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RESEARCH ON THE MIDDLE CAMBRIAN - LOWER ORDOVICIAN SEQUENCE STRATIGRAPHY OF THE DONG VAN AREA IN NORTHEAST VIETNAM

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SUMMARY OF GEOLOGICAL DOCTORAL THESIS

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INTRODUCTION

I. The urgency of the thesis

The Middle Cambrian - Lower Ordovician carbonate - siliciclastic rocks containing trilobites, brachiopods và Crinoids in the Dong Van area in northeast Vietnam were investigated and studied at varying degrees on paleotology and stratigraphy. The differences in the stratigraphic division are variable in thickness, age, stratigraphic relationships as well as in terms of lithostratigraphic contents. The dating and stratigraphic correlation of sedimentary rocks are mainly based on paleontological materials. Therefore, the strata has not found or no fossil, this work encountered many difficulties and led to inconsistencies in stratigraphic division and correlation. The stratigraphic study has not adequately and systematically considered in diagenesis of sedimentary rocks. Thus, the rule of lithofacies change in space and time is not defined in relation to sea-level changes and tectonic movement, so it is not fully reflected in its content and mass. Consequently, it is led to the limited understanding of the origins, evolution and conditions of mineral formation associated with them. In order to overcome these constraints, it is necessary to approach the method of sequence stratigraphy.

Due to the shortcomings in the study of the Middle Cambrian - Lower Ordovician division and correlation above and leverage the strength of the sequence stratigraphic method, the stratotype sections of two formations, Chang Pung and Lutxia formations in the Dong Van area in northeast Vietnam were selected and studied, with thesis title "***Research on the middle Cambrian - Lower Ordovician sequence stratigraphy of the Dong Van area in northeast Vietnam"***.

II. The object and scope of the thesis

The main object and scope of the thesis is the Middle Cambrian - Lower Ordovician sedimentary rocks in the Dong Van area in northeast Vietnam.

III. The objectives of the thesis

To establish the sequence stratigraphic framework for the stratigraphic correlation and the reconstruction of the developmental history of sedimentary environment of the Middle Cambrian - Lower Ordovician strata of the Dong Van area in northeast Vietnam.

IV. The content of the thesis

- To study on the characteristics and rules of distribution of lithofacies of the Middle Cambrian - Lower Ordovician strata of the Dong Van area.

- To study on the characteristics and rules of distribution of sequence stratigraphic unit of the Middle Cambrian - Lower Ordovician strata of the

Dong Van area.

- To study on the reconstruction of the developmental history of sedimentary environment of the Middle Cambrian - Lower Ordovician strata of the Dong Van area in northeast Vietnam.

V. The database of the thesis

The thesis mainly used the collected materials and the results of sample analysis of the research project on science and technology development of the Ministry of Natural Resources and Environment "*Applied research for sequence stratigraphy methodology for the Middle Cambrian – Lower Ordovician sedimentary rocks in the Northeast part of Vietnam"*, project number TNMT.03.48 (2014 - 2016) and project leader by PhD candidate.

The materials, paleontological and petrographical samples of the seven fieldworks together with colleagues and foreigners (Belgium, Japan and Poland) at the Chang Pung and Lung Cu II section in Dong Van area were collected, processed and analyzed by PhD candidate.

PhD candidate has processed and analyzed about 300 samples of microfacies at the University of Leuven, Belgium, under the guidance of Prof. Dr. Rudy Swennen.

In addition, the thesis also used a number of the subject reports and scientific works have published on the paleontology, stratigraphy and sedimentology of the Middle Cambrian - Lower Ordovician strata.

VI. Theoretical and practical significance

* *Theoretical significance*

- This study is the contribution to the application of the suitable sequence stratigraphic model to the Middle Cambrian - Lower Ordovician sedimentary rocks in the Dong Van area in northeast Vietnam.

- The lithofacies characteristics of the Middle Cambrian - Lower Ordovician sedimentary rocks of the Dong Van area in northeast Vietnam are clarified.

