Bed 16 Grey to dark grey, medium-bedded *Amphipora* floatstone, yielding *Amphipora*, *Thamnopora*, *Trupeostrome*, *Desquamatia magnu* and *Gypidula*. 2.5m

Bed 15 Dark grey, medium-bedded wackestone, dominated by *Stachyodes* and *Thamnopora*; together with *Amphipora* and ostracods. 4.5m

Bed 14 Grey to dark grey massive intercalated with thin-bedded wackestone, containing calcisphere and algae. Bioturbations are common. 7.0m

Bed 13 Grey to dark grey *Thamnopora* floatstone, with bioclasts including those of *Stachyodes*, *Amphipora*, brachiopods and calcareous sponge spinule, yielding *Hermatostroma*, *Stringocephalus* and *Thamnopora*. 4.0m

Bed 12 Grey, massive stromatoporoid framestone intercalated with *Chaetetes* limestone and wackestone. Bioclasts include brachiopod, *Thamnopora* and *Stachyodes* fragments. Stromatoporoids are mostly *Stromatopora* and *Gerronostroma*. *Stringocephalus* shows geopetal fabric. 2.1m

Bed 11 Grey to dark grey, medium-bedded coral-stromatoporoid framestone, containing phacelloid corals including *Disphyllum goldfuss* and *D. camaxalyx*, bound by the stromatoporoid *Parallelopora*, together with brachiopods mainly of *Stringocephalus*. 1.2m

Bed 10 Grey to dark grey medium to thick bedded bioclastic packstone intercalated with stromatoporoid rudstone, containing bioclasts such as brachiopod and crinoid fragments, with brachiopods showing geoptal fabric. 10m

Bed 9 Grey to dark grey massive stromatoporoid framestone intercalated with coral and *Chaetetes* limestone, yielding *Stringocephalus*, containing bioclasts such as crinoid and brachiopod fragments packed in the space of famework. Corals are *Lythophyllum*, *Thamnopora*, and stromatoporoids are *Hermatostroma*, *Trupetostroma*. 10.2m

Bed 8 Light grey to grey massive argillaceous limestone, yielding the corals *Sinospongophyllum planotabulatum*, *Sinospongophyllum* sp., *Argutastrea yanshanense*, *Argutastrea dushanensis*, *Hexagonaria pladfordi*, *Cyathophllum* (*Peripaedium*) *dushanense*, *Lythophyllum forgi*, *Lythophllum secudum*, *Lythophyllum lomense*, *Lythophyllum pseudoseptatum*, *Lythophyllum kwangisense*, stromatoporoids and *Chaetetes*. 1.5m

Bed 7 Grey to dark grey, thin bedded to thick-bedded *Amphipora* floatstone and brachiopod limestone, yielding *Stringocephalus*, ostracods, crinoids, gastropods, algae, *Thamnopora* and calcispheres. 6.0m

Bed 6 Dark grey, medium-bedded intercalated with thin-bedded bioclastic packstone bearing *Stachyodes radiata*. 5.0m

Bed 5 Grey to dark grey massive *Chaetetes*-stromatoporoid framestone, yielding *Gerronostroma*, *Chaetetes*, *Cyclochaetetes cylindricus*, *Stachyodes radiatu*, *Stachyodes crassum*, *Thamnopora* and *Hexagonaria*, *Stringocephalus*. 8.0m

Bed 4 Grey, medium-bedded argillaceous coral-stromatoporoid limestone, yielding *Disphyllum*, *aequiseptatum*, *Argutastrea brevisepta*, *Cyathophyllum* (*Peripaedium*) *dushanense*, *Sinospongophyllum pseudocarinatum*, *Sinospongophyllum annulatum*, *Sinospongophyllum planotabulatum*, *Endophyllum* sp., *Glossophyllum dohmi*, *Temnophyllum* sp., *Lythophyl-*

lum conistruction, *Calceola* sp., *Stromatopora* sp., *Emanuella* sp. and *Thamnopora* sp. 1.8m

Bed 3　Dark grey massive stromatoporoid framestone, yielding *Gerronostroma*, *Stromatopora*, *Thamnopora*, and overlain by bioclastic limestone bearing *Sphaerocodium* and *Girvanella*. 8.4m

Bed 2　Medium-bedded mudstone, yielding *Desquamatia desquamatia*, *Emamella* sp., *Atrypa* sp. and *Chonetes* sp.

Xindu Formation

Bed 1　Grey to dark grey medium-bedded mudstone intercalated with shale, siltstone and sandstone.

3 LITHOFACIES

Reef unit is about 135m in thickness, prograding conformably over the basal clastic rocks——Xindu Formation, with reefs in three horizons. Reef cyclicity is distinct and composed of various lithofacies.

3.1 Stromatoporoid framestone

Lithofacies is composed of massive and unbedded stromatoporoid limestone. Massive, dome and tabular stromatoporoids, usually in compact and encrusting forms (pl. I, fig. 5), constituting 75—90% of the rocks and preserved in growth position. Reef framework formed by stromatoporoids possibly up to about 8m in height. Interskeletal cavities are usually filled with coarse, poorly sorted bioclasts of crinoids, bryozoans, ostracods, brachiopods (pl. III, fig. 6), *Thamnopora*, and lime mud.

3.2 *Alveolitella* floatstone

Lithofacies consisting of dark grey *Alveolitella* floatstone, commonly occurring above stromatoporoid framestone, with *Alveolitella* well preserved in the rocks, and ranging from 0.8 to 2.4cm in diameter, larger ones up to 3.6cm. Wall of corallite is unbraded and bound by stromatoporoids. *Alveolitella* corallites constitute about 40% of rocks, and is usually scattered in the rocks. Bioclasts include very few brachiopod and crinoid fragments. Fine peloids are very abundant in the rocks, and constituting matrix together with lime mud.

3.3 *Chaetetes*-stromatoporoid framestone

Massive and unbedded framestone consisting of *Chaetetes* and stromatoporoids. *Chaetetes* with spherical, hemispherical and massive growth forms are bound by stromatoporoids (pl. I, fig. 6; pl. IV, fig. 10), constituting 70—80% of the limestone. Blue algae *Sphaeracodium* and *Girvanella* grew alternately with stromatoporoids. *Chaetetes* bound by stromatoporoids and blue algae form a true framework to resist wave. Interskeletal cavities are filled with bioclastic crinoids, bryozoans, ostracods, brachiopods, algal fragments and lime mud.

3.4 Coral-stromatoporoid rudstone and framestone

Coral, stromatoporoids and brachiopods are dominant fossils in this lithofacies (pl. Ⅳ, figs. 4, 5, 6). Corals occupying more than 50% of limestone, mostly bound by stromatoporoids, which are mainly in irregular and bulbous forms. Corallites of phacelloid *Disphyllum* and large-sized massive *Argutastrea* are entangled by stromatoporoids to form a massive framework. Small-sized massive *Argutastrea*, solitary *Sinospongophyllum* and *Lythophyllum* packed by stromatoporoids usually constituting a bank deposits. Sediments in cavities are composed of mudstone with lighter clay mineral and terrigenous siltstone in content.

