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On some significant unconformities in the Paleozoic and Mesozoic stratigraphy of North Viet Nam

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Abstract. A lot of unconformities and stratigraphic gaps have been discovered in the Paleozoic and Mesozoic stratigraphy of Bac Bo region (North Viet Nam), but their role in the regional geology was not accessed yet in detail. This paper is the first attempt to describe the most significant unconformities and stratigraphic gaps and discussing their role in regional geology. The most important is the angular unconformity of Norian-Rhaetian formations upon various formations of different formations; it marked the change tectonic regime of the region resulting from the indosian orogeny in Viet Nam and in Southeast Asia in common. The gap of Lower Devonian red beds formations (Si Ka Formation, Song Cau Group) upon Lower Paleozoic formations (Upper Cambrian - Than Sa Formation, Lower Ordovician - Lutxia and Na Mo formations) is a regional unconformity, which had been taken place in the epicaledonian terranne of South China and North East of Viet Nam. The gap between the Da Mai Formation and the Dong Dang Formation was a result of a crust rising, but was not through the orogeny activity, although after this gap the structural plan was more differentiated. Other unconformities and stratigraphic gaps seems to be local unconformities, for instance, the one of the Tan Lap Formation (D_2g-D_3 fr *tl*) upon the Ban Pap Formation (D_1p-D_3 fr *bp*) and the unconformity between the Sinh Vinh (O_3-S *sv*) and the Ben Khe (ε-O_1 *bk*) formations.

Keywords: Unconformity; Stratigraphy; Paleozoic; Mesozoic.

1. Introduction

A lot of unconformities and gaps have been described in Paleozoic and Mesozoic stratigraphy of North Viet Nam. From the unconformities and gaps in combination with the facies of underlying and overlying formations geologists can draw the first step for interpretation of their role in the geological development of the region. Although the explaination of the geological development of a region requires data from different geological domains, for instance facial analyses, magmatic activities, tectonical framework etc., the stratigraphic relations (unconformities and gaps or hiatus) play an important role in dealing with this question. This paper is an attempt to design an approach to understand the role of some stratigraphic gaps, hiatuses, and unconformities in the geological development of the country.

The Norian angular unconformity had taken shape during the indosinian orogeny, and has been well-known in the geology of Viet Nam and in Southeast Asia. However, there are a lot of described unconformities and stratigraphic

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gaps in the geology of the country have not yet been assessed, although they play an important role in the interpretation of geological history of the territory. For instance, the gap between Lower Devonian and Lower Paleozoic formations in the stratigraphic sequence of North Bac Bo (Ha Giang, Lang Son, and Thai Nguyen provinces) is a big stratigraphic event in the region. This gap together with the large distribution of Lower Devonian red beds is an obvious evidence of the influence of the Caledonian orogeny. Contrary to the conception of many geologists, in the area of the Da River basin (West Bac Bo region) a gap between Devonian and its underlying formations is not observed. Here the Silurian and Devonian formations are characterized by the continuous sequence from Sinh Vinh Formation (O_3-S *sv)* to Bo Hieng (S_2 *bh*) and Song Mua formations (D_1 *sm*). The stratigraphic sequence proves that the Da River basin was not influenced by the Caledonian orogeny, which occurred in pre-Devonian period.

This paper is the first attempt to describe the most significant unconformities and stratigraphic gaps, and to discuss their role in regional geology.

2. Paleozoic unconformities and gaps

2.1. Numerous unconformities and gaps were described in the Paleozoic of the Bac Bo region

Thanks to the geological mapping of different scales and thematic stratigraphic studies, a lot of unconformities and stratigraphic gaps in Paleozoic of Bac Bo have been discovered and described. Among them, the following unconformities and stratigraphic gaps can be listed:

The unconformity of the Cam Duong Formation ($\mathcal{E}_1$ *cd*) *upon the Da Dinh Fm.* (PR_3 *dd*): this stratigraphic relation can be followed along the contact between these two formations extending from Lang Phoi to Da Dinh villages.