- The sequence stratigraphic framework is established for the Middle Cambrian - Lower Ordovician sedimentary rocks of the Dong Van area in northeast Vietnam.

- The chronosequence stratigraphic framework is proposed for the Middle Cambrian - Early Ordovician period of the Dong Van area in northeast Vietnam.

- The curve of sea-level change of the Dong Van area in northeast Vietnam is correlated with global sea-level changes during Middle Cambrian - Early Ordovician period (following to John W. Snedden and Chengjie Liu, 2010).

- This thesis is the reconstruction of sedimentary environment of the Middle Cambrian - Lower Ordovician strata of the Dong Van area in northeast Vietnam.

* *Practical significance*

- The thesis results will clarify the developmental history of sedimentary environment of the Middle Cambrian - Lower Ordovician strata of the Dong Van area in northeast Vietnam.

- The sequence stratigraphic framework is proposed for the Middle Cambrian - Lower Ordovician sedimentary rocks of the Dong Van area, will contribute to the accuracy of the stratigraphic order of the Middle Cambrian - Lower Ordovician sedimentary rocks of the northeast Vietnam.

- The Middle - Upper Cambrian Chang Pung Formation occurring in the Dong Van area is firstly divided into 4 members, including Xeo Lung, Cang Tang, Lo Lo and Then Van members, for geological mapping and regional stratigraphic correlation.

VII. Major arguments to be defended

Argument 1. The Middle Cambrian - Lower Ordovician sedimentary rocks of the Dong Van area, are composed of six facies association types and fifteen facies types, which occurs in systems tracts.

- The offshore, shallow marine carbonate facies association;

- The shoreface and inner shelf, shallow marine marlstone facies association;

- The shoreface and inner shelf, shallow marine conglomerate limestone facies association;

- The shoreface and inner shelf, shallow marine oolitic limestone facies association;

- The foreshore and inner shelf, shallow marine bioclastic limestone facies association;

- The foreshore and inner shelf, shallow marine calcareous siliciclastic sediments facies association.

Argument 2. The sequence stratigraphic framework is proposed for the Middle Cambrian - Lower Ordovician sedimentary rocks of the Dong Van area in northeast Vietnam, which is composed of 9 sequences (S_1 - S_9) in corresponding to 9 cycle of sea level change. The each of sequence includes three systems tracts: lowstand systems tract (LST), transgressive systems tract (TST) and highstand systems tract (HST).

- The lowstand systems tract (LST) is characterized by foreshore and inner shelf, shallow marine calcareous siliciclastic sediment facies association.

- The transgressive systems tract (TST) consists of limestone facies association deposited in foreshore and inner shelf to offshore, shallow marine.

- The highstand systems tract (HST) contains the thin-bedded lime mudstone formed in offshore, shallow marine and foreshore and inner shelf, shallow marine limestone facies association.

VIII. The new findings of the thesis

1. This study is the analysis to the application of the suitable sequence stratigraphic model to the Middle Cambrian - Lower Ordovician sedimentary rocks in the Dong Van area in northeast Vietnam.

2. The Middle Cambrian - Lower Ordovician sedimentary rocks of the Dong Van area in northeast Vietnam, are composed of six facies association types and fifteen facies types.

3. The sequence stratigraphic framework is proposed for the Middle Cambrian - Lower Ordovician sedimentary rocks of the Dong Van area in northeast Vietnam, which is composed of 9 sequences (S_1 - S_9) in corresponding to 9 cycle of sea level change.

4. The chronosequence stratigraphic framework is proposed for the Middle Cambrian - Early Ordovician period of the Dong Van area in northeast Vietnam.

5. The Middle - Upper Cambrian Chang Pung Formation occurring in the Dong Van area is divided into 4 members, including Xeo Lung, Cang Tang, Lo Lo and Then Van members, for geological mapping and regional stratigraphic correlation.

6. The curve of sea-level change of the Dong Van area in northeast Vietnam is correlated with global sea-level changes during Middle Cambrian - Early Ordovician period.