3.5 *Stachyodes* floatstone

This lithofacies is composed of *Stachyodes* and lime mud. *Stachyodes* are more than 50% of limestone (pl. Ⅰ, fig. 3). Most of them are identified as *Stachyodes radiata*, with wall either unbraded or destroyed; ostracods also common, ranging from 0.12mm to 0.48mm in size. Black lime mud contains cryptalgal peloids with less common bioclasts such as those of *Thamnopora*, crinoids and thin-shell brachiopods except *Stachyodes*.

3.6 *Thamnopora* floatstone

Lithofacies with *Thamnopora* as dominant fossils, which occupy more than 30—50% of the limestone, ranging from 4mm to 5mm in diameter and from 15mm to 30mm in length. Other fossils including *Stachyodes* (2.5mm in diameter) and thin tabular *Chaetetes* (pl. Ⅲ, fig. 1). *Thamnopora* sticks usually graded into *Stachyodes* fragments (pl. Ⅲ, fig. 2). Bioclasts including those of brachiopod shell and crinoid stems. Matrix containing *Thamnopora* consists of cryptalgal lime mud and cryptalgal peloids in which ostracods are common.

3.7 *Amphipora* floatstone

Dark grey, medium-bedded limestone occurring at the top of reef cycle, with *Amphipora* sticks occupying more than 20—40% of the limestone (pl. Ⅲ, fig. 4). *Stachyodes* are less common and often bored by algae and in turn infilled with cryptalgal peloids. *Amphipora* sticks are preserved separately in the black lime mud in which ostracods and calcisphere are abundant. Rareness of bioclasts is proved by less common brachiopod, crinoid and *Thamnopora* fragments. Lime mud shows recrytallization locally. Nonbranching stromatoporoids also rare. Open-space structures developed in the rocks and infilled with granular calcite.

3.8 Bioclastic packstone

Lithofacies consisting of bioclasts and lime mud. Bioclasts coated by algal filament, and sometimes bored by blue algae which occupy more than 60% of the rocks. Well-sorted bioclasts derived from corals, stromatoporoids, crinoids, brachiopods, gastropods, ostracods, *Girvanella* and *Sphaerocodium* (pl. Ⅲ, fig. 5; pl. Ⅳ, fig. 9). In some horizons, bioclasts poorly sorted and dominated by debris. Interbioclastic cavities filled with lime mud matrix.

3.9 Brachiopod wackestone

Lithofacies composed of dark grey medium to thick-bedded limestone, with fossils mostly of small brachiopods 6—9mm in length and 4—7mm in width, occupying more than 20% of the limestone. Cavities in the brachiopods showing geopetal fabric (pl. Ⅱ, fig. 5; pl. Ⅲ, fig. 3), with lime mud occupying 3—10% of cavity, sometimes up to 30% of the space. Poorly sorted bioclasts including brachiopod shells, crinoid and coral fragments and calcareous sponge spinule, which occupy more than 30—40% of the limestone. Matrix composed of black lime mud containing some fine bioclasts and ostracods.

3.10 Bioclastic wackestone

Sporadic bioclasts concentrated locally in the lime mud (pl. Ⅲ, fig. 7), occupying 10% to 30% of the rocks in content. Poorly sorted bioclasts of two sizes, 1—2mm and less than 0.02mm. The larger ones mostly being brachiopod fragments, with some crinoid stems, *Stachyodes* and *Amphipora* sticks, tentaculitids occasionally present. Rocks with dark grey to black lime mud as dominant component.

3.11 Brachiopod-crinoid packstone

Lithofacies characterized by abundant crinoid and brachiopod fragments (pl. Ⅳ, fig. 8), while other bioclasts derived from coral, stromatoporoids and gastropods, which occupy more than 60—70% of the rocks, all showing micrite envelope and serrate brim due to algal boring. Poorly sorted brachiopod and crinoid fragments various in size. Matrix composed of dark colour lime mud with characteristics of recrystallization.

3.12 Sparry bioclastic packstone

Packstone composed of bioclasts such as those of horizontal stromatoporoids bound by algae, brachiopods, crinoids, gastropods and *Thamnopora*. Bioclasts cemented by sparry calcite graded into two sizes, with one ranging from 0.8 to 1.1cm, characterized by those of brachiopod shell and rounded *Thamnopora* sticks; and the other varying from 0.6 to 2.2mm, well-sorted, including those of brachiopods, crinoids and gastropods. Small-sized bioclasts are coated by dark-colour brim due to micritization. Interskeletonal cavities of *Thamnopora* infilled with peloids; some lumps also visible.

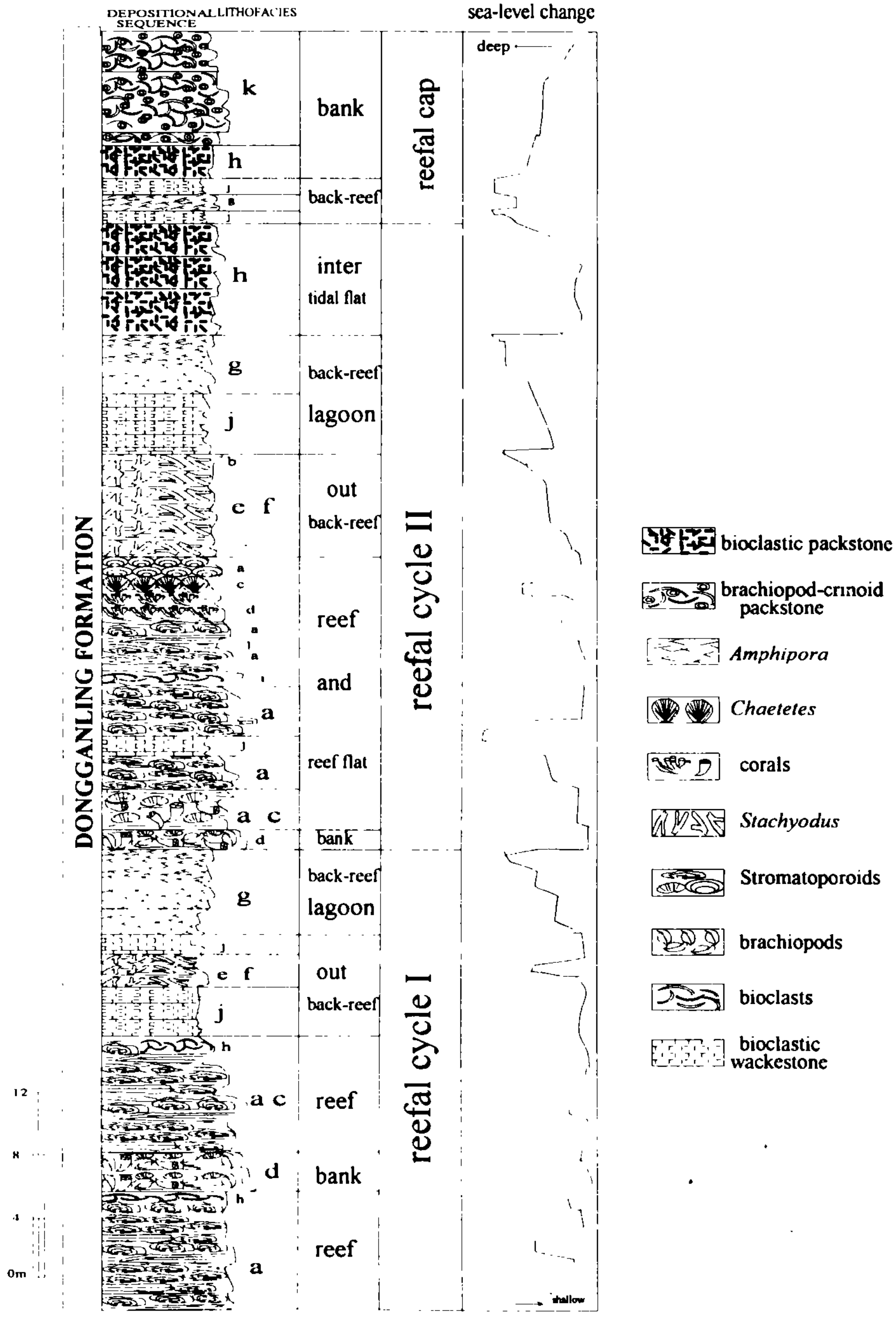
Depositional sequence of Givetian stromatoporoid reef at Yanshan as shown in Text-fig. 1.