The unconformity of the Song Ma Formation ($\mathcal{E}_2$ *sm*) *upon the Nam Co Fm.* (PR_3-$\mathcal{E}_1$ *nc*): The unconformity of the Song Ma Formation ($\mathcal{E}_2$ *sm*) upon the Nam Co Formation (PR_3-$\mathcal{E}_1$ *nc*) can clearly be observed in the Suoi Toi Section (Thanh Hoa Province), Ban Nam - Ban Thay, Ban Mo sections, in the upper course of the Ban Pha Stream (Chieng Pac Commune, Thuan Chau District, Son La Province), in the Na Huong - Na Vien Section, and on Sam Co Pass (Km No.18 - Km No.21 on the road from Mai Son to Song Ma).

The gap between An Phu (NP-$\mathcal{E}_1$ *hg*) *and Ha Giang* ($\mathcal{E}_2$ *hg*) *formations*: The first gap in Lower Paleozoic in the northeast of Bac Bo is observed in the sequence between the Song Chay Group (An Phu Formation) and the overlying Ha Giang Formation that occurs in some sections in Ha Giang Province.

The unconformable relation between the Sinh Vinh (O_3-S s*v) and the Ben Khe* ($\mathcal{E}$-O_1 *bk*) *formations:* This unconformity with basal conglomerate in the bottom of the Sinh Vinh Formation is well exposed in many localities such as Ban Cang, Sinh Vinh Mouth, Ban Ban, and Suoi Nhap Stream (lower section of the Da River basin).

The unconformity of the Lower Devonian upon Lower Paleozoic formations is expressed in the stratigraphic relation of the Si Ka Formation (D_1 *sk*), Song Cau Group (D_1 *sc*) with the underlying formations such as Lower Ordovician Lutxia Formation in Dong Van District (Ha Giang Province), Upper Cambrian Than Sa Formation in Than Sa area (Thai Nguyen Province) and Ha Lang District (Cao Bang Province). The Si Ka Formation belongs to the red continental facies, and its lithological composition and color have led many geoscientists to correlate it with the "Old Red Sandstone" lying at the base of the Devonian System.

The unconformity between Tan Lap (D_2g-D_3 fr *tl*) *and Ban Pap formations* (D_1p-D_3 fr *bp*) is an

interesting unconformity, in which the tongue-shape Tan Lap Formation wedges within the Ban Pap Formation.

The unconformity of the Nam Pia Formation (D_1 *np*) *on Sinh Vinh* (O_3-S *sv*) *and Dong Son* (O_1 *ds*) formations: This stratigraphic relation between Lower Paleozoic and Lower Devonian is expressed in the northeastern side of the Song Ma structure only - in the upper basin of Da River and in the lower basins of the Ma River (West Bac Bo).

The unconformity of the Toc Tat Formation (D_3-C_1fr *tt*) *upon the Lung Nam* (C_1 *ln*) *Formation* occurs in Ha Lang area only, where these formations are exposed.

The unconformity of Upper Permian upon the Da Mai Formation (C_1-P_2 *dm*) has been observed in almost all sections where these formations are exposed.

In the Mesozoic stratography of Bac Bo, many unconformities have been noted, but the most interesting is the Norian-Rhaetian upon formations of different ages. It is a regional unconformity and its important role in the geology not only in Bac Bo, but also in geology of Viet Nam and of Southeast Asia in general.

The most significant unconformities and stratigraphic gaps and their role in the geology of Bac Bo will be presented and discussed in the following sections.

2.2. Unconformity of the Lower Devonian upon Cambrian and / or Ordovician formations

The first regional unconformity has been discovered between Lower Devonian and Cambrian and / or Ordovician formations in the northeastern region of Bac Bo (Ha Giang, Cao Bang, Lang Son, and Thai Nguyen provinces). It is well expressed by the sequence of the Lower Devonian Si Ka Formation (D_1 *sk*) and the underlying formation in many sections in Dong Van District (Ha Giang Province). In all these areas the Silurian sediments have not been discovered, and the Si Ka Formation with basal conglomerate is always observed in direct contact with the underlying Lutxia Formation Late Ordovician in age (Fig. 1, Fig. 8).

