

Biological Diversity, Crisis and Recovery in the Phong Son Formation (D₃-C₁ Ps), Thua Thien-Hue Province, North-Central Vietnam

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To cite this article:

Nguyen Huu Hung, Doan Dinh Hung, Nguyen Ba Hung. Biological Diversity, Crisis and Recovery in the Phong Son Formation (D₃-C₁ Ps), Thua Thien-Hue Province, North-Central Vietnam. *Ecology and Evolutionary Biology*. Vol. 6, No. 4, 2021, pp. 103-112.

doi: 10.11648/j.eeb.20210604.12

Received: July 6, 2021; Accepted: August 10, 2021; Published: November 17, 2021

Abstract: The present of Upper Devonian and Lower Carboniferous sediments and fossils in Hue City, Van Xa area, Huong Thuy District; Thanh Tan, Hien An villages, Dong Lam Quarry, Phong Dien District, Thua Thien-Hue Province has been noted in recent years depend on explosion of limestone underlying the Quaternary cover for cement technology and building. The Phong Son Formation has been established with two members: the underlying Van Xa Member composed of mainly limestone, 280 m thick, containing abundant Famennian brachiopods, crinoids, gastropods; the overlying Hien An Member composed of limestone intercalated with black shale, 210 m thick, containing abundant brachiopods, crinoids, bryozoans, stromatoporoids, corals, trilobites, foraminiferans, gastropods of Latest Famennian-Tournaisian age. Over 1000 macrofossil examples were collected from both the Van Xa Member and Hien An one for analyzing biological diversity, crisis and recovery of all macrofossil group of stratigraphical level of the Phong Son Formation (D₃-C₁ ps). In the Famennian stage, the diversity is related to representatives of phyla Brachiopoda, Cnidaria, Mollusca; belonging to the *Cyrtospirifer-Yunnanella* Assemblage. In the Tournaisian stage, the recovery and diversity is related to representatives of phyla Porifera, Cnidaria, Arthropoda, Brachiopoda, Bryozoa, Mollusca, and Echinodermata; belonging to the *Leptagonia-Phillipsia* Assemblage. The crisis at the DCB of the Phong Son Fm is well displayed in phyla Brachiopoda, Cnidaria and Porifera.

Keywords: Macrofossils, Diversity, Famennian-Tournaisian, Vietnam.

1. Introduction

The Upper Devonian (Famennian)-Lower Carboniferous (Tournaisian) sedimentary rocks in Hue City, Huong Thuy and Phong Dien districts, Thua Thien-Hue Province belonging to the south part of North-central Vietnam (Figure 1) with a part of natural exposure, while the main of them underlying the Quaternary cover. Only in recent years, with explosion of cement technology for building; many quarries in Thua Thien-Hue Province were exposed. According drill data, the rocks of the Phong Son Formation distribute in an elongate trough, 40km long and 3 km wide with a NW-SE strike. The stratigraphic succession of this

formation has been studied in detail by Nguyen Huu Hung *et al.* [16, 32, 33] and named the Phong Son Formation with two members. The lower member named Van Xa Member of the Famennian. The Hien An Member of the Late Devonian-Early Carboniferous. Many fossils of phyla Foraminifera, Porifera, Cnidaria, Mollusca, Brachiopoda, Bryozoa, and class Trilobita of phylum Arthropoda, class Crinoidea of phylum Echinodermata were found in both lower and upper parts of the formation. Some of them were described in previous works (Nguyen Huu Hung [17, 18]; Nguyen Duc Khoa [20]. Recent research of the paleontological team of Vietnam National Museum of Nature has focused in the well-exposed shale beds,

belonging to upper part of the Hien An Member at Dong Lam Quarry, Phong Dien District. About 800 examples

yielding rich brachiopods, crinoids, trilobites, bryozoans, tabulates, stromatoporoids were collected.