4 FACIES

Facies of reef complexes at Yanshan as shown in Text-fig. 2.

4.1 Neritic shelf

Neritic shelf facies crops out under the Yanshan fringing reef and consists of mudstone, sandstone and shale with benthic brachiopods and bivalves. The facies can be traceable in Guilin. The relation between it and overlying carbonate rocks shows a distinct boundary which can be correlated with the Shahe section yielding conodonts. Vertically,

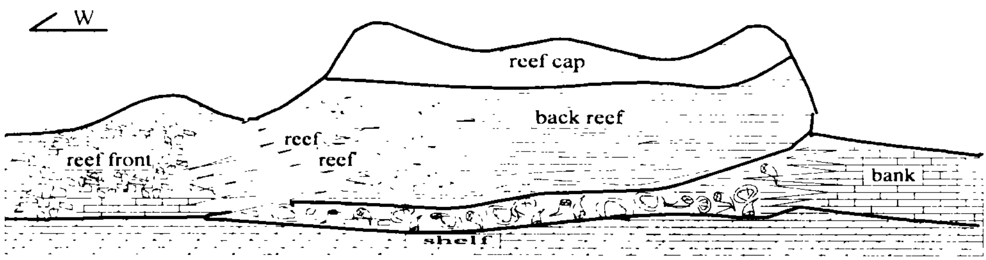


Text-fig. 1 Depositional sequence of Givetian stromatoporoid reef at Yanshan Dacun, Guilin

this facies is graded into nearshore reef facies and offshore open platform facies.

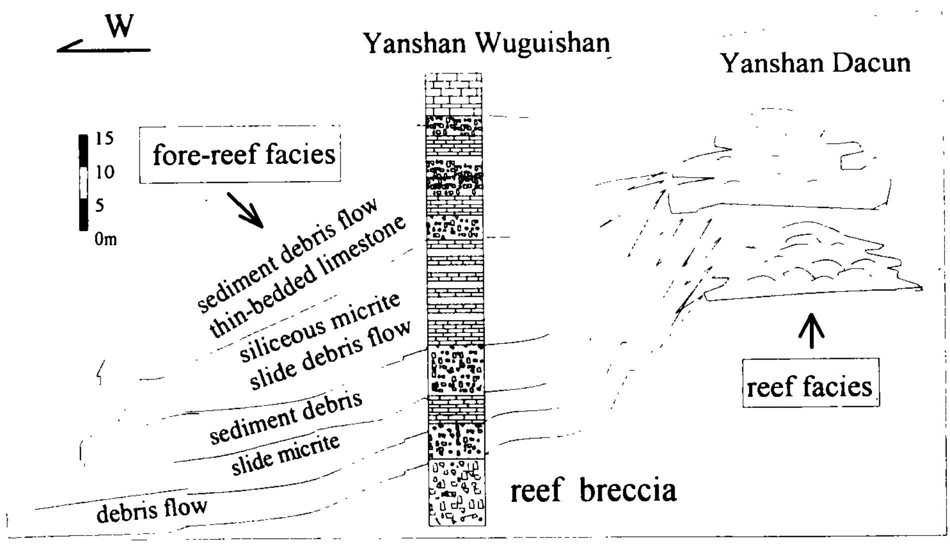
4.2 Fore-reef slope facies

Fore-reef slope facies is exposed in the west of the Yanshan reef, and at Wuguishan



Text-fig. 2　Stratigraphic cross-section of Givetian reefal depositional units at Yanshan near Guilin

as well which is located about 150m south of the Yanshan reef (pl. Ⅰ, fig. 1); both localities showing characteristics of fore-reef slope, on which the adjoining reefs (pl. Ⅰ, fig. 1a) are characterized by medium to thick-bedded calcarenite with fragments of stromatoporoids, crinoids, corals, bryozoans and *Alveolites* (pl. Ⅳ, fig. 3), and the stromatoporoid debris are unrounded (Text-fig. 3).



Text-fig. 3　Depositional sequence and vertical microfacies shifting at Wuguishan near Guilin

Fore-reef slope facies at Wuguishan composed of thin-bedded siliceous micrite intercalcated with slide breccia and sediment debris (pl. Ⅳ, fig. 2), including peloidal wackestone, reef breccia (pl. Ⅳ, fig. 1), thin-bedded siliceous micrite, calcarenites and micrites. Peloidal wackestone containing fragments of stromatoporoids, brachiopods and massive corals, while reef breccia containing broken stromatoporoid, *Chaetetes* and coral colony segments. Bioclasts occupy more than 50%—60% of the rocks. Bioclasts compacted by lime mud and fine cryptalgal peloids. Skeletons of solitary rugose corals, brachiopods, *Thamnopora*, crinoids contributed to the bioclasts. Some intercalations of megabreccia consisting of large blocks and/or parabreccias occur. Bed of debris flow beds are composed of medium to thick calcarenite containing bioclasts of rugose corals, bryozoans, *Thamnopora*, crinoids, stromatoporoids, *Chaetetes*, *Stachyodes* and *Alveolites* and lime mud. Bioclasts in the bed of debris flow are poorly sorted and edged, and primary interbioclast cavities are well-developed and preserved due to more rapid sedimentation. Most of the cavities infilled with well-crystallized calcite during diagenetic stage.

