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Stratigraphic Order in the Sung Village-Len Bac Mountain Section, Yen Hoa Commune, Minh Hoa District, Quang Binh Province, North-Central Vietnam

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Abstract: The Sung-Len Bac Mountain Section is one of the best section to study stratigraphy and paleontology of the Middle-Upper Devonian, Lower Carboniferous to Middle Permian sediments in North-central Vietnam, including formations in the ascending order: The Dong Tho Formation ($D_{2\text{-}3}$ *dt*) is composed of silstone and quartz sandstone, 250m thick containing fish *Bothiolepis* sp, brachiopod? *Holynetes caurongensis*, tentaculite *Homoctenus* sp, plant *Lepidodendropsis* sp. of the Late Givetian-Early Frasnian. The Xom Nha Formation is composed of stylolitic limestone, 20m thick containing conodonts of the *Palmatolepis glabra* Zone of the Famennian age. The La Khe Formation is composed of silstone, shale, sandstone, cherty limestone bearing abundant crinoids, brachiopods, ammonoids, trilobites, plants of the Viséan age. The Muong Long Formation is composed of thick-bedded limestone over 1000m thick, containig foraminifers *Millerella*, *Eostafella*, *Quydatella*, *Fusulinella*, *Obsoletes*, *Triticites*, *Schwagerina*, *Robustoschwagerina*, *Misellina*, *Neoschwagerina*; and brachiopod *Phricodothyris asiatica* of the Carboniferous-Middle Permian age. An abundant fossil assemblage of plants *Archaeocalamites* sp., *Sigillaria* sp., *Lepidodendron* sp. associated with brachiopods *Plicatifera* sp., *Chonetes* sp., *Lingula* sp.; bivalve *Mytilarca* sp.; ammonoids *Sulcogirtyoceras* cf. *limatum*, *Neoglyphioceras* sp.; trilobites *Linguaphillipsia* cf. *subconical*, *Phillipsia propiqua* of nearshore facies has been found in the upper part of the La Khe Formation by the Hanoi Fossil Museum in 2022.

Keywords: Stratigraphy, Paleontology, Dong Tho, Xom Nha, La Khe, Muong Long Formations, North-Central Vietnam

1. Introduction

The Sung Village-Len Bac Mountain Section, Yen Hoa Commune, Minh Hoa District, Quang Binh Province (Figure 1) about 7km north of Quy Dat Town, Minh Hoa District containing sediments and paleontological data of the Dong Tho, Xom Nha, La Khe and Muong Long formations have been reported in previous studies by Mareichev A. M., Tran Duc Luong [6], Le Hung [7, 14, 43]; Nguyen Huu Hung [22-28]; Nguyen Quang Trung, Nguyen Phu Vinh, Pham Huy Thong [29]; Nguyen Van Hoanh, Nguyen Doa, Pham Huy Thong [30]; Racheboeuf P. R., Ta Hoa Phuong, Nguyen Huu Hung, Feist M., Janvier Ph. [35]; Ta Hoa Phuong, Nguyen Huu Hung [37]; Tran Tinh *et al*. [39, 40], Nguyen Van Liem [31-33], Le Hung [7, 14, 44]. However, the stratigraphic relation and boundaries between them also the name for carbonate successions of the Carboniferous-Middle Permian age always are debate topics and questions for discussions [6, 12, 13, 20, 21, 31-33, 39, 40, 41, 43, 45]. This study focuses on the analysis of stratigraphy in ascending order of the section and paleontological assemblages newly discovered in siltstone, sandstone of the uppermost member of the La Khe Formation. The stratigrphic nomenclature for limestone sequence of the Carboniferous -Middle Permian age exposed around Quy Dat Town also discussed in this paper.

Aim of the paper to be clear stratigraphic order of the Devonian-Carboniferous formations, the stratigraphic nomenclature and contribution of the paleontologic data to the La Khe Formation. Biostratigraphic methods are applied

for study. The Bac Son Formation of the Carboniferous-Middle Permian is considered as an invalid name of lithostratigraphc unit, cannot be apply for stratigraphic division in North-central Vietnam.