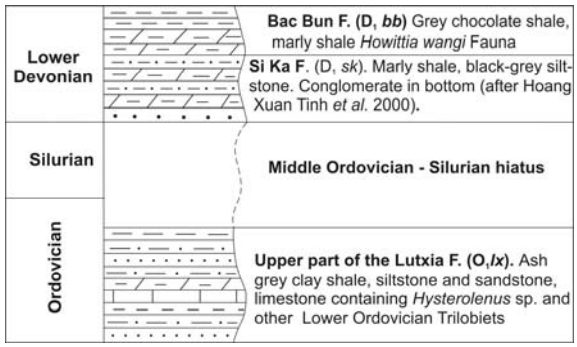

Fig. 1. Unconformity between the Si Ka Formation upon the Lutxia Formation and a Middle Ordovician - Silurian gap between them (Dong Van sections, Ha Giang Province).

By lithological properties, bedding characteristics, color of rock, and by fossil remains the Si Ka Formation itself is a red continental formation, and it has been compared with the "Old Red Sandstone" lying at the base of the Devonian System. Its distribution extends in many areas of North Bac Bo, such as in Dong Van District (Ha Giang Province), Chi Lang and Bac Son districts (Lang Son Province), Than Sa, Trang Xa areas (Thai Nguyen Province). In Ha Lang and Dong Khe districts (Cao Bang Province) it occurrs as lower layer of the Song Cau Group, the lowermost of which often begins by conglomerate with pebble of different lithological composition and dimension.

In the sequence of Ha Lang (Cao Bang Province) and Than Sa sections (Thai Nguyen Province) Ordovician and Silurian sediments are not found, and the Si Ka Formation covers in direct contact with the underlying Than Sa Formation of the Late Cambrian age (Fig. 2, Fig. 8). However, in the Trang Xa area (Thai Nguyen Province), not far from the Than Sa, though the direct contact between the Si Ka and the underlying formation is not observed, but the Upper Ordovician Na Mo Formation and Silurian sediments are also absent. So, in this

area, Silurian sediments do not exist, and the Si Ka Formation can be considered as unconformable upon the Nam Mo Formation (Fig. 3, Fig. 8).

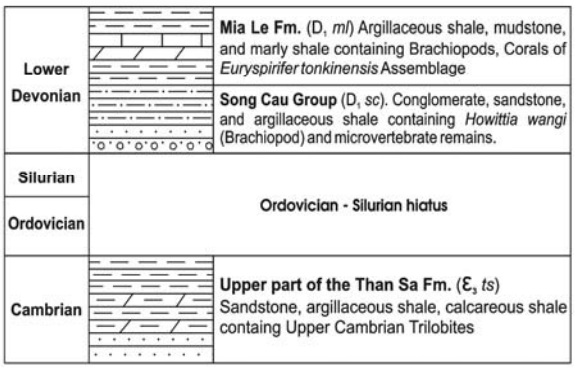

Fig. 2. The Song Cau Group with basal conglomerate unconformable overlies the Than Sa Formation, between which there is an Ordovician-Silurian hiatus (Ha Lang sections, Cao Bang Province).

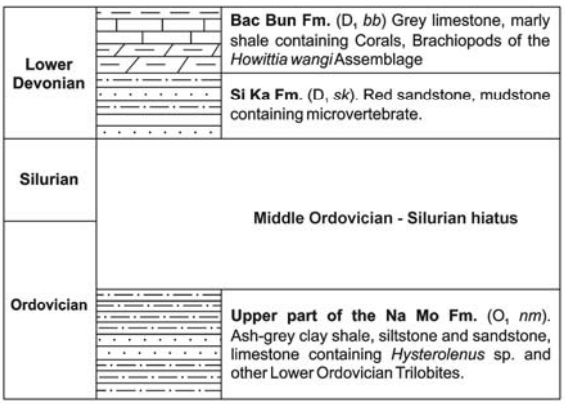

Fig. 3. A Middle Ordovician-Silurian hiatus between Na Mo and Si Ka formations (Trang Xa sections, Thai Nguyen Province).

In Chi Lang and Bac Son areas (Lang Son Province), Ordovician and Silurian sediments have not been found, and there is limestone of Cambrian (?) age, and the Si Ka red sandstone overlies unconformably this Cambrian (?) limestone.