Both underlying and overlying rocks of debris flow beds are thin-bedded siliceous micrite with plastic deformation and graded limestone turbidites, yielding conodonts and tentaculites. Debris flow beds are slightly wedge-shaped, and thin-bedded siliceous micrite is commonly folded.

Fore-reef slope at Wuguishan contains corals *Kwangxiastrea liugingesis*, *Parasociophyllum*, *Spinophyllum*, *Pseudozaphrentis*, *Temnophyllum*, *Disphyllum*, *Themnopora*, *Alveolites*, conodont *Klappèrina disparilis*, *Polygnathus cristatus*, *Schmidtoggnathus hermanni* and *Schmidtodgnathus witlekindt*, indicating deposits of *hermanni-cristatus* to *disparilis* Zone.

Sedimets of the overlying lower *assymitricum* Zone graded into open platform facies still showing fore-reef slope characters.

4.3 Reef core facies

Reef core facies is 18—20m in thickness with a well-exposed complete section observeable on both eastern and western sides of the Yanshan reef exposure (pl. Ⅰ, fig. 1b), where all the reef subfacies, ranging from back-reef lagoon to open platform bank can be clearly identified. Stromatoporoids framestone of the reef core exhibiting different morphologies: tabular or encrusting, domal or hemispherical, bulbous, dendroid robust branching and delicate branching, which are similar to those described in Canada, Germany and the Canning basin in Australia. Approximately horizontal reef beds and a cliff exposure on southern side of the reef allowing direct measurement of the vertical distance from each subfacies to reef core, and hence giving the palaeowater depth by inference. The tabular and encrusting stromatoporoids formed in less than 10m of water, domal and hemispherical colonies developed in deeper water than that of tabular and encrusting forms, may be 10—15m deep, bulbous branching formed at an inferred depth of 10—20m, while dendroid and delicate branching forms flourishing in back-reef at a depth of more than 20m.

a. Tabular and encrusting stromatoporoid zone

Tabular and encrusting stromatoporoids constitute the majority of reefs and often extend laterally for more than 2m in distance (pl. Ⅰ, fig. 2). All in gorwth position parallel to the bedding and locally encrusting underlying skeletal frames, showing enveloping forms with a smooth margin. Relationship between organisms and surrounding sediments in the rock record allow to make some useful generalization (James and Pierre-Andre, 1992). Enveloping forms indicate a low rate of sedimentation and a higher growth rate. Horizontally extended tabular and encrusting forms with smooth margin imply a rough water condition, although organic skeletons with smooth margins are confined to low-energy environments. Bioclastic packstone with abundant brachiopod shells occur usually at the top of this zone, indicating an increase of water roughness.

b. Domal and hemispherical stromatoporoid Zone

Domal and hemispherical stromatoporoids occur mainly in the reef framestone, but not so common as the tabular and encrusting forms. They form massive limestone generally less than 2m in thickness, composed of stromatoporoid colonies in original growth position, and mostly with a smooth margin. Intercolony cavities infilled with bioclastic packstone with abundant *Thamnopora* and brachiopods. The largest domal stromatoporoid colony can be up to 60cm in diameter and more than 40cm in height. *Stachyodes* and *Amphipora* are very few or rare. *Disphyllum* and *Argutastrea* bound by stromatoporoids show a domal or hemispherical outline in many cases.

c. Bulbous stromatoporoid Zone

Bulbous types of massive stromatoporoids are abundant and common in most of the biostrome. Many of them are derived from that overgrown stromatoporoids around solitary corals (pl. Ⅳ, fig. 5). They are often associated with *Lythophyllum* and *Sinospongophyllum* occurring in the reef basement. Brachiopod fragments are common in packstone which filled in intercolony cavities. *Thamnopora* sticks being rare to common, other fragments, including those of bryozoan, *Stachyodes* and *Amphipora* are very few to rare. Bulbous stromatoporoids range from 4cm to 6cm in diameter, the smallest one is only 1cm in diameter. Most bulbous stromatoporoids in the bank facies are in place but some have been moved from original growth position, and many of them are usually overturned.

d. *Chaetetes* Zone

Three basic forms recognizable including hemispherical, digitate, and tabular forms, can be recognized. An environmental interpretation on morphology of *Chaetetes* based on similar fossil organisms indicating tabular *Chaetetes* formed in a setting with shallow, slightly agitated water and hard substrate. *Chaetetes* overgrown extensively on the skeletons and lime mud making tabular *Chaetetes* intercalated with bioclastic packstones. Digitate *Chaetetes* (pl. Ⅰ, fig. 3) are interpreted as indicative of low-energy stable substrate, and quiet, deeper water settings, whereas hemispherical *Chaetetes* indicate moderate-energy stable substrates. Tabular and hemispherical *Chaetetes* are more common than digitate forms in Yanshan reef, constituting reef framework coexisting with stromatoporoids and corals. Digitate forms are usually in a reef flat or basement.

e. Coral Zone

Corals in Yanshan reef include three types in morphology: larger phaceloid and massive corals, such as *Disphyllum* (pl. Ⅰ, figs. 1, 2) and *Argutastrea* (pl. Ⅱ, fig. 4; pl. Ⅳ, fig. 7) forming the reef framework; solitary and small corals such as *Lythophyllum* and *Sinospongophyllum*, occurring in rudstone and considered as formed in the colonization and stabilization stage; and remose corals such as *Thamnopora*, which were densely accumulated, with mud compaction, to form flat mudmounds. Corals of reef framework being preserved in living position, whereas those in the bank deposits showing reworking characteristics.

4.4 Back-reef facies

Back-reef facies of Yanshan reef is characterized by *Amphipora* floatstone, *Thamnopora* floststone, *Stachyodes* floatstone, and bioclastic wackestone containing massive cherts. This facies is distributed behind the reef core facies, occasionally overaggraded on the reef. Overall zonations of massive skeletal morphologies established on Devonian reefs indicate the more massive and encrusting forms living at or close to the reef; while branching forms living away from the reef or in areas sheltered from the direct impact of the extrareef environments. *Stachyodes* concentrated in bioclasts becoming very few and rare toward the inner back-reef and fore-reef slope. Floating *Stachyodes* sticks in the black lime mud containing ostracods and peloids. Calcispheres and *Amphipora* fragments are also common. Acting as a sediment baffler, *Stachyodes* entrapped in micritic material which is believed to have lived in slightly to moderately turbulent waters, in association with *Thamnopora* and *Amphipora*; very few *Stachyodes* were observed in the outcropping reef. Floating *Stachyodes* sticks in the lime mud and peloidal packstone indicate a low-energy and shallow setting——out back-reef.