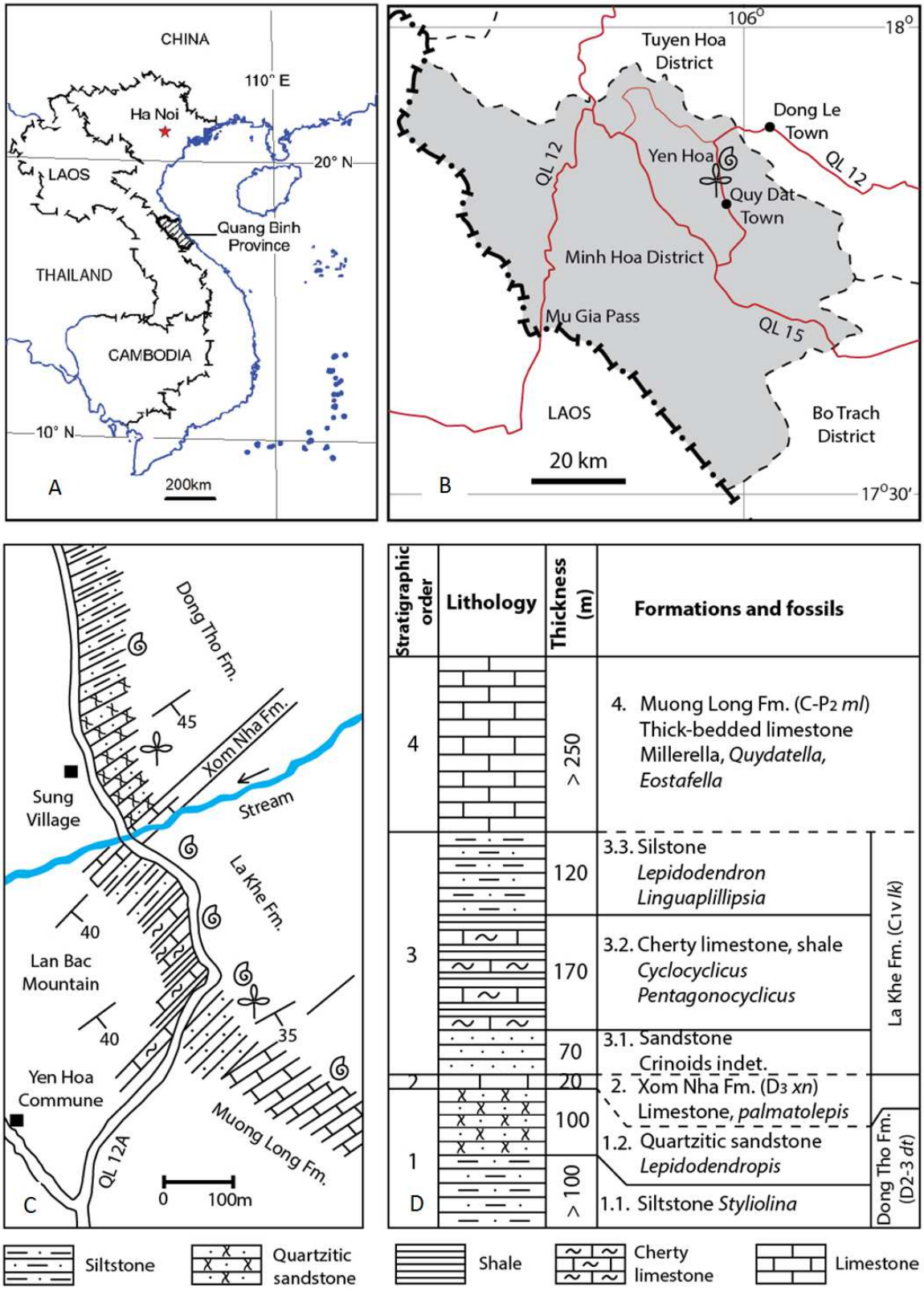

Figure 1. *A -Map shows the position of Quang Binh Province in Vietnam map, B -Position of the section for study, C -Sedimentary distribution and fossil localties, D -Stratigraphic column and fossils of the Midle-Upper Devonian, Lower-Middle Carboniferous sediments in the Sung Village-Len Bac Mountain Section, Yen Hoa Commune, Minh Hoa District, Quang Binh Province, North-central Vietnam mentioned in the text (By Nguyen Huu Hung, Nguyen Ba Hung 2022).*