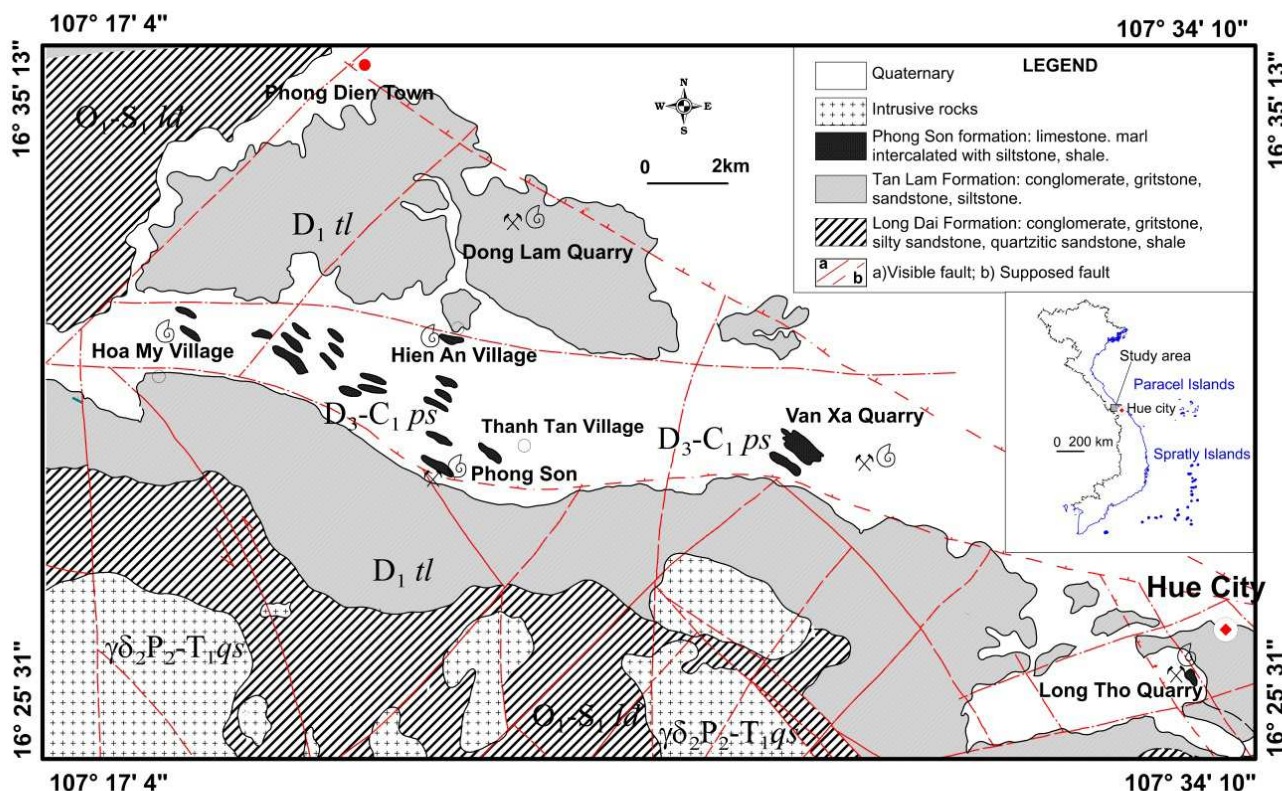


Figure 1. Index map showing distribution of the Phong Son Formation and fossil localities in Thua Thien-Hue Province based on Hue geological map sheet group 1:50.000 scale, that established by Pham Huy Thong *et al.* 1997.

2. Geological Setting

The limestone and argillaceous limestone with intercalation of shale around Hue City, Huong Thuy, Phong Dien districts were assigned to different formations and ages: Visean [8]; limestone of the Lower Carboniferous [21]; the Cu Bai Formation of the Givetian-Frasnian age [22, 23]; the La Khe Formation of the Early Carboniferous age [24].

Nguyen Huu Hung *et al.* [16]; Nguyen Huu Hung [17] have been studied in detail of biostratigraphic sections at Long Tho Quarry, Hue City; at Van Xa Quarry, Huong Thuy District; outcrops at Thanh Tan Village, at Hien An Section, Phong Dien District; and established a new lithostratigraphic unit for stratigraphical succession of the Upper Devonian–Lower Carboniferous, and named the Phong Son Formation, with two member: The Van Xa Member (D₃fm) is characterized by ash-grey, medium-bedded argillaceous limestone regularly interbedded with black shale, yielding brachiopod assemblage of *Cyrtospirifer-Yunnanella* characterizing for the Famennian age. The Hien An Member is composed of black-grey medium to thick-bedded limestone intercalated with shale yielding stromatoporoid–coral assemblage of *Vietnamostroma-Cystophrentis* characterizing for the Devonian–Carboniferous

Boundary; and brachiopod–arthropod assemblage of *Leptagonia-Phillipsia* characterizing for the Tournaisian age. The Phong Son Formation has unclear stratigraphic relations with the Co Bi Formation (D₁ cb) as well as with other units; while Pham Huy Thong *et al.* [26] has represented on the Hue geological map sheet group at 1:50.000 scale as a tectonic wedge between sediments of the Tan Lam Formation (D₁ tl).

3. Materials

About 1000 foraminiferan, poriferan, cnidarian, arthropod, mollusc, bryozoan, echinoderm examples were collected by Nguyen Huu Hung [16, 17]; Pham Huy Thong *et al.* [26]; Nguyen Huu Hung, Doan Dinh Hung, Pham Van Hung, Nguyen Ba Hung (2016); from Long Tho Quarry, Hue City; Van Xa Quarry, Huong Thuy District; a bomb hole at Thanh Tan Village, some natural exposes on the plains around Hien An, Hoa My, Phong Xuan villages, and Dong Lam Quarry, Phong Dien District, Thua Thien-Hue Province.

4. Fossil Taxa

About 100 fossil taxa of eight animal phyla collected from the Phong Son Formation are determined and synthesized in the following table:

Table 1. Fossil list of the Van Xa and Hien An Members in Thua Thien-Hue Province.