Thamnopora debris occurs throughout the reef facies but reaches its greatest abundance in the brachiopod and *Thamnopora* bank facies. They display a preference for muddy and argillaceous substrate. In the back reef facies, *Thamnopora* are also present within the dark-coloured micrite. *Thamnopora* fragments appear short and discrete in lime mud. Bioclasts are fine-grained and include those of brachiopods and crinoids, ostracods are also abundant. From here upwards *Thamnopora* debris graded into *Stachyodes* fragments, indicating an out back-reef under slightly agitated water condition.

Delicate branching *Amphipora* is usually considered as a typical back-reef fauna with a lower diversity and monotonous assemblage, which is dominant in presumably deeper-water areas on the outer fore-reef and in the protected areas behind the reef, especially abundant in the inner back-reef. *Amphipora* sticks are not so densely accumulated in Yanshan reef as in Kueilin Formation, preserved in floating manner. Dolomization is indistinct. Gastropods and ostracods are also common. Densely packed amphiporoids pointing to dry tidal pools, whereas sporadic *Amphipora* sticks with reworking features possibly indicate a deeper and lower energy setting. *Amphipora* floatstone is totally 8—10m in thickness, and more common than *Stachyodes* floatstone and *Thamnopora* floatstone.

5 REEF CYCLE

Sediments of Yanshan reef show distinct reef cyclicity, including rhythms and cycles. Reef rhythms are reflected by the size change of bioclasts. In the *Stachyodes* limestone, *Stachyodes* fragments show upward-coarsening rhythms, whereas in the reef framestone, overlying bioclastic packstone contains upward-fining brachiopod shell fragments. Shifting in morphology also forms a rhythm from tabular and encrusting forms to domal and hemispherical and then to dendroid and delicate branching forms. Variation in reef builders from stromatoporoids to phaceloid corals and to *Chaetetes* actually indicate another kind of rhythm.

Reef cycles in Yanshan reef are composed of associations of different lithofacies, with megacycle consisting of lower shelf clastic deposits and upper shallow-water carbonate rocks, while carbonate cycle including lower reef and associated deposits and upper bank deposits referred to reef cap. Two reef cycles being recognized as: first cycle, beginning with mudstones containing abundant brachiopods and *Thamnopora* which constitute the reef basement; above the basement, reef framework well developed, forming an 8m high stromatoporoid reef, with a layer of bioclastic packstone marking the end of the cycle. Second cycle, beginning with the characteristic stromatoporoid-coral rudstone, composed of *Chaetetes*-stromatoporoid reef and back reef deposits. Lithologically the first type of cycle includes: 1)coral and stromatoporoid rudstone; 2)coral and stromatoporoid framestone; 3)bioclastic packstone; 4)bioclastic wackestone and *Thamnopora* floatstone; 5)*Stachyodes* floatstone; 6)peloidal wackestone; and 7)*Amphipora* floatstone. The second type of cycle contains the following lithofacies (in descending order): 1)coral and stromatoporoid rudstone; 2) stromatoporoid framestone; 3) bioclastic wackestone; 4) stromatoporoid framestone; 5)bioclastic packstone; 6)stromatoporoid framestone; 7)stromatoporoid-coral framestone; 8) stromatoporoid-*Chaetetes* framestone; 9) *Stachyodes* floatstone; 10) bioclastic wackestone and *Thamnopora* floatstone, and 11)*Amphipora* floatstone.

Each cycle seems to be ended in an *Amphipora* floatstone of back-reef facies. The second displays a sea-level rise, but the sedimentation rate could keep up with it. In each cycle, the lower part characterized by rudstone indicates an initial flooding; the middle part consisting of reef core and associated deposits reflects a subsidence of platform and consistent sea-level rise, whereas the upper part composed of back-reef deposits denotes a sea-level fall. Following sea-level rising and falling the platform indicates the beginning of another reef cycle. The lithofacies sequences consisting of a cycle show a shifting in microfacies toward the sea, matrix in rudstone of reef basement is argillaceous (pl. Ⅰ, fig. 1; pl. Ⅰ, fig. 6), relating to transgressive and sea-level rise. Dolomites with dark cloudy ferroan cores and limpid rims occur at the top of the stromatoporoid framestone, which can be interpreted as the result of sea-level fall, because the stromatoporoid reefs grew close to sea-level, especially in the reef crest, and even a slightly falling sea-level produces subaerial exposure. The dominant floatstone containing *Amphipora*, *Stachyodes* and *Thamnopora* in the Yanshan reef can be interpreted as the existence of a well-developed central lagoonal facies coexisting with circum reef-core and fore-reef deposits.

6 SEA-LEVEL CHANGE AND REEF DEVELOPMENT

Pomar(1991) proposed four orders of accretional units in terms of four (1-M to 4-M) hierarchies of sea-level cycles while studying the upper Miocene Reef Complex of Mallorca, Spain. These orders show similar patterns to those in Yanshan reef: open paltform facies with subhorizontal bedding in the lower part; reef and slope facies with sigmoidal bedding in the central part; and horizontal beds of lagoonal facies in the upper part. Such patterns are also distinct in the Yanshan reef. The vertical microfacies shifting indicates that the depositional sequence of the Yanshan reef consists of two reef cycles, each proving the sediment aggradation keeping up with the sea-level rise. The lower unit with open-platform sediments, composed of corals, brachiopods, bulbous stromatoporoids and lime mud, indicates an extensive sea-level rise and a final flooding surface. The middle unit with reef framestone constituted by stromatoporoids, corals and *Chaetetes*, prograded on the open-platform sediments during lowstands of sea-level. The upper unit with back-reef sediments, consisting of *Amphipora*, *Stachyodes* and *Thamnopora* and lime mud, evinces a sea-level fall. The hierarchy of accretional units implies a hierarchy of relative sea-level fluctuations of different amplitudes, and reefs can be shown to grow faster than both relative sea-level rise and basin subsidence. The growth potentiality of coral-stromatoporoid reef is at its maximum near the sea surface and decreases with depth. During sea-level rise and marine flooding, terrigenous mud and sand were common in the carbonate sediments and unfavorable to the massive, domal and tabular stromatoporoids and massive corals were not flourishing. Seville stromatoporoid and coral frameworks were well developed during lowstand sea-level with less or rare terrigenous mud and sand under condition with more agitated water.

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PLATE EXPLANATION

Plate Ⅰ (All figures from Yanshan Dacun)

1. General view of Givetian coral-stromatoporoid reef at Yanshan. a. fore-reef slope, b. reef, c. back reef.
2. Photograph showing outcrop of stromatoporoid skeleton with ragged margin indicating a relatively high sedimentation rate and high stability to water roughness.
3. Microphotograph showing thin section of stromatoporoid reef limestone with brachiopods bound by stromatoporoids. DC-46, ×2.
4. Cut and polished slab of *Stachyodes* limestone, with *Stachyodes* preserved in the black lime mud. DC-19.
5. Microphotograph showing thin section of argillaceous limestone with abundant bioclasts including those of *Thamnopora*, brachiopods and *Chaetetes*. DC-13, ×2.
6. Microphotograph showing transverse thin section of *Rhaphidopora rotunada* (Lecompte, 1939). DC-42, ×2.