2. Geological Setting

Four stratigraphic units of the Middle-Upper Devonian and Lower Carboniferous to Middle Permian sediments have been established in North-central Vietnam. The Dong Tho Formation was first described by Mareichev A. M. and Tran Duc Luong. in Dovjikov A. E. *et al*. [6] based on the stratotype in the Dong Tho Mountain, Chuc A area, Huong Khe District, Ha Tinh Province. The formation is characterized by black shale, grey quartz sandstone containing brachiopods *Atrypa reticularis*, *Spinulicosta spinulicosta*, *Stropheodonta* sp., *Schizophoria* sp.; bivalves *Mytilarca* sp., *Nucula* sp.; bryozoans *Fenestella* sp., *Senicoscinium* sp., algae *Sycidium*. The formation dated as the Frasnian in age, with total thickness of 800m, overlying conformably upon the Givetian -Frasnian sediments. The Xom Nha Formation established by Nguyen Huu Hung in Le Hung *et al*. [14] on the basis of stratotype in Xom Nha Hamlet (presently Cay Da Hamlet) 2,7km western from Quy Dat Town, Xuan Hoa Commnue, Minh Hoa District, Quang Binh Province, composing of two members: The Lower member is composed of light grey, medium-bedded limestone, 70m thick; yielding abundant stromatoporoids *Stachyodes costulata*, *S. angulata*, *S. parallelloporoides*; corals *Scoliopra denticulata*, *Thamnopora polyforata*, *Temnophyllum isetense*, and conodonts of the *Palmatolepis gigas* Zone [22]. The Middle member is composed of dark grey limestone, 10m thick containing abundant conodonts of the *Palmatolepis triangularis* Zone; crinoids *Devonovicrinus* sp., *Tjeecrinus* sp.; gastropods *Euryzone* sp., *Humboldtiella* sp. The upper member is composed of light grey, stylolitic limestone, 200m thick; containing abundant conodonts of the *Palmatolepis glabra* Zone. The La Khe Formation bears the name of the La Khe Railway Station near the boundary between Ha Tinh and Quang Binh provinces (18°04'30", 105°48'30") was proposed by Mareichev A. M. and Tran Duc Luong [6]; where located stratotype of the formation. Its lithologic components are composed mainly of sandstone, siltstone, shale and limestone lens containing brachiopod, crinoid, coral and foraminiferal fossils of the Viséan age with total thickness 500-600m. The Muong Long Formation was established by Nguyen Van Hoanh, Nguyen Doa, Pham Huy Thong [29] for the Geological map 1:200.000, Song Ca Sheet in the western areas of Nghe An Province, North-central Vietnam. The stratotype of the formation is composed of mainly grey thick-bedded limestone, 700-800m thick; exposed in Muong Long Commune, Ky Son District, Nghe An Province, containing the foraminiferal zones *Millerella*, *Profusulinella*, *Fusulinella*, *Obbsoletes*, *Tricites*, *Schwagerina*, *Robustoschwagerina*, *Misellina*, and *Neoschwagerina*.

3. Methods and Materials

The biostratigraphic methods applied for collections of paleontological samples. All materials sampled by geology tools in the field works from the siltstone, shale and cherty limestone just following stratigraphic order from the lowermost bed to the highest one. After that samples coved by soft materials such as cotton wool, toilet paper and notification. With soft samples, can be used glue for stone to stone covering on surface of sample (in Vietnam, the super glue 502 is always used for this work). In the laboratory, paleontological samples processed by geology tools and Air Scriber. All paleontological samples photographed by Leica Microscope Camera IC90E, and CanonEOS60D with macro lenses 100mm. About 100 fossil and lithologic examples have been collected from the La Khe Formation at the Sung Village-Len Bac Mountain Section and housing at the Hanoi Fossil Museum, VMT Building, No 1, Lane 82, Duy Tan Street, Hanoi City, Vietnam.