Fossil taxa	Member	Locality	Age
Foraminifera			
<i>Septabrusiina kinginica</i>	Hien An Member	Hien An	Latest Famennian
<i>Septatournayella</i> sp.	+	+	+
<i>Chernyshinella</i> sp.	+	+	+
<i>Septabrusiina</i> cf. <i>kazakhstanica</i>	+	+	Tournaisian
<i>Septatournayellina</i> cf. <i>segmentata</i>	+	+	+
Porifera			
<i>Vietnamostroma vietnamense</i>	Hien An Member	Hien An	Latest Famennian
<i>Pseudolabechia huanjiangensis</i>	+	+	+
<i>Rosenella miniarensis</i>	+	+	+
<i>Clavdictyon</i> cf. <i>regulare</i>	+	Dong Lam	Tournaisian
Cnidaria			
<i>Syringopora reticulata</i>	Hien An Member	Hien An	Latest Famennian
<i>S. geniculata</i> var. <i>haiphongensis</i>	+	+	+
<i>S. distans</i>	+	+	+
<i>Syringopora</i> sp.	+	+	+
<i>Michelina</i> sp.	+	Dong Lam	Tournaisian
<i>Alveolitidae?</i>	+	+	+
<i>Pseudozaphrentis</i> sp.	Van Xa Member	Thanh Tan	Famennian
<i>Zaphrentoides</i> sp.	+	+	+
<i>Cystophrentis kolaohoensis</i>	Hien An Member	Hien An	Latest Famennian
<i>C. roniewiczze</i>	+	+	+
<i>C. grandis</i>	+	+	+
<i>Cystophrentis</i> sp.	+	+	+
Arthropoda			
<i>Phillipsia</i> cf. <i>ohmorensis</i>	Hien An Member	Dong Lam	Tournaisian
<i>Linguaphillipsia</i> sp.	+	+	+
<i>Paleophillipsia</i> sp.	+	+	+
<i>Archaeogonus</i> sp.	+	+	+
<i>Paladin</i> sp.	+	+	+
Mollusca			
<i>Bellerophon</i> sp.	Van Xa Member	Van Xa	Famennian
<i>Pseudozygopleura</i> sp.	+	+	+
<i>Straparollus</i> sp.	Hien An Member	Dong Lam	Tournaisian
<i>Schizodus</i> sp.	+	+	+
Bryozoa			
<i>Fistulipora</i> sp.	Hien An Member	Dong Lam	Tournaisian
<i>Stenopora</i> sp.	+	+	+
<i>Fenestella</i> sp.	+	+	+
<i>Ptiloporella</i> cf. <i>vodoresovi</i>	+	+	+
<i>Polypora</i> sp.	+	+	+
<i>Rhombopora</i> sp.	+	+	+
Brachiopoda			
<i>Athyris concentrica</i>	Van Xa Member	Van Xa	Famennian
<i>Athyris</i> cf. <i>concentrica</i>	+	+	+
<i>Monelasma</i> cf. <i>deschayesi</i>	+	+	+
<i>Monelasma</i> sp.	+	+	+
<i>Yunnanella</i> cf. <i>hanburyi</i>	+	+	+
<i>Yunnanella</i> cf. <i>ksikwangshaensis</i>	+	+	+
<i>Yunnanella</i> sp.	+	+	+
<i>Leiorhynchus</i> sp.	+	+	+
<i>Plectorhynchella</i> sp.	+	Long Tho and Van Xa	+
<i>Plectorhyncha perchaensis</i>	+	+	+
<i>Cyrtospirifer miculus</i>	Van Xa Member	Van Xa and Thanh Tan	Famennian
<i>Cyrtospirifer chaoi</i>	+	+	+
<i>Cyrtospirifer sinensis</i>	+	Hoa My	+
<i>Tenticospirifer tenticulum</i>	+	Van Xa and Thanh Tan	+
<i>T. cf. vilis kwangsiensis</i>	+	Van Xa	+
<i>Theodosia anosofi</i>	+	Thanh Tan	+
<i>Cyrtopsis</i> sp.	+	+	+
<i>Uchtospirifer</i> sp.	+	+	+
<i>Platyspirifer paronai</i>	+	+	+
<i>Mucrospirifer</i> cf. <i>muralis</i>	+	+	+
<i>Ambocoelia</i> sp.	+	+	+
<i>Anatrypa</i> sp.	+	+	+

Fossil taxa	Member	Locality	Age
<i>Martinothyris</i> sp.	+	+	+
<i>Protathyris</i> sp.	+	+	+
<i>Leptagonia analoga</i>	Hien An Member	Dong Lam	Tournaisian
<i>Leptagonia</i> sp.1	+	+	+
<i>Leptagonia</i> sp.2	+	+	+
<i>Globosochonetes</i> sp.	+	+	+
<i>Rugosochonetes</i> sp.	+	+	+
<i>Semiproductus</i> sp.	+	+	+
<i>Buxtonia</i> sp.	+	+	+
<i>Plicatifera</i> sp.	+	+	+
<i>Pugilis</i> sp.	+	+	+
<i>Schuchertella</i> cf. <i>oversbyi</i>	+	+	+
<i>Schuchertella</i> sp. A	+	+	+
<i>Schuchertella</i> sp. B	+	+	+
<i>Schellwienella</i> cf. <i>burlingtonensis</i>	+	+	+
<i>Schellwienella</i> sp. 1	+	+	+
<i>Schellwienella</i> sp. 2	+	+	+
<i>Serratocrista</i> sp.	+	+	+
<i>Actinoconchus</i> sp.	+	+	+
<i>Cleiothyridina</i> sp.	+	+	+
<i>Rhipidomella</i> sp.	+	+	+
<i>Schizophoria</i> sp. 1	+	+	+
<i>Schizophoria</i> sp. 2	+	+	+
<i>Macropotamorhynchus</i> sp.	+	+	+
<i>Fusella</i> sp.	+	+	+
<i>Brachythyridina</i> sp.	+	+	+
<i>Unispirifer</i> sp.	+	+	+
<i>Cyrtospirifer</i> sp.	+	+	+
<i>Choristites</i> sp.	+	+	+
<i>Syringothyris</i> sp.	+	+	+
Echinodermata			
<i>Glossocrinus</i> cf. <i>whidhomei</i>	+	+	+
<i>Cyclocaudex</i> cf. <i>medius</i>	+	+	+
<i>Taranshicrinus</i> sp.	+	+	+
<i>Cyclocaudiculus</i> cf. <i>varius</i>	+	+	+
<i>Cyclocyclicus</i> sp. A	+	+	+
<i>Cyclocyclicus</i> sp. B	+	+	+
<i>Stenocrinus</i> sp.	+	+	+
<i>Pentagonocyclicus</i> sp. B	+	+	+
<i>Floricyclus</i> sp.	+	+	+

5. Discussions on Biological Diversity

5.1. Foraminifera

Five foraminiferan taxa of *Septatournayellina* cf. *segmentata*, *Septatournayella* sp., *Septabrusiina kinginica*, *Septabrusiina* cf. *kazakhstanica*, *Chernyshinella* sp. are related to representatives of family Tournayellidae Dain [6]; known from the Late Devonian to the Early Carboniferous. In the Phong Son Formation, these foraminifers are only discovered in the limestone beds belonging to lowermost part of the Hien An Member, occupying 27% total number of taxa of the Latest Famennian-Earliest Tournaisian stage (Figure 2b).