Plate Ⅱ (All figures from Yanshan Dacun)

1. View of rugose coral *Disphyllum* colony. DC Ⅱ-16, ×1.
2. Thin section of *Disphyllum* sp. in Yanshan reef-core facies, DC-12, ×1.2.
3. (1) View of bulbous *Chaetetes* bound by stromatoporoids. DC-43, ×1. (2) microphotograph showing thin section of *Thamnopora* bafflestone. a. stromatoporoids, b. *Thamnopora*, DC-21, ×2.
4. Outline of massive *Argutastrea* sp. in the reef-core facies. ×0.8.
5. Cut and polished slab of brachiopods showing geopetal fabric. ×1.
6. (1) Microphotograph showing thin section of argillaceous limestone and marls with brachiopods and *Thamnopora*. DC-6, ×2. (2) Cut and polished slab of coral-stromatoporoid limestone, showing rugose corals, *Thamnopora*, brachiopods and stromatoporoids.

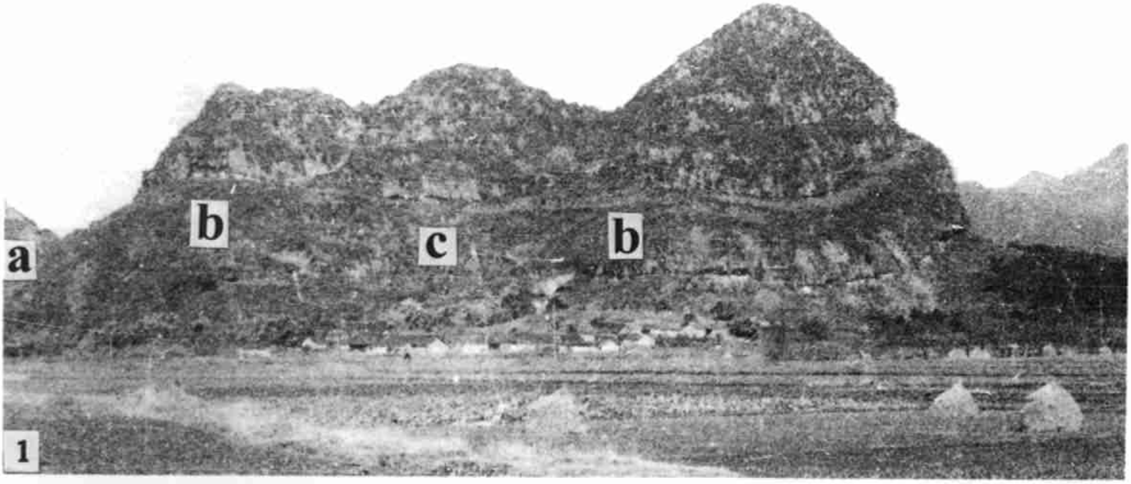
Plate Ⅲ (All figures from Yanshan Dacun)

1. Microphotograph showing thin section of *Thamnopora* bafflestone. a. stromatoporoids, b. *Thamnopora*, DC-21, ×2.
2. Microphotograph showing thin section of *Thamnopora* bafflestone with *Thamnopora* fragments. DC-70, ×2.
3. Microphotograph showing thin section of brachiopod wackestone with brachiopods indicating a distinct geopetal fabric, and bioclasts including those of brachiopods, crinoids and ostracods. DC-51, ×2.
4. Microphotograph showing thin section of *Amphipora* floatstone. DC-33, ×2.

5. Microphotograph showing thin section of crinoidal packstone with crinoids cemented by lime mud. DC-8, ×2.
6. Microphotograph showing thin section of stromatoporoid reef limestone. a. brachiopods, b. lime mud in the stromatoporoid skeleton, c. residual pore space formed during post-burial phase. DC-51, ×2.
7. Microphotograph showing thin section of wackestone with bioclasts mainly of brachiopod, gastropod and ostracod fragments. DC-32, ×2.

Plate Ⅳ (Figs. 1, 2 from Yanshan-Wuguishan, others from Yanshan Dacun)

