



## Microfacies characteristics and sedimentary environment of the Visean Stage, Early carboniferous coral reef formation, Cat Ba Island, Vietnam

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### ABSTRACT

The early carboniferous coral reef of the Cat Ba Island, Vietnam is mainly developed in the interior of the carbonate platform. In this article, we present our new study results on microfacies characteristics and the sedimentary environment of the rocks in the coral reef profiles based on the analysis of the carbonate microfacies as the major means. Three types of microfacies have been identified: Bioclastic packstone, coral framestone, bioclastic grainstone. The facies model is composed of the open platform facies, coral reef facies and the shoal facies. According to this microfacies analysis, the sedimentary environment during the coral reef evolution was reconstructed. It is indicated by the assemblage of microfacies and its longitudinal regularities along the profiles; Generally, the coral reef has developed in the shallow water environment while the open platform has formed in the subtidal zone.

### 1. Introduction

The coral reef addressed in this study is situated in the South of the Cat Ba Island, Northwestern Tonkin Gulf in Figure 1. This reef formation is supposed to be very sensitive to the change in the living environment as well as to the clastic sediment influx. The carboniferous limestone is very common in northern Vietnam, in which it is dominated by the bio-carbonate. It means that studying lithological composition, microfacies of this formation can to some extent help define paleo-environment of the region and hence geological history is thereby reconstructed. The study area belongs to a sub-basin of the Tonkin Gulf (Tran Van Tri and Vu Khuc, 2011), NE Vietnam. This area is composed of the Permo-Carboniferous carbonate rock of the Bac Son Formation (C-P bs), as shown in Figures 1 and 2, which are mainly dominated by gray, thickly bedded or massive limestone

containing bio-fragments, such as foraminifera, coral, and peduncle (Tong Duy Thanh and Vu Khuc, 2005). The timing of the reef formation was considered as the Early Carboniferous Visean Stage and it has built up to ~6m high and ~12m of lateral extension in the Cat Ba Island. Within the Early Carboniferous limestone in the Cat Ba Island, two species of coral have been identified, namely: Rugose corals *Donophyllum* sp. and *Thysanophyllum* sp. These are the two main biosources for the reef formation and are characterized by the plexiform and columnar morphologies. They have been compacted and aligned to subsequently form the firm wave barriers and are the most important components of the reef core (Figure 3A-F).

Microfacies analysis of the carbonate rocks is an important proxy for studying carbonate sedimentology and recently there have been a number of studies on the microfacies of the

carbonate rocks in Vietnam, China and around the world. Significant achievements have been made (Gong Enpu and Elias Samankassou et al., 2007; Gong Enpu and Zhang Yongli et al., 2007; Guan Changqing et al., 2004). In the study areas, the previous studies on the Late Devonian to the Early Carboniferous carried out by the predecessors mainly focused on

Paleontology and Stratigraphy, with less or no study on coral reef morphological characteristics nor growth and construction model; This study discusses the application of the microfacies analysis as a major proxy to define microfacies characteristics and sedimentary environment of the coral reef in the area.