5.2. Porifera

Three stromatoporoid taxa: *Rosenella miniarensis* is related to representatives of the family Rosenellidae Yavorsky [17]; known from the Middle Ordovician to the Late Famennian. *Vietnammostroma vietnamense* is related to representatives of the, *Pseudolabechia huanjiangensis* is

related to species of family Pseudolabechiidae Bogoyavlenskaya [17]; known from the Early Silurian to the Late Devonian. All stromatoporoids cited above were collected from the limestone beds belonging to base of the Hien An Member. These beds are correspondent to the beds of the D-C Boundary in Vietnam. *Clavdictyon* sp. is related closely to representatives of Order and Family Uncertain [17], from the Middle Silurian to the Late Devonian (Famennian stage). In Vietnam, representatives of genus *Clavdictyon* Sugiyama was reported from the Upper Devonian limestone (Frasnian) of the Cu Bai Formation; and from the calcareous shale of the Lower Tournaisian, belonging to the upper part of the Hien An Member. In the Latest Famennian-Earliest Tournaisian stage, poriferans occupy 14% total number of taxa (Figure 2b); while in the Tournaisian stage, they occupy ~2% (Figure 2c).

5.3. Cnidaria

Pseudozaphrentis sp. is related to representatives of family Disphyllidae Hill [8]; from the Late Silurian to the Late Devonian.

Zaphrentoides sp. is related to representatives of family Zaphrentoididae Schindewolf [14, 27]; from the Early Carboniferous to the Late Permian.

Cystophrentis kolaohoensis, *C. roniewiczze*, *C. grandis*, *Cystophrentis* sp. belonging to family Cystophrentidae Yü [27]; were reported from the Latest Famennian.

Syringopora reticulata, *S. geniculata* var. *haiphongensis*, *S. distans*, *Syringopora* sp., are related to representatives of family Syringoporidae de Fromente [14]; known from the Late Ordovician to the Early Permian.

Michelina sp. is related to representatives of family Micheliniidae Waagen & Wentzel [16, 17]; known from the Late Silurian to the Late Permian.

The cnidarid fossils are discovered in both carbonate facies and shale facies. In the Famennian stage, cnidarids occupy 7% total number of taxa (Figure 2a); in the Latest Famennian-Earliest Tournaisian occupy 59% (Figure 2b); and in the Tournaisian stage occupy ~4% (Figure 2c).

5.4. Arthropoda

Many fossils belonging class Trilobita, chiefly pygidium: *Archaeogonus* sp., *Phillipsia* cf. *ohmorensis*, *Linguaphillipsia* sp., *Schizophillipsia* sp., *Paleophillipsia* sp. are related to representatives of family Phillipsidae Oehlet [10]; and *Paladin* sp. related to representatives of subfamily Ditomopyginae Hufé [34] known from the Early Carboniferous to the Middle Permian.

In the Phong Son Formation, arthropod fossils are only discovered in the Tournaisian stage, occupy ~10% total number of taxa (Figure 2c).

5.5. Mollusca

Bellerophon spp. from the Van Xa Member, is related to representatives of family Bellerophontidae McCoy; known from Late Cambrian to Triassic.

Pseudozygopleura sp. is related to representatives of family Pseudozygopleuridae Knight; known from Paleozoic and Mesozoic sediments. It was collected from the Van Xa Member.

Straparollus sp. is related to representatives of family Euompalidae de Koninck; known from Paleozoic sediments. It is collected from the shale beds of the Hien An Member.

Schizodus sp. is related to representatives of family Modiomorphidae Miller; known from Paleozoic and Mesozoic sediments. It is rare in shale beds of the Hien An Member.

In the Phong Son Formation, mollusc fossils are discovered in the Famennian stage, occupy ~10% total number of taxa (Figure 3a); and ~4% in the Tournaisian stage (Figure 2c).

5.6. Bryozoa

Fistulipora sp. is related to representatives of family Fistuliporidae Ulrich known from Ordovician to Permian.

Fenestella sp., *Polypora* sp., *Ptiloporella* cf. *vodoresovi* are related to representatives of family Fenestellidae King

[31] known from Ordovician to Triassic.

Stenopora sp. is related to representatives of family Stenoporidae Waagen et Wentzel [31] known from Devonian to Triassic.

Rhombopora sp. is related to representatives of family Rhabdomesidae Vine [31] known from Ordovician to Permian.

Bryozoan fossils in the Phong Son Formation are only discovered in the Tournaisian stage, occupy ~12% total number of taxa (Figure 2c).

5.7. Brachiopoda

Leptagonia analoga, *Leptagonia* sp.1, *Leptagonia* sp.2 are related to representatives of family Rafinesquinidae Schuchert [2, 4] known from Ordovician to Carboniferous.

Subglobosochonetes sp., *Globosochonetes* sp., are related to representatives of family Anopliidae Muri-Wood [13, 15] known from Tournaisian; and *Rugosochonetes* sp. related to family Rugosochonetidae Muri-Wood [5] known from the Devonian to the Permian.

Semiproductus sp. is related to representatives of family Overtoniidae Muri-Wood & Cooper [5] known from the Late Devonian to the Early Permian.

Plicatifera sp. is related to representatives of subfamily Plicatiferinae Muri-Wood & Cooper [29] known from the Early Carboniferous.

Buxtonia sp. is related to family Buxtoniidae Muri-Wood & Cooper known from the Late Devonian to the Late Permian.