Another unconformity of Devonian sediments on older formations is observed in the east of Bac Bo (Quang Ninh Province), but in this area the age of underlying and overlying formations is different from those in the north of Bac Bo. The underlying formations are Co To and Tan Mai formations of Ordovician-Silurian age, and the overlying is Middle-Upper Devonian Do Son Formation, so the gap between underlying and overlying formations is shorter and later than the one in the north of Bac Bo.

The Lower Devonian red sediments are very widely exposed in South China (Yunnan and Guangxi provinces) and have been described as the Lianhuashan Formation and its equivalents, which consist mainly of sandstone, mudstone, and basal conglomerate in many cases. The Lower Devonian red sediments are very widely exposed in South China (Yunnan and Guangxi Provinces) and have been described as the Lianhuashan Formation and its equivalents, which consist mainly of sandstone, mudstone, and basal conglomerate in many cases. The great thickness (reach to more 1000m) and abundant microvertebrate remains are the most remarkable characteristics of these continental and sub continental sediments.

Obviously, this "red sandstone" was deposited in the continental and subcontinental environment after the Caledonian orogeny.

2.3. Unconformity between Nam Pia and Sinh Vinh, Dong Son formations

The Nam Pia Formation (D_1 *np*) is Lochkovian-Pragian in age and extends in the northeastern side of the Song Ma structure - in the upper basin of Da River and in the lower basins of Ma River (West Bac Bo). According to Bui Phu My, at the Nam Pia Mouth section (upper basin of the Da River), the lowermost beds of the Nam Pia Formation consists of puddingstone, conglomerate and gritstone, which rests unconformably upon the Sinh Vinh Formation (O_3-S *sv*). In the lower part of the Ma River basin, near the Ham Rong bridge area (vicinity of Thanh Hoa Town), an unconformity occurrs between the Nam Pia and the underlying Dong Son Formation (Fig. 4, Fig. 8), but it was characterized as "pseudo-conformity".

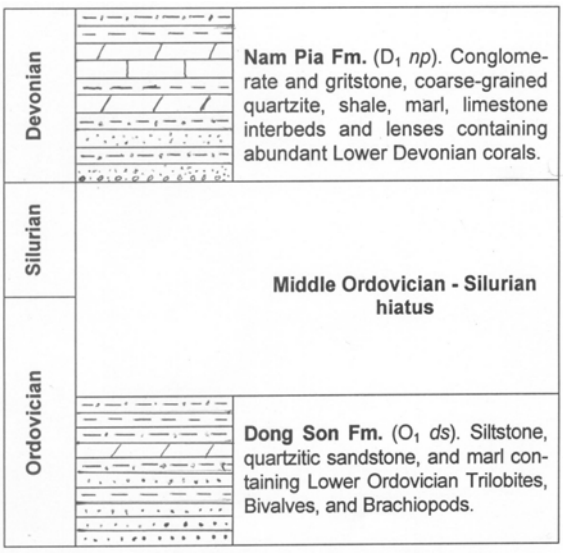

Fig. 4. Middle Ordovician-Silurian hiatus between the Lower Ordovician Dong Son Formation and the Lower Devonian Nam Pia Formation in the vicinity of Thanh Hoa Town.

The stratigraphic relation between Lower Paleozoic formations and Lower Devonian of those formations is interesting and is worth noting for an analysis. The unconformity occurrs only in the northeastern side of the Song Ma structure, while in adjacent areas of the lower section of the Da River, where Paleozoic sediments are widely spread and well studied, and there is no hiatus in the sequence from Ordovician to Lower Devonian.

The stratigraphic relation between Lower Paleozoic formations and Lower Devonian of those formations is interesting and is worth noting for an analysis. In the lower basin of the Da River, Paleozoic sediments are widely spread and well studied, and there is no hiatus or unconformity between Ordovician and Devonian sediments. While in the northeastern side of the Song Ma structure the hiatus is occurrs between Ordovician or Silurian and Lower Devonian. Thus, this hiatus took place only in the margin of an uplifting structure, but not in the center of the sedimentary basin. These evidences evoke a suggestion that perhaps the western region of Bac Bo was not influenced by the Caledonian orogeny as the eastnorthern region, and in the lower Da River basin the sedimentation did not cease during Silurian - the time when it was in the northeast.