IX. Structure of the study

The thesis consists of 174 pages in A4 format, including 5 chapters and introduction and conclusion:

Chapter 1. History of research and features of regional geology

Chapter 2. Theoretical basis and Methodology

Chapter 3. Lithofacies characteristics of the Middle Cambrian - Lower Ordovician sedimentary rocks of the Dong Van area

Chapter 4. Sequence stratigraphy of the Middle Cambrian - Lower Ordovician sedimentary rocks of the Dong Van area

Chapter 5. Developmental history of sedimentary environment of the Middle Cambrian - Lower Ordovician strata of the Dong Van area

X. Acknowledgments

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Chapter 1
HISTORY OF RESEARCH AND FEATURES OF REGIONAL GEOLOGY

1.1. LOCATION

The location of the studied Dong Van area is located in the north-east of Ha Giang province, belonging to two Dong Van and Meo Vac districts of Ha Giang Province, covering an area of about 800 km^2, located in 105^{0}15' to 105^{0}30' east longitude and 23^{0}14' to 23^{0}23' north latitude, is the northernmost area of Vietnam (Fig 1.1).

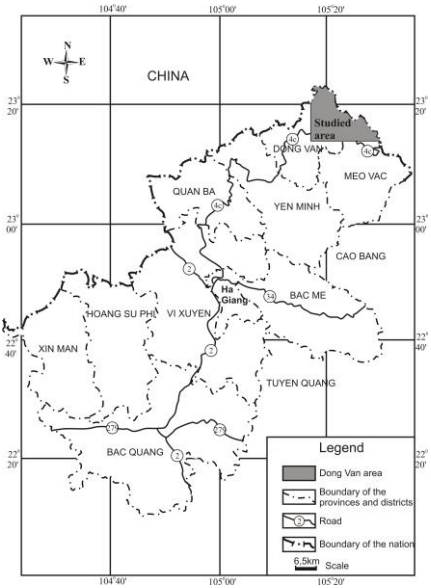


Figure 1.1. Scheme of location of the studied Dong Van area in northeast Vietnam.

1.2. CHARACTERISTICS OF NATURAL GEOGRAPHY

1.3. HISTORY OF STRATIGRAPHIC RESEARCH

1.3.1. The period before 1954

The works on the stratigraphy and trilobites in Middle - Upper Cambrian in northernmost Vietnam (Haut Tonkin) were conducted by

French geologists. Deprat J. (1915) differentiated the Lower Palaeozoic into seven series such as Cambrian Coc Bai, middle - Upper Cambrian Chang Pung, Lower Ordovician Lutxia, Middle Ordovician Lung Co, and Upper Ordovician Si Ka, Bac Bun and Mia Le series. Mansuy H. (1915, 1916) described in detail the 35 species of trilobites, brachipods, and established the new Tonkinella in northernmost Vietnam, those are credible contributions to the age determination of the Middle Cambrian - Lower Ordovician sedimentary rocks there. Kobayashi T. (1944) reviewed and revised the previous studies of Deprat J. and Mansuy H. in Haut Tonkin and Yunnan. Saurin E. (1956) summarized the Cambrian system of Indochina at the 20th International Conference on Geology in Mexico.

1.3.2. The period after 1954

After 1960, with the mapping of the North Vietnam geological map, 1/500,000 edited by Dovjikov A., the Cambrian strata were discovered in Bac Kan, Thai Nguyen and Thanh Hoa. However, in terms of stratigraphy, the authors did not acknowledge the presence of Middle Cambrian in the North of Vietnam.