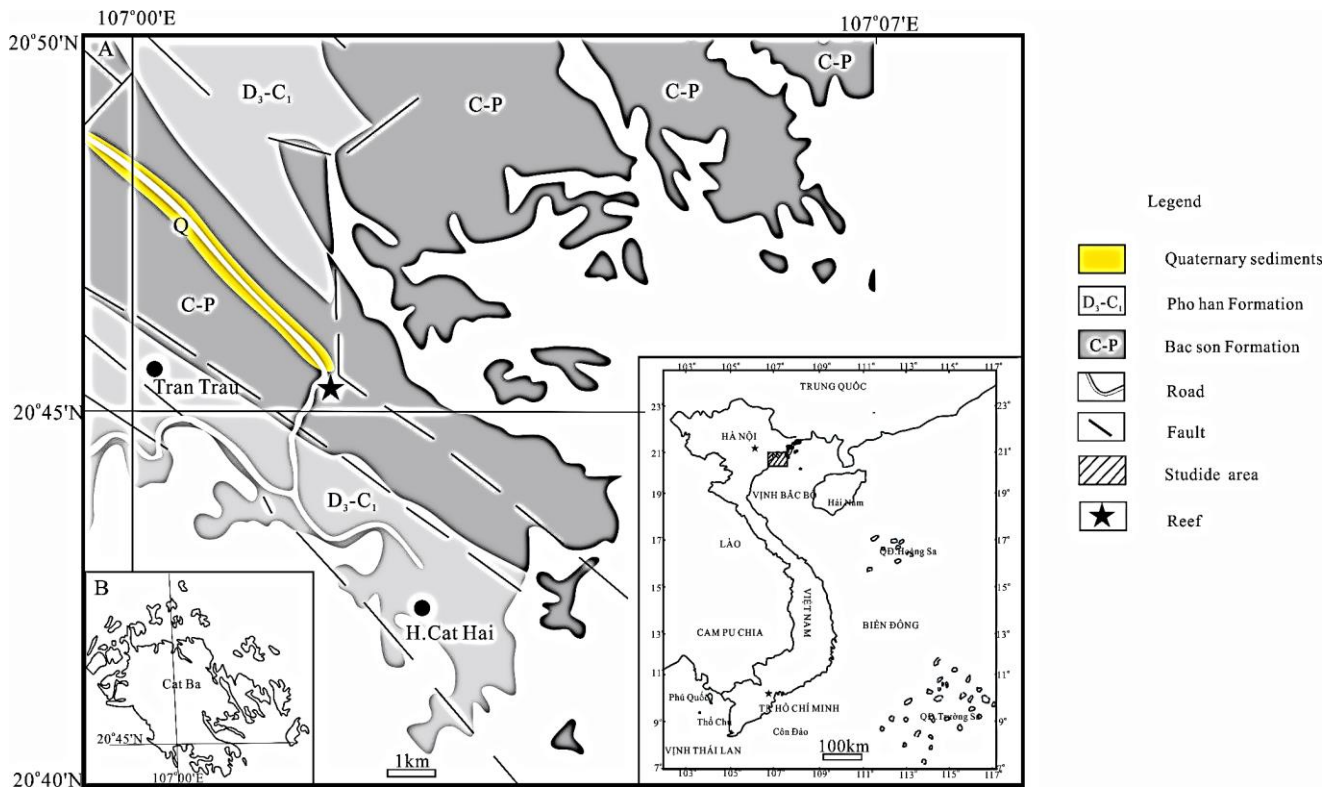


Figure 1. Location of the coral reef in the Cat Ba Island, Hai Phong Province, North Vietnam

System	Series	Stage	Cat Ba	Reef	
Permian					
Carboniferous	Pennsylvanian	Gzhelian	Bac Son Formation		
		Kasimovian			
		Moscovian			
		Bashkirian			
	Mississippian	Serpukhovian			
		Viscan			★
		Tournaisian		Pho Han Formation	
Devonian	Famennian				