2.4. Unconformity between Tan Lap and Ban Pap formations

An interesting unconformity is the one between the Tan Lap (D_2g-D_3 fr *tl*) and the Ban Pap (D_1p-D_3 fr *bp*) formations (Fig. 5, Fig. 8). The Ban Pap Formation consists of grey bedded limestone containing abundant fossils of Corals, Stromatoporoids, Brachiopods, and others, and widely extends in both the east and the west of Bac Bo region. It is an uninterrupted formation, the lowermost beds of it has been dated as Emsian based on Conodonts (*Pol. Excavates* Zone: *Pandorinellina steinhornensis*, *Pol. excavatus*, *Pol. nothoperbonus*) and Dacryoconarids (*Nowakia barrandei* Zone), and the uppermost beds is Frasnian, may be lower Frasnian with Conodonts *Pa. transitans* and some Stromatoporoids.

The Tan Lap Formation consists mainly of sandstone containing land plant remains of Lepidodendropsis, and is restrictively exposed in some areas of Chi Lang and Bac Son districts (Lang Son Province). It unconformably rests upon limestone of the Ban Pap Formation with basal conglomerate (Fig. 5, Fig. 8), among whose pebbles are grains of igneous rocks transported from a nearby erosive area with granite massifs. In its turn, the Tan Lap Formation is conformably covered by Early Frasnian limestone of the Ban Pap Formation. With these stratigraphic relations and the restrictive distribution areas, the Tan Lap Formation is referred to a tongue-shape stratigraphic body wedges itself in the Upper part of the Ban Pap Formation. This unconformity and the tongue-shape Tan Lap Formation bearing *Lepidodendropsis* plant remains show that there was an interruption in sedimentary process by a rising of the crust, but was partially only, and this is a local unconformity.

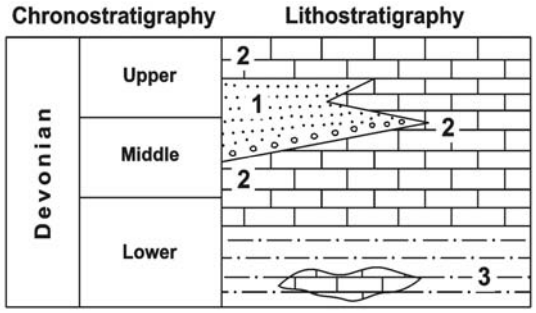

Fig. 5. The tongue-shape Tan Lap Fm. wedges within the Ban Pap Fm. Tan Lap section, Lang Son Province. (1: Tan Lap Fm.; 2: Ban Pap Fm.; 3: Mia Le Fm.).

An analogue has been observed in the stratigraphic sequence of Middle-Upper Devonian of South China. According to the oral information of Hou Hong-fei, there was Middle Devonian coarse terrigenous formation, a similar formation of the Tan Lap, wedges itself in the Middle-Upper Devonian limestone formation.

2.5. Unconformity between Dong Dang and Da Mai formations

The Da Mai Formation in eastern Bac Bo region has been dated as Early Carboniferous - Middle Permian, while the lowermost of the overlying Dong Dang Formation is referred to Upper Permian (Changhsingian). The unconformable relation between the Dong Dang Formation and the underlying Da Mai Formation has been observed in almost all sections where these formations are exposed (Fig. 6, Fig. 8). This unconformable boundary is marked by the change in lithology, between the light-grey thick-bedded limestone and the black-grey terrigenous-cherty or black-grey carbonaceous shale and marl beds. According to the above mentioned data, the gap between Da Mai and the Dong Dang formations is corresponding to the Wuchiapingian, i.e. the first time of the Late Permian epoch. The stratigraphic relation between Dong Dang and the overlying Hong Ngai and Lang Son formations of Early Triassic age is likely conformable, but there is a short gap between those formations, in fact.