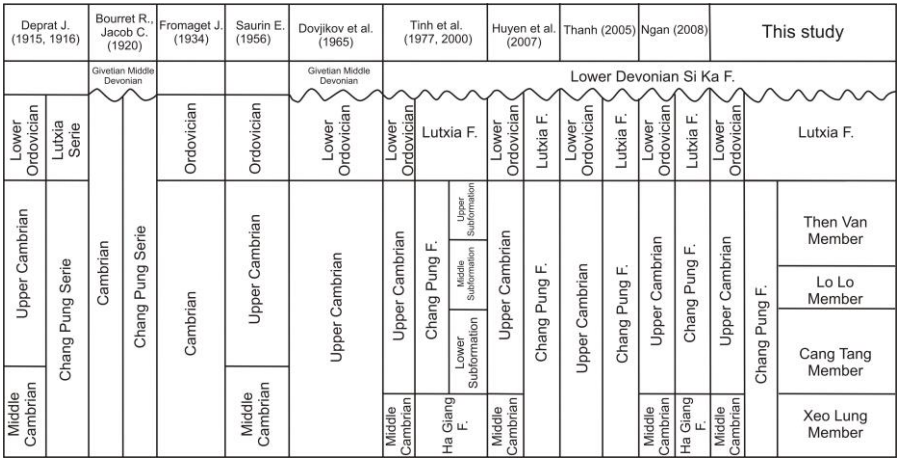


Figure 1.2. Scheme of division of the Middle Cambrian - Lower Ordovician sedimentary rocks in the Dong Van area in northeast Vietnam

In the Dong Van area, Vietnamese geologists performed on the palaeontological and stratigraphic studies and made the geological maps of Bao Lac 1: 200,000 edited by Hoang Xuan Tinh. The Middle Cambrian - Lower Ordovician sedimentary rocks has been divided into the Upper Cambrian Chang Pung and Lower Ordovician Lutxia formations (Tong Duy Thanh et al., 2005; Hoang Xuan Tinh et al., 1977, 2000; Pham Kim Ngan et al., 2008). Tran Huu Dan (in Dang Tran Huyen et al., 2007)

indicated the occurrence of the Middle Cambrian sediments that are not belonging to the Middle Cambrian Ha Giang Formation, but they were in the lower part of the Chang Pung Formation in Dong Van area. Therefore, the authors refined the Middle Cambrian - Lower Ordovician sedimentary rocks was divided into the Middle - Upper Cambrian Chang Pung and Lower Ordovician Lutxia Formation (Fig 1.2).

1.4. FEATURES OF REGIONAL GEOLOGY

1.4.1. The Middle Cambrian - Lower Ordovician sections

1.4.1.1. The Chang Pung section

The Chang Pung section is located in Thuong Phung Commune, Meo Vac District, Ha Giang Province, which is the stratotype of the Chang Pung Formation (Fig 1.3). The Chang Pung section was redescribed and proposed the members 1 - 21 belonging to the Middle - Upper Cambrian Chang Pung Formation with 739m thick, and the members 22 - 25 belonging to the Lower Ordovician Lutxia Formation with 92m thick. The Lutxia Formation is conformably underlain by the Chang Pung Formation, and is unconformably overlain by the Lower Devonian Si Ka Formation.

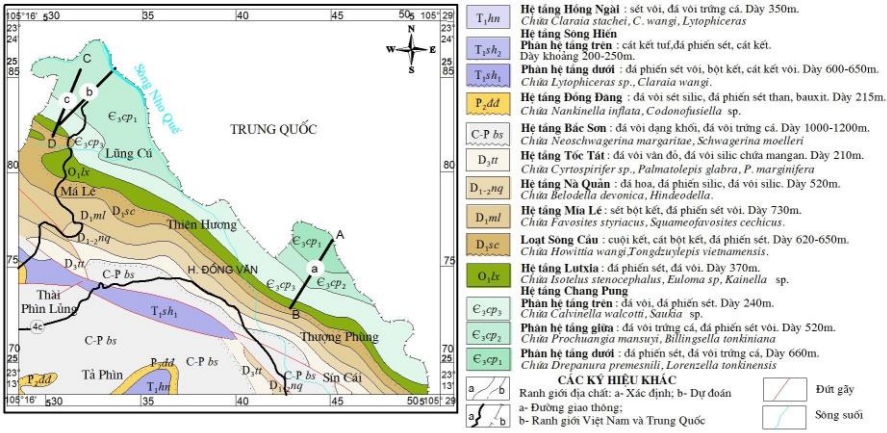


Figure 1.3. Scheme of geological map of the Dong Van area in northeast Vietnam at scale 1 : 200.000 (following Hoang Xuan Tinh et al., 2000).