1. General view of reefal breccia, a large, non-rounded stromatoporoid breccia.
2. Thin-bedded limestone intercalated with debris flow beds in fore-reef slope facies.
3. Cut and polised slab of bioclastic limestone showing stromatoporoid and crinoidal fragments in fore-reef slope facies.
4. Coral-stromatoporoid rudstone.
5. Microphotograph showing thin section of coral-stromatoporoid limestone with *Lythophyllum* bound by stromatoporoids. a. stromatoporoids; b. *Lythophyllum*, c. *Chaetetes*. DC-41, ×1.
6. Cut and polished slab showing *Argutaśtrea* bound by stromatoporoids.
7. General view of reef basement with an overturned *Argutastrea* sp.
8. Cut and polished slab of bioclastic packstone showing crinoids and brachiopod shells in reef core facies. YSJ-20, ×1.
9. Microphotograph showing thin section of bioclastic packstone with bioclasts including those of crinoids, brachiopods and sponge spicules. DC-68, ×2.
10. Cut and polished slab showing *Chaetetes* bound by stromatoporoids.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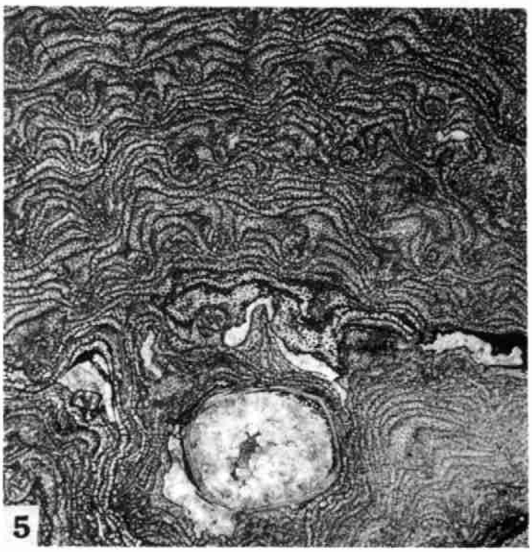
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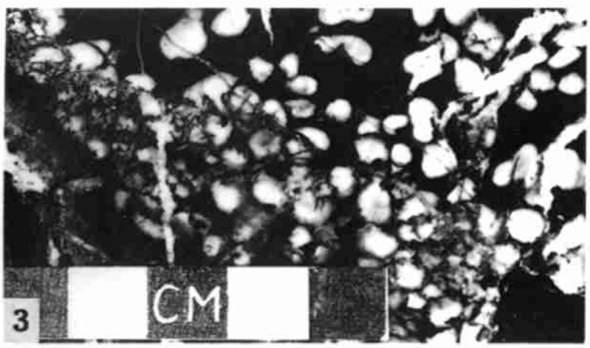
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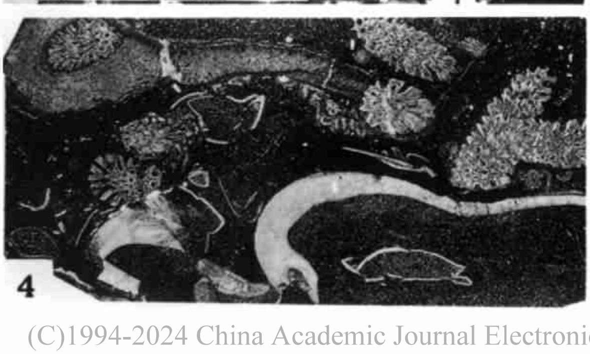
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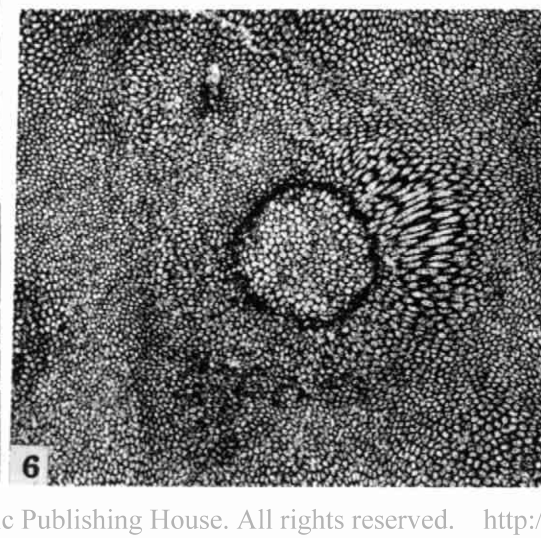
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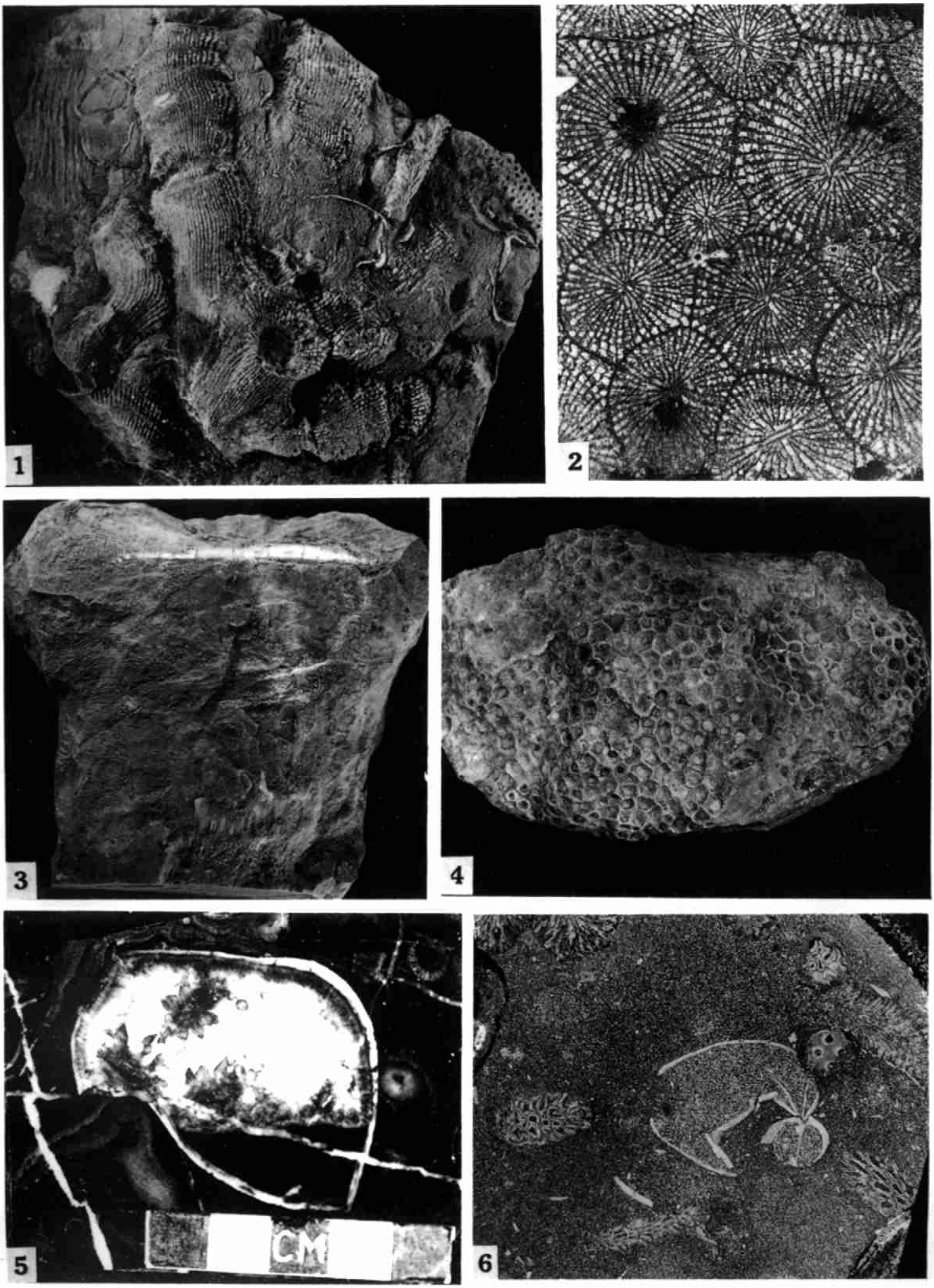
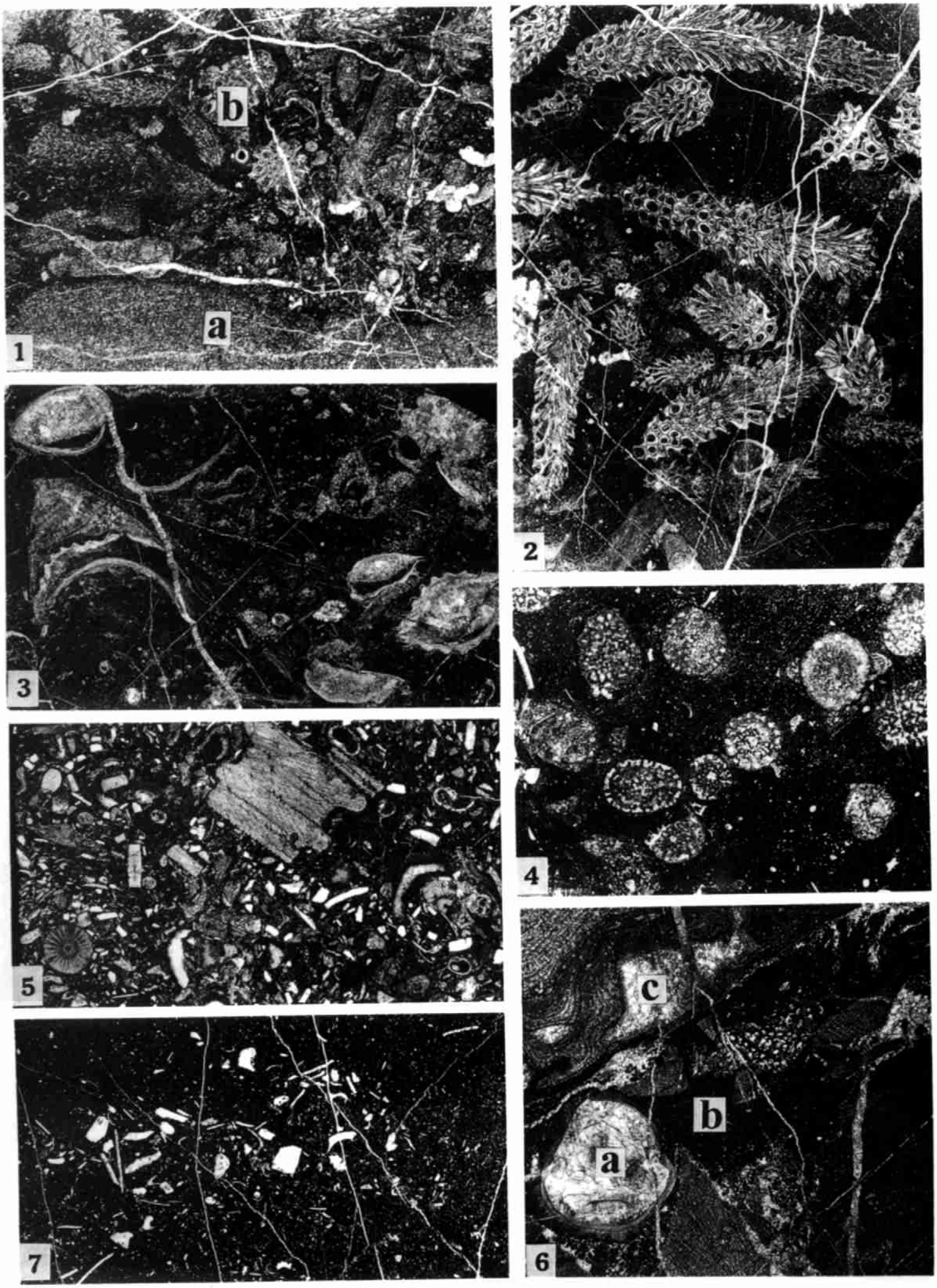
Middle Devonian (Givetian) Coral-Stromatoporoid Reef at Yanshan, North of Guilin, Guangxi, South China