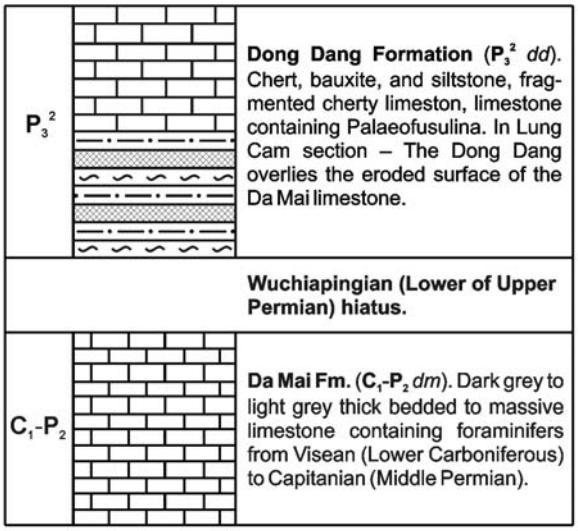

Fig. 6. A short hiatus between Dong Dang Formation and Da Mai Fm. corresponding to Wuchiapingian (Upper Permian) was noted. Doan Nhat Truong's new data shown that the top of Da Mai Fm. can be up to Wuchiapingian, in this case the hiatus is even shorter - between adjoining Wuchiapingian and Changhsingian stages.

According to Doan Nhat Truong's new data in some localities the top of Da Mai Formation bears the foraminifers of *Codonofusiella - Reichelina* Assemblage, and has been dated as Wuchiapingian age (Late Permian). By the presence of *Palaeofusulina* the lowermost of the Dong Dang Formation has been referred to Changhsingian stage of Upper Permian, thus the gap in the sequence of Upper Permian in eastern Bac Bo is short (between the two adjacent Wuchiapingian and Changhsingian times only).

Relating to this unconformity and the bauxite deposit in Dong Dang Formation, Doan Nhat Truong wrote that the bauxite ore deposit in the Lower part of the Dong Dang Formation was formed during karstic process in the continental environment on the limestone of the Da Mai

Formation. After that, the limestone of the Dong Dang Formation was deposited in the marine environment, at a transgressive time corresponding to the Changhsingian. Thus, the bauxite and other components of the Dong Dang Formation were deposited in different environments, and the combination of them in one formation is temporary only.

3. Mesozoic unconformities and gaps

In the north of Viet Nam, the numbers of unconformities in Mesozoic stratigraphy have been recorded, and the main ones could be listed as follows.

The Hong Ngai Formation (T_1 *hn*) and its synchronous Lang Son Formation (T_1 *ls*) appear to conform overly with Dong Dang Formation (P_3^2 *dd*), though the conodont *parva* Zone (characteristic zone of the lower Triassic boundary) has not been found, so a short depositional gap could happen.

In the west of Bac Bo, the Co Noi Formation lies unconformably upon the Yen Duyet Formation (P_3 *yd*).

The unconformity of the Song Hien Formation (T_1 *sh*) upon the Dong Dang Formation (P_3^2 *dd*) has been observed in the sections located in the west of Cao Bang Town and in Binh Gia area (Lang Son Province).

The Lan Pang Formation (T_2a *lp*) rests unconformably upon the Lower Triassic Song Hien Formation or Upper Paleozoic limestone.

The effusive Khon Lang Formation (T_2a *kl*) rests unconformably upon Upper Permian limestone and the Lower Triassic Bac Thuy Formation.

The Yen Binh Formation (T_2a *yb*) rests unconformably with basal conglomerate upon the Ha Giang Formation (ε_2 *hg*).

The Mau Son Formation (T_3c *ms*) appears to underly unconformably the coal-bearing Van Lang Formation (T_3n-r *vl*).

The Van Lang Formation (T_3n-r *vl*) rests unconformably upon older sediments for instance the Ordovician Phu Ngu Formation, the Carnian Na Khuat Formation (T_3c *ms*).

The Hon Gai Formation (T_3n-r *hg*) unconformably rests upon Lower Paleozoic Tan Mai Formation or upon Upper Paleozoic limestone.

The Suoi Bang Formation (T_3n-r *sb*) unconformably rests upon many older formations, from Proterozoic (Sin Quyen, Nam Co formations) to Anisian (Dong Giao Formation) and even Carnian Nam Mu Formation (Fig. 7, Fig. 8).