Figure 2. Simplified stratigraphy of the study area

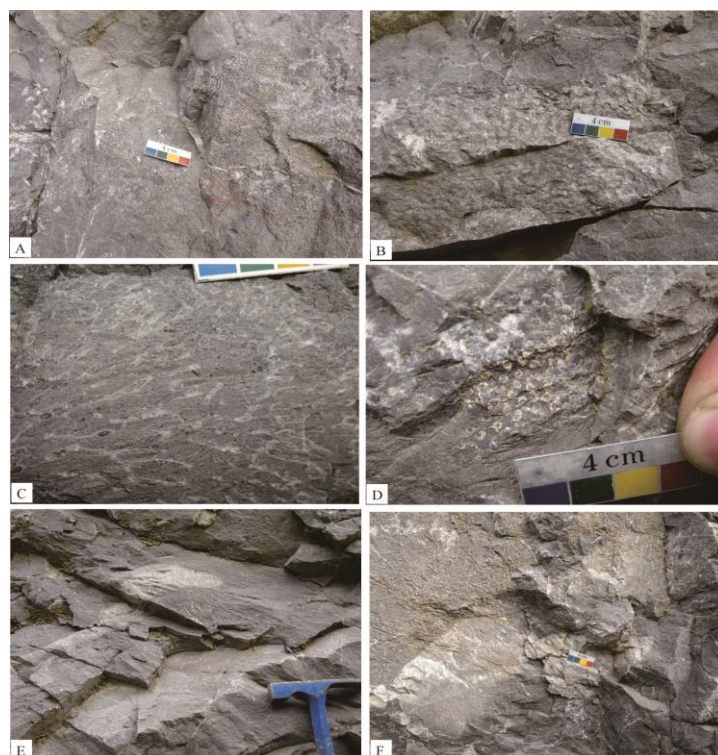


Figure 3. Field photos of coral reef

(A, B, C, D: Field view of the fasciculate framestone; E, F: Field view of the corniform framestone)

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## 2. Materials and Method

Sedimentary microfacies analysis features tremendous significance for the grasping of Sedimentary environment model in the geological time and the lithofacies-paleo-Geography. Influenced by the F/Fbiota

extinction event and the global climate change, the Carboniferous Period was considered a stage of gradual restoration in the process of biological evolutionary process (Chevalier and Aretz, 2005; Rodríguez et al., 2012; Wood, 2001; Webb, 1994). Although many scientists have introduced their own interpretations it is gradually realized that if we can define depositional environment, which is closely linked to the biota extinction sea level change then the mechanism of the biota extinction can be solved.

By using this approach, thirty six samples have been collected from the stratigraphic sections of the coral reef in the Cat Ba Island for microfacies analysis. Under the microscope, the biotypes, degrees of abrasion, rock compositions and the grain parameters in the thin section were examined.

For a long time, microfacies have been suggested to be a good indication of sedimentary environment and are closely associated with sea level change. Therefore, microfacies types are also important parameters for studying the sea level variation in the past.

### **3. The granular characteristics of carbonate rock**

The coral reef limestone in the Cat Ba Island is a set of depositions of the gray or light gray thickly bedded or massive limestone without terrigenous clasts. The carbonate granular composition consists of bioclasts and the pelletoids, with minor oolite, which are commonly observed in the shallow water environment of carbonate platform and massive limestone. Whereas, the oncolites is widely in the high-energy environment. Composition and their characteristics of various types of the carbonate granules are described as follow:

#### **3.1. Bioclasts**

The content of bioclasts reaches the highest value and the biotypes are diversified as well as widely distributed. In the coral reef profiles of the Cat Ba Island. The most abundant bioclasts comprise of the following species listed in decreasing order: echinodermata, algae, foraminifera as well as some single corals which all demonstrate marine benthic organisms.

The foraminifera class: It is the most widely distributed fossil in the profiles, its species are diversified and hence it is an important rock-forming contributor. The numbers of foraminifera classes are few. Only few of them have been fragmented while most of the rest foraminifera have been well preserved with little micritization was identified in various degrees. The size of the foraminifera shells varies between 0.1-0.12mm (Figure 4A).

In the profiles, the crinoid stem is a common and widely distributed biological fossil. It mostly consists of crinoid stem pieces, which show a clear monocrystalline structure. The content of crinoid stem is relatively richer in the calcareous mudstone and the granular limestone was observed in the upper part of the profiles. The crinoid stem have been broken and dispersed and/or subject to micritization (Figure 4C). In some stem pieces, the lattice structures could be seen.

The fossils of a single coral appeared in the profiles contain algae, and its shells, which have been mostly broken, with only a few of well preserved shells (Figure 4D).

Other bioclasts: In addition to the major components of the above 3 types of bioclasts, other species, including algae, dielectric class and gastropods, etc. have also identified.

#### **3.2. Pelletoids**

The pelletoids are the powdered scrap and other carbonate granules. This product distribution is variable and shows spherical and oval morphologies. The particle size mostly ranges from 0.05-0.1mm, with no internal structure. Some fine biological skeletal fragments and ostracoda can be seen in the thin section. The pelletoids have been cemented by bright micro crystal cementation (photo 4-D) and they are unevenly alignments with no layer structures.