4. The Sung Village-Len Bac Mountain Section

Sediments of four stratigraphic units cited about are recognized in the Sung Village - Len Bac Mountain Section, along the National Highways named QL12A, SE direction to Quy Dat Town (Figures 1B, C), from the bottom to the top of the section is as follows:

4.1. Dong Tho Formation (D_{2-3} dt)

Sediments of the Dong Tho Formation exposed on this section with the presence of two members (Figures 1C, D):

Member 1.1. Red-brown weathering siltstone of 150m thick rests conformably upon the limestone of the Quy Dat Formation (D_2gv *qd*) [7] or the Muc Bai Formation (D_2gv *mb*) [39-45]. In a lowermost bed of Member 1.1, Nguyen Huu Hung [35] discovered some fish remains that were described by Janvier Ph. [35] as *Bothriolepis* sp. Many brachiopods belonging to suborder Chonetidina have been collected; one of them is *Holynetes caurongensis* n. sp. described by Racheboeuf P. [35], and *Megachonetes* sp. identified by Nguyen Dinh Hong [29]. Other fossils: *Homoctennus* sp., *Styliolina* sp., *Costulatostyliolina* (Tentaculita); *Pterinopecten lanshaensis*, *Pterinopecten* sp. (Bivalvia); *Sycidium haikouensise*i (Charophyta) have been found [35].

Member 1.2. Belonging to the upper part of the Dong Tho Formation, composed of mainly quartzitic sandstone intercalated with some siltstone layers, 100m thick. Some plants of genus *Lepidodendropsis* (Lycopodiophyta) have been found in it. Age of the formation on the basis of paleontology dated the Late Givetian-Early Frasnian.

4.2. Xom Nha Formation (D_3 xn)

The Xom Nha Formation in this section is recognized by a bed of stylolitic limestone of 20m thick. It occurs in a small stream across the National Highways Ql12A, insert between the Dong Tho Formation underlying and the La Khe Formation overlying. Many conodonts *Palmatolepis glabra glabra*, P. glabra *pectinata*, *Polygathus* sp., *Hidodeolla* sp., *Nothognathella* sp. of the Late Famennian age [14, 22] have

been found. We suggest it is a tectonic contact.

4.3. La Khe Formation (C_1v lk)

Lower Member is composed of well sorted, light-grey quartz sandstone intercalated with pinkish-grey sandstone, 70m thick, very poor paleontologic remaints.

Middle Member is composed of grey thick-bedded cherty limestone intercalated with black shale of 170m thick. The cherty limestone beds at bottom of this member contain abundant crinoid stems of 2-3mm diameter, forming stone structure resemble natural granitic rocks; while at the top of member 2 exposed thick-bedded cherty limestone containing abundant crinoid stems of 5-7mm diameter of *Cyclocyclicus* sp., *Pentagonocyclicus* sp., *Moscovicrinus* sp.; foraminifers *Plectogyra* sp., *Parathurammina* sp., Textulariida; some solitary corals, brachiopods undetermined. The black thin-bedded shale contains brachiopods *Rugosochonetes* sp., *Plicochonetes* sp., *Punctospirifer* sp.

Upper Member is composed of mainly pinkish-grey siltstone with some interbeds of yellow medium-grained sandstone, 120m thick. The abundant fossil assemblages of plants *Archaeocalamites* sp., *Sigillaria* sp., *Lepidodendron* sp. associated with brachiopods *Plicatifera* sp., *Chonetes* sp., *Plicochonetes* sp., *Schellwenella* sp., *Productus* sp., *Camarophoria* sp., *Lingula* sp.; bivalve *Mytilarca* sp.; ammonoids *Sulcogirtyoceras* cf. *limatum*, *Neoglyphioceras* sp.; trilobites *Linguaphillipsia* cf. *subconica*, *Phillipsis propiqua* of the Late Viséan age has been found. The La Khe Formation underlies the Muong Long Formation in the ascending order with not clear contact, it seems a tectonic contact.