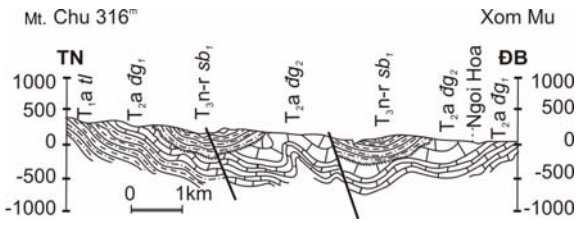

Fig. 7. The Chu Mt. - Xom Mu Hamlet Section, 7 km southwestward from Hoa Binh Town, shows the angular unconformity of the Suoi Bang Formation (T_3 n-r *sb*) upon the Dong Giao Formation (T_2 a *dg*) illustrated by Tran Van Tri.

The Ha Coi Formation (J_{1-2} *hc*) covers with angular unconformity Lower Paleozoic beds of the Tan Mai Formation. As in Thai Nguyen City, these beds lie unconformably upon Norian-Rhaetian coal-bearing Van Lang Formation.

The Yen Chau Formation (K_2 *yc*) unconformably rests upon different older sediments.

The Nam Ma Formation (K *nm*) and the Ban Hang Formation (K *bh*) unconformably cover different older sediments, for example Nam Po (J_1 *np*) and Ha Coi (J_{1-2} *hc*) formations.

The Late Jurassic effusive Tam Lung Formation unconformably lies upon Lower Triassic terrigenous beds of the Lang Son Formation, as well as upon Middle Triassic formations.

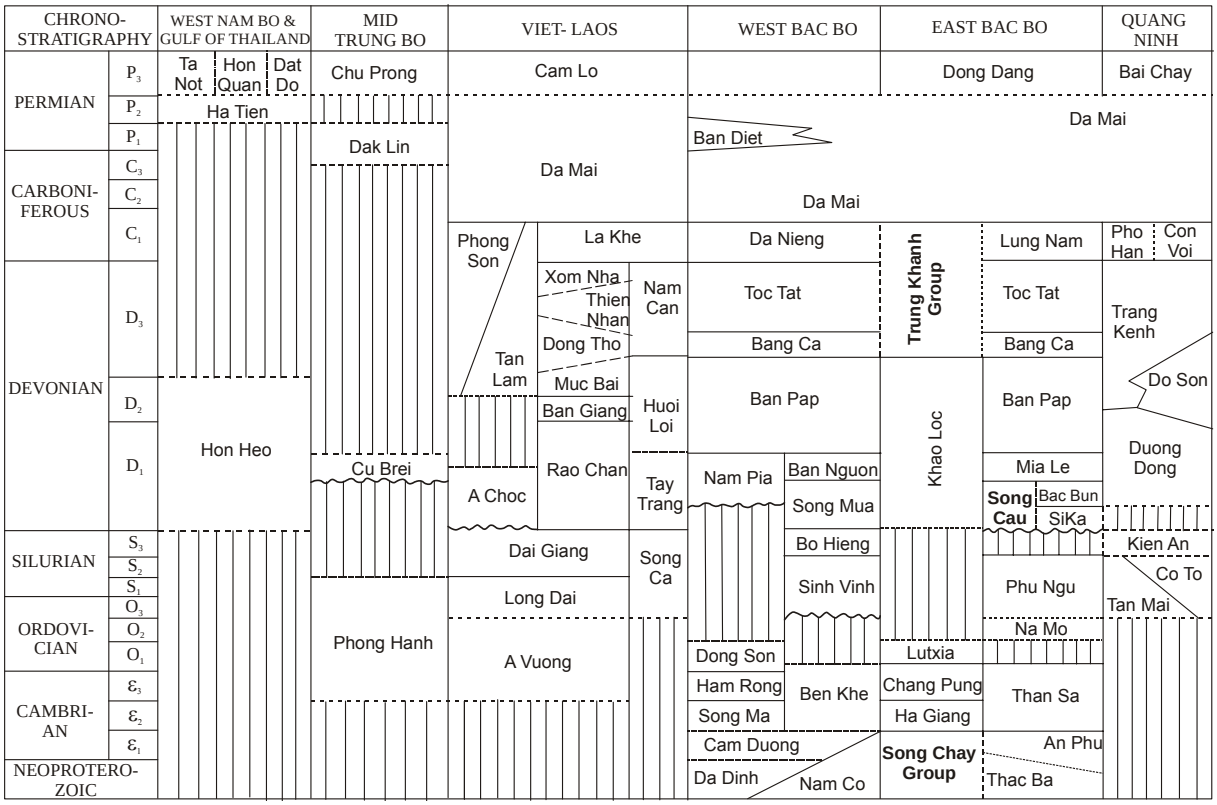

Fig. 8. Stratigraphic correlation of Paleozoic Units in Viet Nam.