#### **3.3. Other granular composition**

In addition to the above granular components, there are also small amount of binding organisms and some undefined granules in the rocks. These unknown granules are mainly distributed in the middle and the lower of profiles. They usually demonstrate spherical and strip morphologies, which are mostly fine-grained calcite. The granules have been coated by a 0.2-1mm layer of mud and inside of the spheres were filled by mud granules and bioclasts.

### **4. Microfacies classification and characteristics of the coral reef profiles**

The reef facies of the Viséan Stage, Carboniferous System limestone in the Cat Ba Island is characterized by super thickly bedded, dark gray, pure carbonate rocks of more uniform lithofacies. The Viséan reef facies of the Cat Ba Island were subdivided into three categories from top to bottom as the mud limestone, granules limestone and coral framestone (Figure 4).

#### **MF1: Bioclastic packstone (Figure 4A)**

These microfacies are mainly appeared in the substrate of the coral reef and the cap rocks. In the coral layer, the bioclasts mainly consist of the metacrinus, foraminifera together with minor algae fragments and the pelletoids. The bioclasts mostly comprise mud crusts or micritization. Between the granules, there are mud supports or bright crystal cementation.



The microfacies manifested the eroded and encrusted biodetritus that have deposited in fine grain matrix with no passage to the open sea and no influx of terrigenous clasts. The presence of these facies suggests that the depositional environment as well as the energy flow were excellent and very calm, which is located near the wave base or just below it. Therefore, they often appeared in the open platform environment with open water circulations (FZ7) (Microfacies of Carbonate Rocks, 2006 (translated by Ma Yongsheng)).

**MF2: Coral framestone (photo2-B)**

These microfacies are mainly observed in the coral reef and the coral layer. They have been formed by the compaction of plexiform or localized rugose coral barriers. The coral grid frames inside the reef are usually oriented due to compaction, with small amounts of bioclasts seen within corals (Figure 5), leading to the reef become firmer and harder for resisting the wind and waves erosion. The reef grids within the coral layer are usually dispersed in distribution and small scale of development. The microfacies mainly appear in the reef facies environment (FZ5) (Microfacies of Carbonate Rocks, 2006 (translated by Ma Yongsheng)).

**MF3: Bioclasts grainstone (Figure 4C)**

These microfacies are mainly observed in the coral reef cap rocks and the substrate of the coral layers. In the spine crumbs and foraminifera-dominated bioclast with minor amount of pelletoids and algal fragments while other bioclasts were rarely seen. The bioclasts is characterized by fine grained granularity and good sortness with bright cementations between the granules. These facies imply the environment above the wave base and is usually observed in the shallow water environment at the platform edge (FZ6) (Ma Yongsheng, 2004).

**5. Analysis of sedimentary facies of the reef profiles**

Based on the results of microfacies analysis of the coral reef limestone, the sedimentary environment of the Cat Ba coral reef profiles has been defined as the open platform environment, which corresponds to the epicontinental sea deposit of the Early Carboniferous period. The following sedimentary facies have been identified in the profiles (Figure 5):

- Open platform facies;
- Coral reef facies;
- Platform shoal facies.

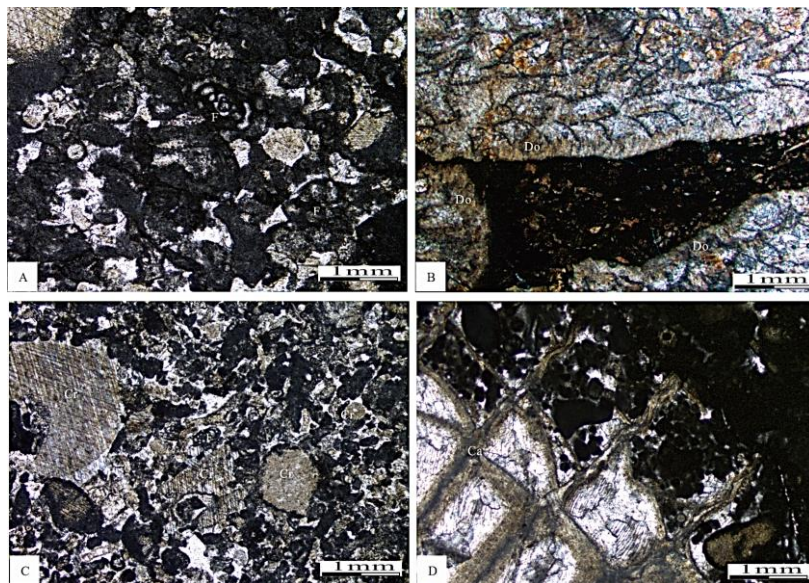


Figure 4. Different microfacies

A. Microfacies MF1 bioclastic packstone; B. Microfacies MF2 Coral framestone  
C. Microfacies MF3 bioclasts grainstone; D. single coral, *Caninia* sp., cross section