Figure 2. *The fossil assemblages in the Upper part (Member 3.3) of the La Khe Formation: A –Plant Archaeocalamites sp., B –Plant Sigillaria sp., C –Plant Lepidodendron sp., D –Ammonoid Sulcogirtyoceras cf. limatum., E -Brachiopod Chonetes sp., F -Brachiopod Lingula sp., G -Bivalve Mytilarca sp., H –Trilobite Linguaphillipsis cf. subconica, x 5; I –Trilobite Phillipsia propinqua, x 5.*

5. Muong Long Formation (C-P_2 *ml*)

The thick-bedded limestone sequence well exposed at the end of the section with about over 1000m thick, forming a mountain range at the southeast side of Quy Dat Town. Macrofossils are composed of *Spirifer* cf. *bisulcatus*, *Chonetes praecarboniferus*, *Reticularia lineata*, *Antiquatonia* aff. *hindi*, *Gigantella* (?) sp., *Phricodothyris asiatica* (brachiopods); *Cyclocyclicus* sp., *Pentagonocyclicus* sp (crinoids), and some solitary corals undetermined. Microfossils are composed mainly of foraminiferal zones *Millerella*, *Eostafella*, *Quydatella*, *Fusulinella*, *Obsoletes*, *Triticites*, *Schwagerina*, *Robustoschwagerina*, *Misellina*, and *Neoschwagerina* [7, 14, 31, 32, 44].

6. Discussions and conclusions

6.1. Stratigraphy

The presence of the Dong Tho Formation in the Sung Village-Len Bac Mountain Section is considered as parastratotype in the Truong Son Zone [6, 24, 25], although its thickness less than that in the Dong Tho Mountain, but its fossils assemblages showing clearly the Late Givetian-Early Frasnian age. The lower boundary of the formation is very clear, conformable upon the bed containing brachiopods Emanuella takwanensis, E. haugi, Atrypa (Desquamatia) ventricosa, Spinatrypa quydatensis; corals Thamnopora polygonalis, T. nicholsoni, Pseudogrypophyllum stenotabulatum, Temnophyllum isetense; stromatoporoids Actinostroma bifarium, Stachyodes radiata, Idiostroma quydatensis, Vacuustroma *minuta* of the Late Givetian age of the Quy Dat Formation [7] or Muc Bai Formation [23, 25, 39-44].

The presence of the Xom Nha Formation is very restricted, only one bed of stylolitic limestone of 20m thick, exposed along a small stream across the National Highways QL12A. This limestone bed inserted between the Dong Tho Formation underlying and La Khe Formation overlying. Fossil conodonts have found in this bed showing the Famennian age [23, 24, 37]. So, it is correlated to the upper part of the Xom Nha Formation (D_3 *xn*).

The La Khe Formation in North-central Vietnam has studied early. It was first investigated by Deprat J. [2] named "Schistes marneux de Bai Duc à *Phillipsia propinqua*" in Bai Duc area, Tuyen Hoa District; Fromaget J. [9] named "Schistes de La Khè à *Phillipsia gemmulifera* et *Chonetes comoides*" in the La Khe Railway Station area, Huong Khe District, Ha Tinh Province. The name of La Khe Formation was used by Mareichev A. M. and Tran Duc Luong in Dovjikov A. E. *et al*. [6] for the Geological map 1:500.000, North Vietnam in the Truong Son Zone. At present, the name "La Khe Formation" of the Viséan age is used rather widely in the stratigraphic, geologic works in Vietnam [4, 6, 7, 10, 12-14, 20, 21, 28, 39, 40, 41, 43] but the upper boundary of the formation is still a question? There are much viewpoints of this boundary: unconformity underlying the "Undivided upper Paleozoic sediments of the Middle Carboniferous-Permian age" by Mareichev A. M. and Tran Duc Luong in Dovjikov A. E. [6]; unconformity underlying the "Limestone containing corals, brachipods and foraminifers *Danella*, *Endothyranopsis*, *Millerella*, *Profusulinella*, *Obsoletes*, *Triticites*, *Schwagerina*, *Fusulinella* of the Namurian age to the Asselian age by Nguyen Van Liem and Le Hung in Duong Xuan Hao [7]; unconformity underlying the Song Nan and Huoi Ren formations (Carboniferous-Permian) by Le Hung [14], Le Hung in Vu Khuc [45], Le Hung in Vu Khuc, Bui Phu My [43]; conformity underlying the Muong Long Formation by Nguyen Van Hoanh, Nguyen Doa, Pham Huy Thong [30]; conformity underlying the Bac Son Formation by Tran Tinh *et al*. [39, 40]; Doan Nhat Truong in Tran Van Tri, Vu Khuc [41]; conformity underlying the Da Mai Formation by Tong-Dzuy Thanh, Nguyen Duc Khoa in Vu Khuc [45]; Tong-Dzuy Thanh [42]. We suggest that the section of uppermost member of the La Khe Formation in the Len Bac Pass is regressive type, so we agree with the viewpoint of Mareichev A. M. and Tran Duc Luong [6].