(a) Chang Pung section; (b) Lung Cu section; (c) Lung Cu II section.

1.4.1.2. The Lung Cu II section

The Lung Cu II section is well exposed and about 1000 m northwestern of the original Lung Cu section (Deprat, 1915). This section was investigated from northeastern of the Xeo Lung Village pass the Lung Cu flag tower, to Lo Lo Village, and ending at Then Van Village belonging to

Lung Cu Commune. The Lung Cu II section, was described and proposed the members 1 - 21 belonging to the Middle - Upper Cambrian Chang Pung Formation, 1.080m thick, and the members 22 - 25 belonging to the Lower Ordovician Lutxia Formation, 145m thick. The lower boundary of the Chang Pung Formation is not observed. The Chang Pung Formation is conformably overlain by the Lutxia Formation. The Lutxia Formation is unconformably overlain by the Lower Devonian Si Ka Formation.

1.4.2. Biostratigraphy

On the stratigraphy and paleontology of the Middle Cambrian - Lower Ordovician sedimentary rocks in the Dong Van area are closely related to Northwestern Vietnam and South China. The biostratigraphy was divided into 8 trilobite zones (Pham Kim Ngan et al., 2008) and 2 brachiopod zones (Tran Huu Dan in Dang Tran Huyen et al., 2007).

1.4.3. Geological structure

According to the structural - tectonic study materials, the Dong Van area belongs to the Song Hien structure zone in the folding standard region East Vietnam (Dovjikov et al., 1965) or the folding system Viet Bac (Trần Văn Trị et al., 1977). According to the geological and mineral map at the scale 1: 200,000 Bao Lac sheet, edited by Hoang Xuan Tinh (1977), the Dong Van area is located in the north of Bao Lac sheet. There are two major fault systems in the region, including the northwest-southeast fault system and the northeast - southwest fault system.

Chapter 2
THEORETICAL BASIS AND METHODOLOGY

2.1. THEORETICAL BASIS

This section presents the theoretical basis of the petrography of sedimentary rock, lithofacies and sequence stratigraphy.

2.2. METHODOLOGY

Ph.D. student have used the following research methodologies: (1) The stratigraphic method including lithostratigraphic method and biostratigraphic method; (2) group method of studying the material composition; (3) method of facies analysis and (4) sequence stratigraphic method.

2.3. TECHNICAL USES

Group of techniques used include document processing, investigating section of sedimentary geology, collection and analysis of samples.

Chapter 3
LITHOFACIES CHARACTERISTICS OF THE MIDDLE CAMBRIAN - LOWER ORDOVICIAN SEDIMENTARY ROCKS OF THE DONG VAN AREA

3.1. PETROGRAPHY

The Middle Cambrian - Lower Ordovician sedimentary rocks of the Dong Van area is characterized by the carbonate and siliciclastic - carbonate mixed rocks. It contains carbonate mud, carbonate sparite cement, allochems and terrigenous materials.

3.2. LITHOFACIES

The Middle Cambrian - Lower Ordovician sedimentary rocks of the Dong Van area are divided into six facies association types and fifteen facies types (Fig 3.1):

3.2.1. Offshore, shallow marine carbonate facies association

- *The thin-bedded lime mudstone facies formed in offshore, shallow marine (Ltb)*: Appearing at the lower part of the Chang Pung and Lung Cu II sections in the Xeo Lung Member of the Chang Pung Formation in Dong Van area. It contains the ash-gray, greenish-gray, and light gray, thin (2 - 10cm) to medium (10 - 20cm) bedded mudstone.