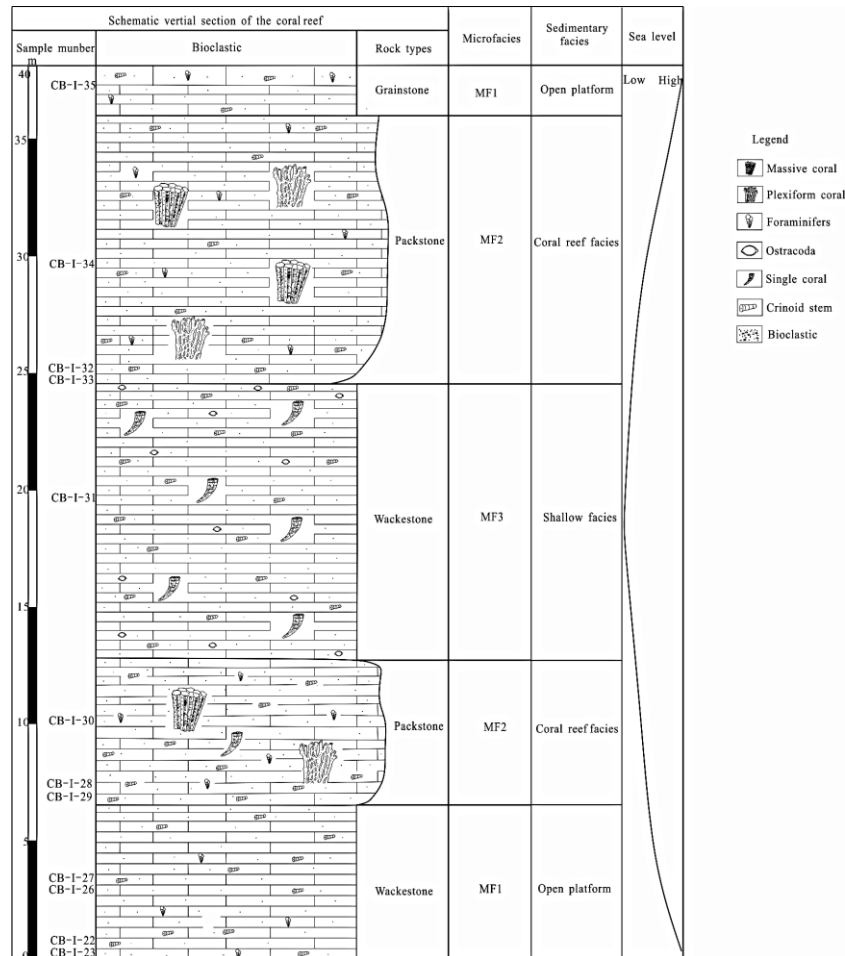


Figure 5. Schematic vertical section of the Cat Ba coral reef

Their major sedimentary characteristics are described as follows:

Open platform facies: they are located below the normal wave base plane; the active wave function was relatively weak suggesting low energy hydrodynamic regime (low mud granules content). The biological differentiations are low and it is supposed to belong to the combination of the benthos and the substrate is most of the dominant packstone. Less content of pelletoids were also observed, which are mainly composed of MF1 and it is an indication of weak turbulent environment of the open platform.

Coral reef facies: it is composed of MF2, and the corals are characterized by growths of plexiform or massive group which are oriented due to compaction. The deposits have formed between the corals that has smaller amount of bioclastics and larger amounts of plaster. Algae fragments have been badly preserved while the corals show very high yields and quickly

deposited at the bottom of the sea. Thus the growths of normal shoal organisms were restricted; a small content of algae and other organisms were observed in the rocks as well as in the thin sections. The rock type was defined as the coral packstone and wackestone. It demonstrates the warm, medium - high energy environment above the wave plane.