Pugilis sp. is related to representatives of family Dictyoclostidae Stehli [2] known from the Early Carboniferous to the Late Permian.

Schuchertella cf. *oversbyi*, *Schuchertella* sp. A, *Schuchertella* sp. B, and *Serratocrita* sp. are related to representatives of family Schuchertellidae William known from the Devonian to the Permian.

Schellwienella cf. *burlingtonensis*, *Schellwienella* sp. A, *Schellwienella* sp. B are related to representatives of family Pulsiidae Cooper & Grant [2, 4] known from the Devonian to the Permian.

Athyris concentrica, *Athyris* cf. *concentrica*, *Actinoconchus* sp., *Cleiothyridina* sp., *Protathyris* sp. are related representatives of family Athyrididae McCoy known from the Silurian to the Triassic.

Monelasmina cf. *deschayesi*, *Monelasmina* sp. are related to representatives of subfamily Monelasminiinae Happer, 2000 known from the Late Devonian.

Rhipidomella sp. is related to representatives of subfamily Rhipidomellinae Schuchert known from the Silurian to the Permian.

Schizophoria sp.1, *Schizophoria* sp.2 are related to representatives of family Schizophoriidae Schuchert & Le Ven known from the Ordovician to the Permian.

Yunnanella cf. *hanburyi*, *Yunnanella* *ksikwangshaensis*, *Yunnanella* sp. are related to representatives of family Yunnanellidae Rzonnsnikaya known from the Famennian.

Leiorhynchus sp. is related representatives of subfamily Camarotoechiinae Schuchert & LeVene known from the

Silurian to the Permian.

Plectorhyncha perchaensis, *Plectorhynchella* sp. are related to representatives of subfamily Plectorhynchellinae known from the Devonian to the Carboniferous.

Macropotamorhynchus sp. is related to subfamily Trigonirhynchiinae Schmidt known from the Carboniferous.

Cyrtospirifer miculus, *Cyrtospirifer chaoi*, *Cyrtospirifer sinensis*, *Tenticospirifer tenticulum*, *T. cf. vilis kwangsiensis*, *Theodosia anosofi*, *Cyrtopsis* sp., *Uchtospirifer* sp., *Platyspirifer paronai* are related to representatives of family Cyrtospiriferidae Termier & Termier [28, 29] known from the Devonian to the Carboniferous.

Mucrospirifer cf. muralis is related to representatives of family Mucrospiriferidae Pitrat known from the Devonian to the Carboniferous.

Ambocoelia sp. is related to representatives of family Ambocoeliidae George known from the Devonian to the Carboniferous.

Anatrypa sp. is related to representatives of subfamily Atrypinae Gill [28] known from the Silurian to the Late Devonian.

Martinothyris sp. is related to representatives of family Elythridae Frederiks [15] known from the Devonian to the Permian.

Protathyris sp. is related to representatives of subfamily Protathyridinae Boucot, Johnson & Staton [30] known from the Silurian to the Devonian.

Fusella sp., *Brachythyris* sp., *Unispirifer* sp. are related to representatives of family Spiriferidae King [2.13] known from the Carboniferous to the Permian.

Choristites sp. is related to representatives of family Brachythyrididae Frederiks [28] known from the Late Devonian to the Permian.

Syringothyris sp. is related to representatives of subfamily

Syringothyridinae Frederiks known from Late Devonian to the Permian.

Brachiopod fossils are abundant both in the Van Xa Member and in the Hien An Member. In the Famennian stage, they occupy 86% total number of taxa (Figure 2a), and in the Tournaisian stage occupy ~51% (Figure 2c).

5.8. Echinodermata

Glossocrinus cf. whidhomei is related to representatives of family Glossocrinidae Goldring [1] known from the Devonian to the Carboniferous.

Cyclocaudex cf. medius is related to representatives of family Cyclomischidae Moore & Jeffords [3, 9] known from the Devonian to the Carboniferous.

Taranshicrinus sp. is related to representatives of family Taranshicrinidae Sisova [3, 9] known from the Devonian to the Carboniferous.

Cyclocaudiculus cf. varius is related to representatives of family Leptocaphidae Moore & Jeffords [1] known from the Devonian to the Carboniferous.

Cyclocyclicus sp. A, *Cyclocyclicus* sp. B, *Pentagonocyclicus* sp. are related representatives of incerti ordinis known from the Ordovician to the Permian.

Floricyclus sp. is related to representatives of family Floricyclidae Moore & Jeffords [9, 11] known from the Devonian to the Carboniferous.

Stenocrinus sp. is related to representatives of family Stenocrinidae Dubatolova [1, 9] known from the Famennian.

Echinoderm fossils in the Phong Son Formation are chiefly representatives of class Crinoidea J. S. Miller [3, 11]; and dominated in the shale beds of the Hien An Member, occupy ~18% total number of taxa of the Tournaisian stage (Figure 2c).