The stratigraphic nomenclature for limestone sequence of Carboniferous-Middle Permian in North-central Vietnam always is a debate topic for discussions. This limestone sequence is first described by Mareichev A. M. and Tran Duc Luong in Dovjikov A. E. [6] under the name "Undivided upper Paleozoic sediments of the Middle Carboniferous-Permian age", sea-covered advance upon the La Khe Formation. In later stratigraphical, geological works, this limestone sequence described under the different names. Nguyen Van Liem [7, 32, 33] established "the Bac Son Series " in order to replace the terms "Uranopermians", "Upper Paleozoic", "Anthrocolithic", "Middle Carboniferous-Permian", "Productus limestone", "Fusulinids limestone", "Undivided upper Paleozoic sediments of the Middle Carboniferous-Permian age" that were used in Indochina by French [3, 5, 8, 15-19], Tran Thi Chi Thuan [38] and Russian [6]. Nguyen Van Liem [7, 32, 33] has given a criteria for the "Bac Son Series" as following: Lithologic component is composed of limestone, dolomitic limestone intercalated with sandstone argillite silicon at the bottom and sandstone argillite bauxite bearing silicon or coal in the upper part, 1500-2500m thick. Twelve foraminiferal horizons in ascending order: *Dainella*, *Endothyranopsis*, *Millerella*, *Profusulinella*, *Fusulinella*, *Obsoles*, *Triticites*, *Schwagerina*, *Robustoschwagerina*, *Misellina*, *Neoschwagerina*, *Paleofusulina* showing from the Viséan Stage of Lower Carboniferous to the Djunfian Stage of Upper Permian, with a stratigraphic interrupt between the *Neoschwagerina* and *Paleofusulina* horizons. In later studies, the Bac Son Series were considered as a formation (the Bac Son Formation), and has been used rather largely in geological mapping 1:200.000, 1:50.000 of North Vietnam by the General Department of Geology and Minerals of Vietnam. We suggest that both the Bac Son Series of Nguyen Van Liem [7, 32, 33] and the Bac Son Formation which recently using in geological mapping in Vietnam cannot be corresponded to any lithostratigraphic unit in the International Stratigraphic Code, so it should be an invalid stratigraphic unit. Tong-Dzuy Thanh, Nguyen Duc Khoa in Vu Khuc [45]; Tong-Dzuy Thanh [42] proposed "the

Da Mai Formation" sensu Nguyen Xuan Bao [34] replacing the Bac Son Formation for much reasons (see Tong-Dzuy Thanh, Vu Khuc *et al*. 2011, p. 228). Le Hung in Vu Khuc [44] proposed the Song Nan Formation of Carboniferous age and the Huoi Ren Formation of Permian age for the limestone sequence of Caboniferous-Middle Permian exposed around Quy Dat Town. We suggest that both formations established by Le Hung on the basis of foraminiferal zones, so do not applied for the division of lithostratigraphic units. The Da Mai Formation established by Nguyen Xuan Bao [34] in the Geological map 1:200.000, Van Yen Sheet is composed of both the Upper Devonian sediments and Carboniferous-Permian one, so do not use for stratigraphic division of the Upper Paleozoic in North-central Vietnam. Here we use the Muong Long Formation established by Nguyen Van Hoanh, Nguyen Doa, Pham Huy Thong [30] for stratigraphic division of the limestone sequence of the Carboniferous-Middle Permian age in the Sung Village-Len Bac Mountain Section.