The platform shoal facies: they comprise MF2, which is enriched by granule content and massive content. The pelletoids are mainly biological abrasive granules. Most of the biological fossils have been broken with high differentiation degrees. The biological granules have been closely linked to the mud crystallization, strong abrasion and good sortness. The Metacrinus stems have been mostly broken, dispersed and mixed with foraminifera in crystal grainstone. The sediments between the granules and plaster have been washed away by the wave activities

suggesting a depositional environment above the normal wave plane with medium turbulence of the warm shoal open platform.

The changes in the sedimentary facies in the profiles of the Cat Ba coral reef associated with 3 sedimentary facies. The coral reef facies frequently appears in a multitude of horizons, and quick sea level variation and hence leading to formation of different sedimentary facies: Open platform facies → coral reef facies → platform shoal facies.

## **6. The sedimentary facies modes of the coral reef limestone and the sedimentary environment**

### **6.1. The sedimentary facies model of the coral reef limestone**

Based on the changes in sedimentary facies, the variation in the coral reef profiles of the Cat Ba Island have been studied and were defined into 3 different sedimentary facies (Figure 5). It was considered to be triggered by the frequent sea level fluctuation. Pursuant to the Walther Law, we can use the sedimentary facies model that is horizontally configured to conduct interpretations on the facies changes of the Cat Ba Coral reef profiles. The depositional model derived from a local facies model is an open platform and the transitional zone of the platform edge summarized by the Wilson cycle such a model formed by the open platform facies → coral reef facies → platform shoal facies (Figure 4).

### **6.2. Sedimentary environment**

Based on the microfacies markers in the stratigraphic sections, initial analysis on the sedimentary environment has been conducted in the study area, in which we focussed on sedimentology and paleontology proxies. The coral reef has usually grown up in various kinds of the clastic beaches such as shell limestone, foraminifera crumbs, limestone granules, and the substrate they lived on should be the clastic beaches that have been formed in early stages. They were subsequently felt into cemented bottom. The Early Carboniferous limestone in the Cat Ba is located in the subtropical region, low latitude, and medium salinity where the group corals, single corals and foraminifera all

indicate a kind of warm sedimentary environment with strong shallow water regime.

In the open platform environment, since the high stand sea level, the hydrodynamic condition was relatively weak the content of the benthos has decreased in the resulted packstone and wachestone. The high stand sea level was followed by a period of sea level drop. Due to the influence of the increased flow energy, the coral plexiform group has gradually evolved and developed into the prism shape group. Within the coral groups, plaster and fine bioclastics have been deposited containing a small content of foraminifera and pelletoids. All of these characteristics indicated a medium flow energy regime for the growth and development environment of the coral reef. Due to the fast sea level variation, depositional environment has shifted accordingly. Meanwhile, the relevant biological combinations were also altered, thus affecting the development of the coral reef. In the study area, the locations with higher energy of the sedimentary environment should be associated with the shoal facies within the open platform. The types of the sedimentary rocks were mainly the bioclastic grains of limestone and in such an environment, the kinetic energy of the water was rather strong and hence the coral reef growth has ceased. Therefore, the pre-forming bioclastic beaches became an excellent substrate for the developments of the coral reefs.

## **7. Conclusion**

Through the comprehensive analysis of the carbonate microfacies of the Early Carboniferous Visean Age reef facies, the following conclusions are obtained through our research:

1. The Early Carboniferous carbonate granules of the Cat Ba coral reef are mainly composed of bioclastics and pelletoids.

2. The profiles of the coral reef limestone demonstrates three types of microfacies: MF1 bioclastic packstone, MF2 coral framestone and MF3 bioclastic grainstone.

Through the three types of microfacies, three types of sedimentary environment have been interpreted accordingly: Open platform

environment, coral reef environment and the shoal environment. The data derived from the measured profile and the sedimentary microfacies analysis suggested that the sedimentary environment of Cat Ba region is a shoal environment within an open platform.

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