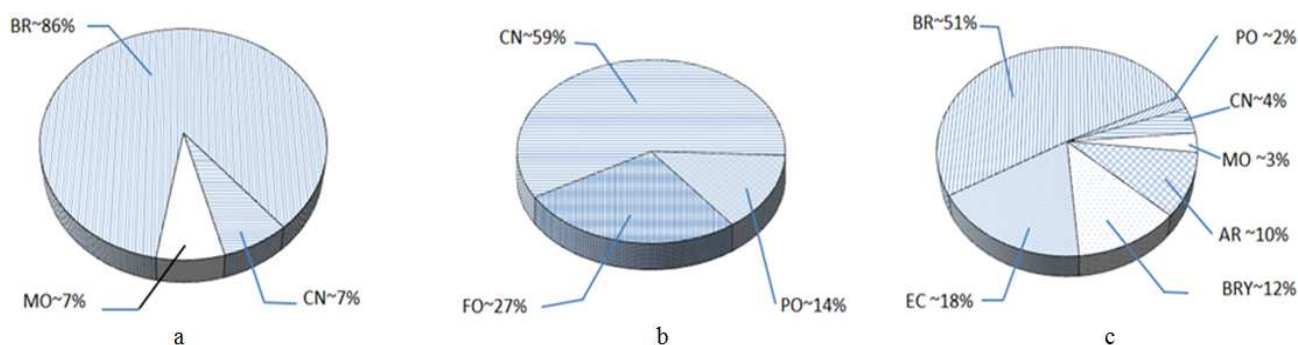


Figure 2. Synthetic diagrams comparing clade generic richness percentage among 3 stages of fossils in the Phong Son Formation: Figure 2a –the Famennian stage; Figure 2b –the latest Famennian-Earliest Tournaisian; Figure 2c –the Tournaisian stage. FO=Foraminifera, PO=Porifera, CN=Cnidaria, AR=Arthropoda, BR=Brachiopoda, BRY=Bryozoa, MO=Mollusca, EC=Echinodermata.

6. Discussions on Biological Crisis at the DCB in the Hien An Member

Presently the Devonian-Carboniferous Boundary (DCB) in the Phong Son Formation are not studied in detail. The DCB may be at the base of the Hien An Member. It is composed of

black-grey, medium to thick-bedded limestone; about 150m thick; exposed in the western rice field of Hien An Village; where, 2 foraminifers (*Septabrusiina kinginica*, *Septatournayella* sp.); 3 stromatoporoids (*Rosenella miniarensis*, *Vietnamostroma vietnamense*, *Pseudolabechia huanjangensis*); 6 cnidarians (*Pseudozaphrentis* sp., *Zaphrentoides* sp., *Cystophrentis kolaohoensis*, *C. roniewiczzeae*, *C. grandis*, *Cystophrentis* sp.); 22 brachiopods

(*Athyris concentrica*, *Athyris* cf. *concentrica*, *Monelasmina* cf. *deschayesii*, *Monelasmina* sp., *Yunnanella* cf. *hanburyi*, *Yunnanella* *ksikwangshaensis*, *Yunnanella* sp., *Leiorhynchus* sp., *Plectorhyncha perchaensis*, *Plectorhynchella* sp., *Cyrtospirifer miculus*, *Cyrtospirifer chaoi*, *Cyrtospirifer sinensis*, *Tenticospirifer tenticulum*, *T.* cf. *vilis kwangsiensis*, *Theodosia anosofi*, *Cyrtopsis* sp., *Uchtospirifer* sp., *Platyspirifer paronai*, *Mucrospirifer* cf. *muralis*, *Ambocoelia* sp., *Anatrypa* sp.); 2 molluscs (*Bellerophon* spp., *Pseudozygopleura* sp.) are disappeared; occupied ~37% total number of taxa of the Phong Son Fm.

7. Discussions on Biological Recovery in the Upper Part of the Hien An Member

The upper part of the Hien An Member is composed of chiefly black shale intercalated with thin to medium-bedded limestone, that exploded in a large hole for the exploitation of limestone (Dong Lam Quarry; Hien Xuan Village, Phong Dien District; 16°31'05", 107°21'24"). Macrofossils are rich in species individual of Brachiopoda: *Schellwienella*, *Schuchertella*, *Leptagonia*, *Plicatifera*, *Buxtonia*, *Pugilis*, *Fusella*, *Brachythyrida*, *Unispirifer*, *Choristites*, *Syringothyris*, *Rugosochonetes*; representatives of Bryozoa: *Fistulipora*, *Fenestella*, *Polypora*, *Ptiloporella*, *Stenopora*, *Rhombopora*; of Trilobita: *Phillipsia*, *Linguaphillipsia*, *Schizophillipsia*, *Paleophillipsia*; of class Crinoidea: *Glossocrinus*, *Cyclocaudex*, *Taranshicrinus*, *Cyclocaudiculus*, *Cyclocyclicus*, *Pentagonocyclicus*, *Floricyclus*, *Stenocrinus*.

4 foraminifers (*Chernyshinella* sp., *Septabrusiina* cf. *kazakhstanica*, *Septabrusiina* *kinginica*, *Septatournayellina* cf. *segmentata*), 1 stromatoporoid (*Clavdictyon* cf. *regulare*); 6 cnidarians (*Syringopora* *reticulata*, *S. geniculata* var. *haiphongensis*, *S. distans*, *Syringopora* sp., *Michelina* sp., *Alveolitidae*?), 5 arthropods (*Archaeogonus* sp., *Phillipsia* cf. *ohmorensis*, *Linguaphillipsia* sp., *Schizophillipsia* sp., *Paleophillipsia* sp.); 2 molluscs (*Straparollus* sp., *Schizodus* sp.); 6 bryozoans (*Fistulipora* sp., *Fenestella* sp., *Polypora* sp., *Ptiloporella* cf. *vodoresovi*, *Stenopora* sp., *Rhombopora* sp.); 27 brachiopods (*Leptagonia analoga*, *Leptagonia* sp.1, *Leptagonia* sp.2, *Subglobosochonetes* sp., *Globosochonetes* sp., *Rugosochonetes* sp., *Semiproductus* sp., *Plicatifera* sp., *Buxtonia* sp., *Pugilis* sp., *Schuchertella* cf. *oversbyi*, *Schuchertella* sp. A, *Schuchertella* sp. B, *Serratocrita* sp., *Schellwienella* cf. *burlingtonensis*, *Schellwienella* sp. A, *Schellwienella* sp. B, *Rhipidomella* sp., *Schizophoria* sp.1, *Schizophoria* sp.2, *Macropotamorhynchus* sp., *Protathyris* sp., *Fusella* sp., *Brachythyrida* sp., *Unispirifer* sp., *Choristites* sp., *Syringothyris* sp.); 9 echinoderms (*Glossocrinus* cf. *whidhomei*, *Cyclocaudex* cf. *medius*, *Taranshicrinus* sp., *Cyclocaudiculus* cf. *varius*, *Cyclocyclicus* sp. A, *Cyclocyclicus* sp. B, *Pentagonocyclicus* sp., *Floricyclus* sp., *Stenocrinus* sp.) are recovered; occupied ~63% total number of taxa in the Phong Son Fm.