Plate Ⅱ

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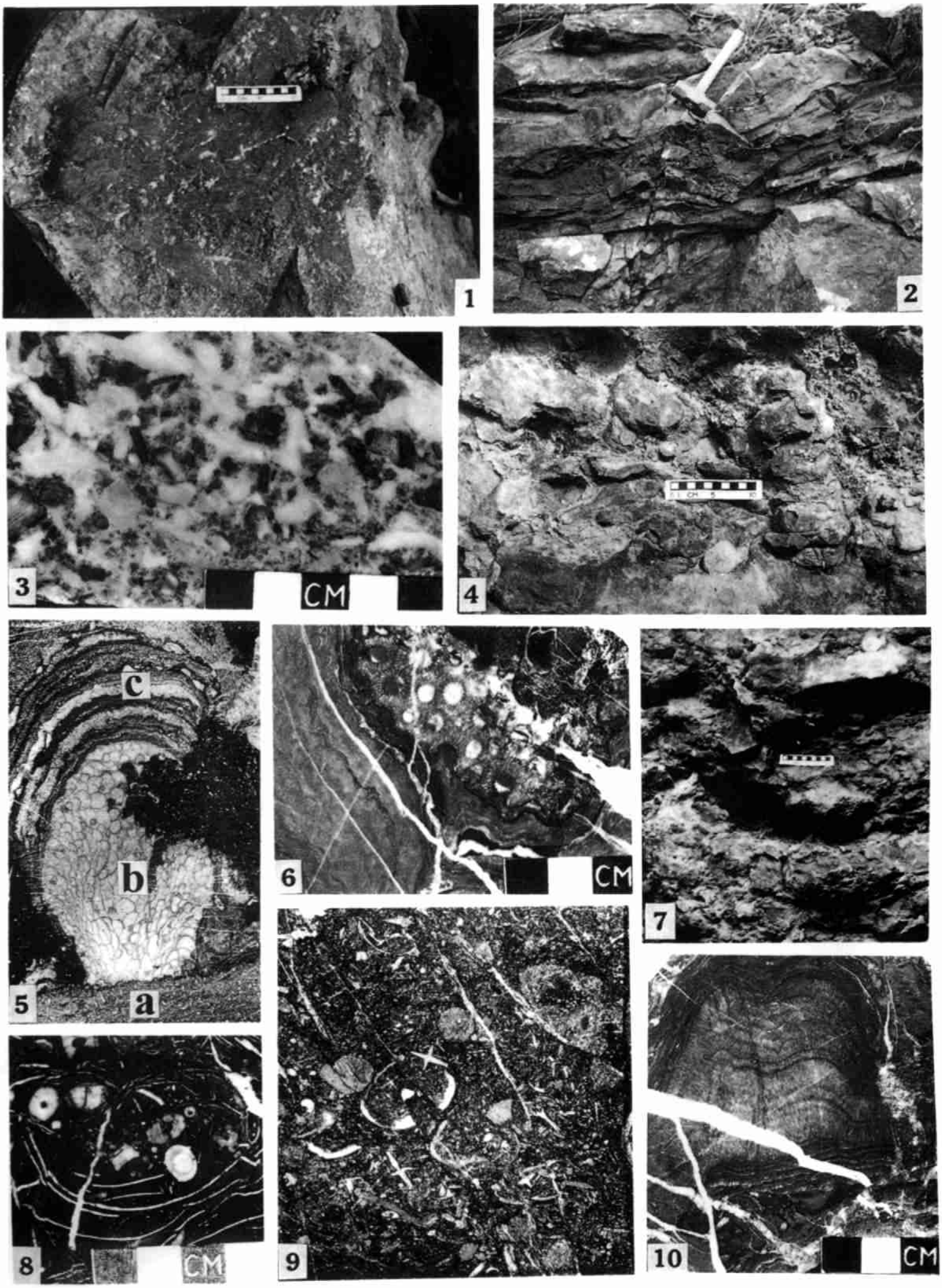
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