From above mentioned unconformities and gaps, the Norian-Rhaetian is the most interesting one because it marked a new period in the geological development of Viet Nam and Southeast Asian in common. In the tectonic differentiation of the Bac Bo region in Mesozoic, other unconformities probably are local ones.

4. Discussion and inclusion

1. The angular unconformity of Suoi Bang, Van Lang, and Hon Gai formations of Norian-Rhaetian age upon various formations of different ages is an important event in regional geology; it marked the change tectonic regime of the region resulting from the indosian orogeny in Viet Nam and in Southeast Asia in common. The indosinian movement has happened from Permian, but the intensified phase took place in Norian of Late Triassic by the collision of the Malaya plate with the Indochina. This angular unconformity has been largely recorded not only in Viet Nam, but also in Southeast Asia and South China, so there is no need to discuss more about it.

2. The unconformity of Lower Devonian Si Ka Formation and Song Cau Group upon Lower Paleozoic formations is an important one, but its role in regional geology has not yet been properly accessed by geologists. The stratigraphic gap of Late Ordovician and Silurian largely occurs not only in the north of North Viet Nam (Viet Bac in Vietnamese), but also in Guangxi and Yunnan provinces of China. The red beds facies sediments (Si Ka Formation in Viet Nam and Lianhuashan in South China) also largely extend in the same areas with unconformable relations upon Lower Paleozoic. By lithologic characteristics of

rocks such as red color, coarse grain and cross bedding sediments, and plant and microvertebrate fossil remains, these formations can be referred to fluvial and continental facies. It is reasonable to compare these formations with Old Red Sandstone in epicaledonian deposits in West Europe. From the above materials, supposing that the north of North Viet Nam (Ha Giang, Cao Bang, Lang Son, and Thai Nguyen provinces) and South China were under influence of the Caledonian Movement (Guangxi Movement by Chinese geologists), and during pre-Devonian, the terranne was raised in somewhere northward from the north of North Viet Nam. In Devonian, the north of North Viet Nam was the southern margin of a continent, where alluvial and continental deposits took place.

In conclusion, supposing that the unconformity of Lower Devonian upon Lower Paleozoic formations was influenced by the Caledonian movement, and it should be an important regional one in the north of North Viet Nam and South China.

Perhaps the continental regime in South China had not long existed, and at the beginning of Late Lochkovian (Bac Bun in Viet Nam, Nagaoling in South China) the terrane had been gradually submerged. From that time forwards, the shallow marine environment has been dominated in the terrane, and in this basin fine-grained and carbonate sediments contain abundant organic remains were deposited.

3. The gap between Da Mai and Dong Dang formations is a short unconformity, and it lasted during the Wuchiapingian (last time of Middle Permian) only. New data of Doan Nhat Truong researches show that the Da Mai age could last up to Wuchiapingian, in this case the gap is even shorter - in range of time between adjoining Wuchiapingian and Changhsingian stages of Upper Permian. There is no facial change in underlying and overlying formations, except the thin lowermost beds of the Dong Dang Formation, almost all adjoining Da Mai and Dong Dang formations are composed of ligh grey, thick bedded limestone containing abundant foraminifers. There is no expression of an orogeny in Permian, and the unconformity between Dong Dang and Da Mai formations would be influenced by the local raising only.

4. Many other unconformities and gaps even with conglomerate in the bottom of the overlying formation are not regional, but perhaps are only local unconformities. Among them in Paleozoic, there are the Nam Pia Formation ones that overly the Dong Son Formation and the tongue-shape Tan Lap Formation wedging the Ban Pap Formation, and many others. Perhaps almost all unconformities in Mesozoic, except the Norian-Rhaetian, are also the local ones.

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