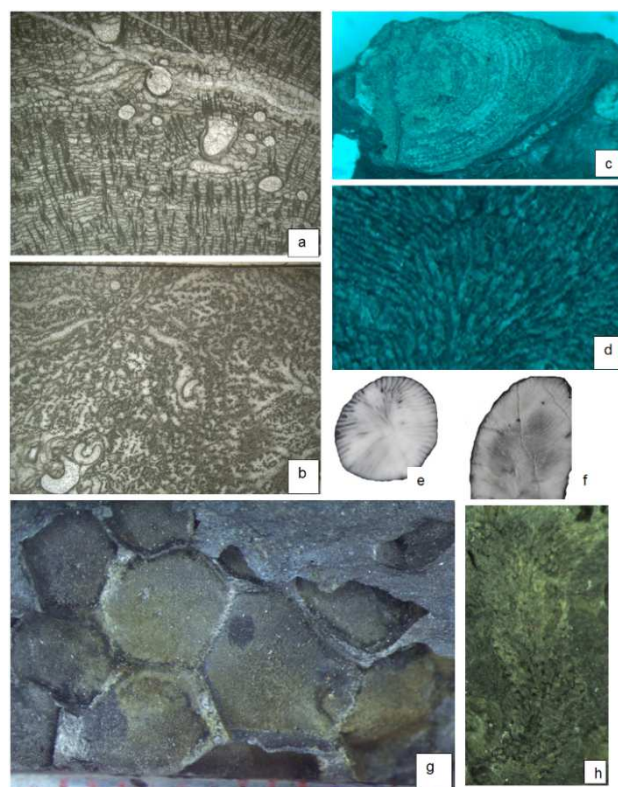


Figure 3. Fossils in the Hien An Member: a, b –*Vietnamostroma vietnamense* Hung, x10; c –*Clavdictyon* cf. *ulare* Dong, x 3; d, h – *Alveolitidae* ?, d x 5, h x 3; e, f – *Cystophrentis* sp., x 1; g – *Michelina* sp., x 7.

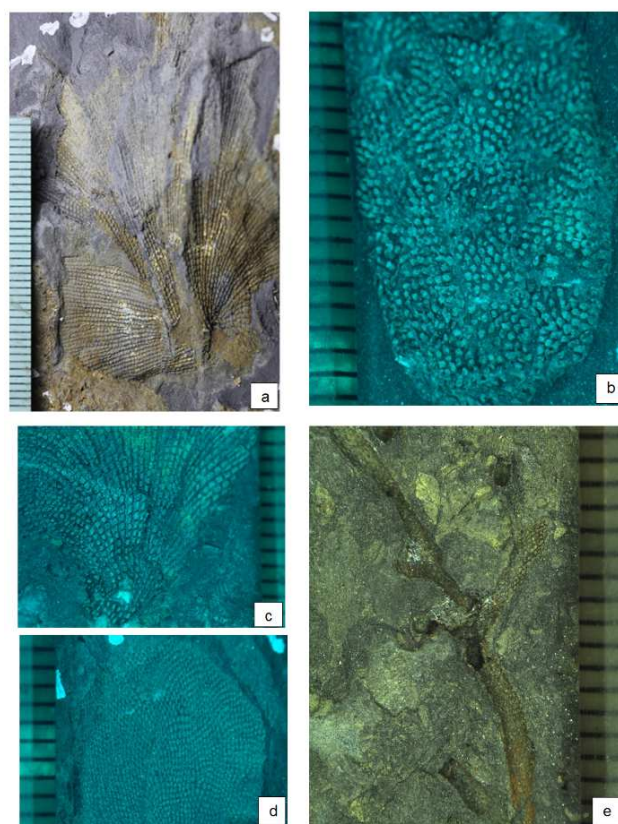


Figure 4. Bryozoan fossils in the Hien An Formation: a – *Fenestella* sp., b – *Rhombopora* sp., c – *Ptiloporella* cf. *vodoresovi* Nekhoroshev; d – *Polypora* sp., e – *Fustulipora* sp..

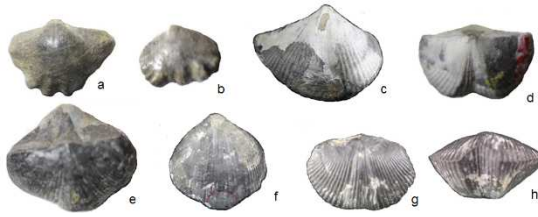


Figure 5. Brachiopod fossils of the Van Xa Member (Famennian): a – *Yunnanella synplicata* Grabau, x 1,5; b – *Yunnanella hanburii* (Davidson) x 1,5; c – *Cyrtospirifer cf. schelonius* Nalivkin, x1,2; d – *Cyrtospirifer chaoi* (Grabau), x 1,5; e – *Uchospirifer nalikini* Liaschenko, x1,5; f – *Tenticospirifer sp.*, x1,5; g, h – *Platyspirifer cf. paronai* (Martelli), x1,5.