6.2. Paleontology

A part of paleontological data including trilobites, foraminifers, brachiopods, stromatoporoids, algae from the Dong Tho, Xom Nha, La Khe, Muong Long formations have been described by Deprat J.[2], Fromaget J. [9], Nguyen Van Liem [31], Nguyen Huu Hung [22, 23, 26], Nguyen Huu Hung in Vu Khuc [44]; Janvier Ph. [35], Racheboeuf P. [35]. They are reliable documentations; other fossils such as plants, tentaculites, crinoids, conodonts, ammonoids only identified, but not described.

The fossil assemblages from the uppermost part of the La Khe Formation (Member 3.3) is one of the highlights of paleontology. The plant assemblage includes representatives of three genera: *Lepidodendron* also known as "scale tree" (Figure 2C) is one of the most abundant trees of the Carboniferous period; it lived in some of the wettest parts of the prehistoric coal swamps and commonly grew in dense stands. *Archaeocalamites* (Figure 2A), the genus is characterized by its Calamites-like axis, in which the longitudinal ribs pass directly across the nodes, known from the Givetian to the Early Permian. *Sigillaria* (Figure 2B) is known from the Middle Devonian to the Early Permian. The ammonoid assemblage includes *Sulcogirtyoceras* cf. *limatum* (Figure 2D), *Neoglyphioceras* sp. known from the Late Viséan age. The brachiopod assemblage includes *Plicatifera* sp., *Chonetes* sp. (Figure 2E), *Plicochonetes* sp., *Schellwenella* sp., *Productus* sp., *Camarophoria* sp., *Lingula* sp. (Figure 2F) showing the Viséan age in general. The trilobite assemblage is composed of *Linguaphillipsia* cf. *subconica* (Figure 2H), *Phillipsia propiqua* (Figure 2I). The first species was described by Kobayashi and Hamada [11] from the Lower Carboniferous in Japan, the secondary was described by Deprat J. [2] from the Viséan shale in Bai Duc area, Tuyen Hoa District. One bivalve genus *Mytilarca* (Figure 2G) known largly from the marine Paleozoic sediments. In summary, we suggest the member 3.3 of the La Khe Formation belonging to the Late Viséan age.

6.3. Paleogeography

We consider the Dong Tho Formation belonging to a regressive cycle. The siltstone rocks containing fishes, brachiopods, tentaculites of open-sea facies to quartzitic sandstone bearing plants of nearshore facies. The Xom Nha Formation belonging to marine transgressive cycle. Reef limestone contains the biota of stromatoporoids, corals of carbonate platform to stylolitic limestone containing the biota of conodonts of deep marine facies.

Stratigraphic order of the La Khe Formation in the section cited above: the bottom is represented by quartz sandstone of littoral facies. The facies become deeper at the middle part characterizing by shale and limestone containing brachiopods, crinoids, corals, foraminifers of reef biota. The top of formation is represented by siltstone and sandstone containing abundant plants and brachiopods *Lingula* of nearshore facies. The plant assemblages of continental facies associated with marine animals are very interesting questions for paleogeoraphy of the Carboniferous period in Vietnam's territory. We suggest that in the Viséan time, near Quy Dat Town there have been appearances of an old small continent or an old island; the plant fragments from this land slid down coastal area. On other hand, the precence of brachiopod *Lingula* in the Member 3; although no big deal in the geological ageing, but it is regarded as an indicator of delta and very nearshore environments. The Muong Long Formation is characterized by grey thick-bedded limestone of over 1000m thick with abundant fossils of Foraminifera, Brachiopoda, Bivalvia, Crinoidea, Coralla of carbonate platform facies. The presence of the Muong Long Formation is not only around Quy Dat Town, but also in the western areas of Nghe An Province, in Thanh Hoa, Ha Tinh, Quang Binh provinces; and it can be correlated with those in adjacent regions on territory of Laos and South China. We suggest that, the Muong Long Formation belonging to a largest marine transgression in the Carboniferous-Permian time, not only in Vietnam, but also in Indochina and South China.

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