- *The dolomitic limestone facies deposited in offshore, shallow marine (DL)*: Distributing at the Xeo Lung and Lo Lo members of the Chang Pung Formation. It consist of the ash-gray, light-gray, and

thin (2 - 10cm) to medium (10 - 40cm) bedded dolomitic limestone. The Xeo Lung Member of the lower part of the Chang Pung Formation is mainly occupied by very thick (120cm) bedded dolomitic limestone.

3.2.2. The shoreface and inner shelf, shallow marine marlstone facies association

- *The limestone-shale alternation facies indicates deposition in shoreface and inner shelf, shallow marine (L-S)*: It is mainly distributed at the upper part of the Lutxia Formation. The component of facies contains alternations of the ash-gray, greenish-gray, and thin (2 - 5cm) mudstone and the greenish-gray, dark gray, thin (1 - 3cm) shale. The horizontal - lenticular bedding structure occurs in this rock.

- *The limestone - marlstone alternation facies reflects sedimentation in shoreface and inner shelf, shallow marine (L-M)*: It is mainly occurred in the Chang Pung and Lutxia formations. The composition consists of the ash-gray, greenish-gray, and thin (0,2 - 5cm) mudstone or wackestone interbedded with the nodular or lenticular marlstone. The paralled - lenticular bedding structure occurs in this rock.

3.2.3. The shoreface and inner shelf, shallow marine conglomerate limestone facies association

- *The intraclastic limestone facies reflects deposition in shoreface and inner shelf, shallow marine (IL)*:

Appearing at the lower part of the Then Van Member of the Chang Pung. It contains the ash-gray, greenish-gray, and dark gray, thin to medium - bedded intraclastic limestone. The intraclast is composed of ranging from 0.1 to 2 cm in size, distorted, subcircular, light gray to dark gray, pinkish lime mud, which is distributed uniformly in rock and tend to be oriented.

- *The limestone conglomerate facies formed in shoreface and inner shelf, shallow marine (LC)*:

It is scattered distribution at the upper part of the Chang Pung and Lutxia formations. The composition mainly consists of the ash-gray and medium to thick - bedded conglomerate limestone. It is characterized by the elongated and rounded conglomerate lithoclast, lenght x width in average size is 10cm x 2cm, which is ash-gray lime mud and and tend to be horizontal parallel direction.

3.2.4. The shoreface and inner shelf, shallow marine oolitic limestone facies association

- *The cross-bedding limestone facies deposited in shoreface and inner shelf, shallow marine (CL)*: Appearing at the upper part of the Then Van Member of the Chang Pung. It contains the ash-gray, greenish-gray, and light gray, medium to thick - bedded (20 - 50cm) cross-bedding limestone within abundant allochems. The silt-size particles are mainly composed of calcite minerals arranged in cross-bedding direction due to the one current flow.

- *The oolitic limestone facies indicates deposition in shoreface and inner shelf, shallow marine (OG)*: It is mainly occurred in the Chang Pung and Lutxia formations. The composition consists of the ash-gray, greenish-gray, and medium to thick - bedded (10 - 60cm) oolitic limestone. It is characterized by the spherical, like-fish egg grains with well roundness and sorting, which is about 0,5 - 1,5mm in diameter and disorder distributing in the rock.

- *The oncolitic limestone facies reflects sedimentation in shoreface and inner shelf, shallow marine (OL)*:

Appearing at the Cang Tang Member of the Chang Pung. The composition consists of the ash-gray, medium to thick - bedded (30 - 50cm) limestone. The component is characterized by the elliptical or spherical

oncoid grains with nucleus and cortex, which is varied from one milimet to several milimet in diameter and disorder distributing in the rock.

3.2.5. The foreshore and inner shelf, shallow marine bioclastic limestone facies association

- *The bioturbated wackestone facies formed in foreshore and inner shelf, shallow marine (WB)*:

It is mainly occurred in the upper part of the Cang Tang Member to the lower part of the Then Van Member of the Chang Pung Formation. It contains the ash-gray, greenish-gray, grayish weathering, thin-bedded mudstone and bioturbated wackestone. This rock is irregular surface and bioturbated bedding structure.