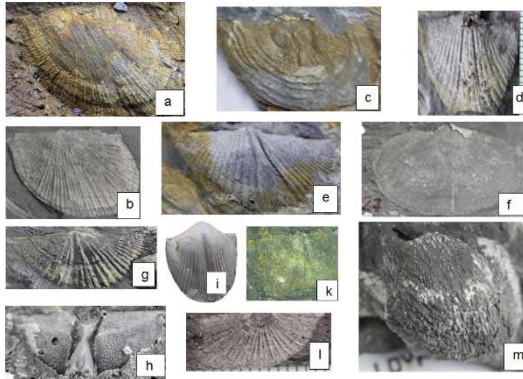


Figure 6. Brachiopod fossils in the Hien An Member: a – *Schellwienella cf. burlingtonensis* Weller, x 1; b – *Schuchertella cf. oversbyi* Qian & Roberts, x 1; c – *Leptagonia analoga* (Phill.), x 1; d – *Fusella sp.*, e – *Unispirifer sp.*, x 1,2; f – *Schizophoria sp.*, x 1,5; g – *Brachythyris sp.* X 1; h – *Syringothyris sp.*, x 1,2; i – *Choristites sp.*, x 1; k – *Rugosochonetes sp.*, x 2; l – *Serratocrista sp.*; k – *Buxtonia sp.*, x 1,2.

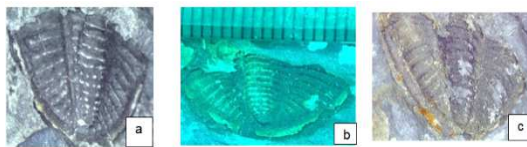


Figure 7. Trilobite fossils in the Hien An Member: a – *Phillipsia cf. ohmorensis* Okubo, x 3; b – *Linguaphillipsia sp.*, x 3; c – *Archaeogonus sp.*, x 3.

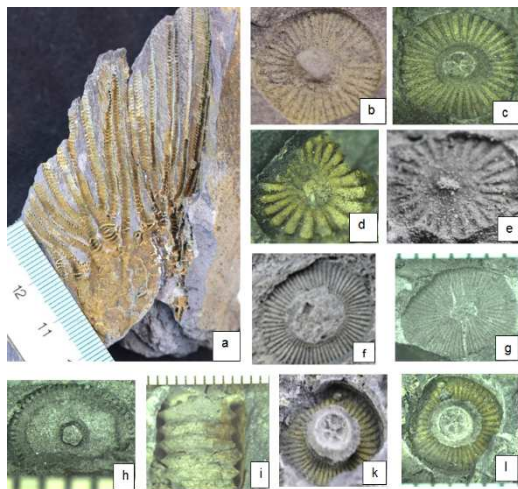


Figure 8. Crinoid fossils in the Hien An Member: a – *Glossocrinus cf. whidhomei* Lane, Maples & Waters; b – *Cyclocaudex cf. medius* Gluchowski, x 5; c – *Taranshicrinus sp.*, x 5; d, e – *Cyclocaudiculus cf. varius* Gluchowski; d x 7, e x 5; f – *Cyclocyclicus spp.*, x 3; g – *Stenocrinus sp.*; h, i – *Pentagonocyclicus sp.* B; k, l – *Floricyclus sp.*



Figure 9. Crinoidea in the shale beds of the Hien An Member.



Figure 10. Crinoid *Glossocrinus cf. whidhomei* Lane, Maples & Waters; mould of calyx, arms and pinules.

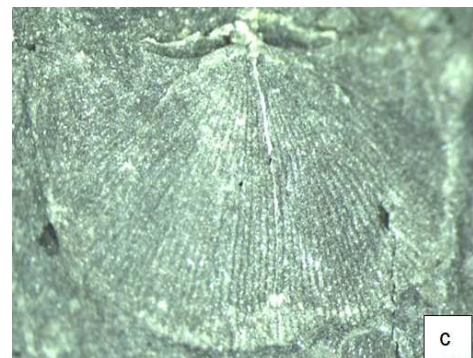


Figure 11. Brachiopod *Rugosochonetes sp.*, x 5.

8. Conclusion

In the Van Xa Member, the biological diversity is well displayed in Brachiopoda, with abundant representatives of genera *Yunnanella*, *Cyrtospirifer*, *Uchospirifer*,

Tenticospirifer, *Platyspirifer*. In the Hien An Member, the representatives of phyla Brachiopoda, Arthropoda, Bryozoa, Echinodermata played a role in recovery and diversity with the presence of genera *Schellwienella*, *Schuchertella*, *Leptagonia*, *Fusella*, *Unispirifer*, *Schizophoria*, *Brachythyris*, *Syringothyris*, *Choristites*, *Rugosochonetes*, *Serratocrista*, *Buxtonia*, *Fenestella*, *Rhombopora*, *Ptiloporella*, *Polypora*, *Fustulipora*, *Phillipsia*, *Archaeogonus*, *Cyrtospirifer*-*Yunnanella* Assemblage. In the Tournaisian stage, the diversity and recovery is related to representatives of Porifera, Cnidaria, Arthropoda, Brachiopoda, Bryozoa, Mollusca, and Echinodermata belonging to the *Leptagonia*-*Phillipsia* Assemblage. The crisis at DCB is related to brachiopod, stromatoporoid, rugose representatives with completely disappearance of genera *Yunnanella*, *Cyrtospirifer*, *Uchtospirifer*, *Tenticospirifer*, *Platyspirifer*, *Vietnamostroma*, *Cystophrentis*.

Acknowledgements

This work is supported by Vietnam Academy of Science and Technology for the project of “Paleontological collection on Vietnam territory”, coded BSTMV 28/15-18; to whom we sincerely acknowledge.

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