- *The wackestone to grainstone facies reflects deposition in foreshore and inner shelf, shallow marine (W-G)*:

It is mainly occurred in the upper part of the Xeo Lung Member to the Lo Lo Member of the Chang Pung Formation and scattered distribution at the Lutxia Formation. The component is characterized by alternations of the wackestone and lends of bioclastic limestone with regular boundary surface. This rock is wave-current lenticular bedding structure.

- *The bioclastic limestone facies deposited in foreshore and inner shelf, shallow marine (BL)*:

Distributing at the upper part of the Lutxia Formation and the middle part of the Chang Pung Formation. It consist of the ash-gray, green-gray, and medium to thick bedded bioclastic limestone. The components of bioclast are dominatly lime mud shell with disorder distributing in the rock, which are mainly brachiopods, cinoids and trilobites.

- *The stromatolitic limestone facies reflects deposition in foreshore and inner shelf, shallow marine (SL)*:

It is marker for stratigraphic correlation of the Lo Lo Member of the middle part of the Chang Pung Formation in Dong Van area. It mainly contains the ash-gray, greenish-gray, and medium -bedded (20 - 40cm), stratified aggrading stromatolitic limestone yielding peloid grains.

3.2.6. The foreshore and inner shelf, shallow marine calcareous siliciclastic sediments facies association

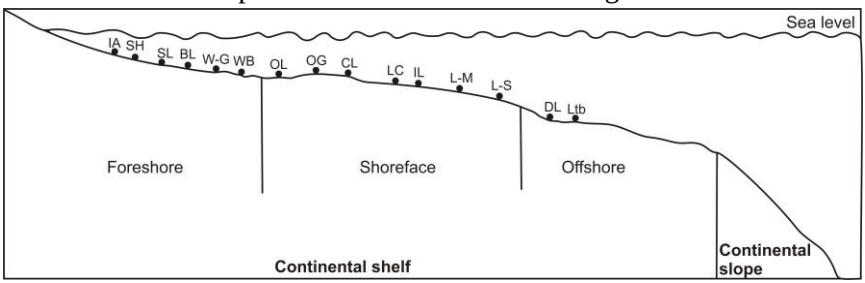
- *The calcareous shale facies formed in foreshore and inner shelf, shallow marine (SH)*:

It is commonly appeared at the Chang Pung and Lutxia formations in Dong Van area. The component of facies mainly contains ash-gray, yellowish and pink-yellowish weathering shale. It abundantly yields well-

preserved specimens of trilobites and brachiopods. This rock is laminate bedding structure.

- The calcareous sandstone - siltstone facies deposited in foreshore and inner shelf, shallow marine (IA):

It is often occurred with SH facies in the Chang Pung and Lutxia formations in Dong Van area. The component of facies mainly contains ash-gray, yellowish and pink-yellowish weathering thin-bedded sandstone - siltstone. It abundantly yields fair and well-preserved specimens of trilobites and brachiopods. This rock is cross-bedding structure.



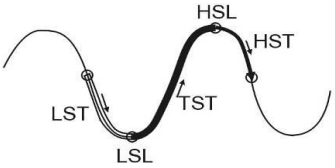
Hình 3.1. The distributed position of fifteen facies of the Middle Cambrian - Lower Ordovician sedimentary rocks of the Dong Van area.

Chapter 4

SEQUENCE STRATIGRAPHY OF THE MIDDLE CAMBRIAN - LOWER ORDOVICIAN SEDIMENTARY ROCKS OF THE DONG VAN AREA

4.1. SEQUENCE STRATIGRAPHIC MODEL

Based on the analysis of sequence stratigraphic models in the world and in Vietnam, consequently, the model of Tran Nghi (2011-2012) is consistent with the studied object of the thesis. (Fig 4.1).



LST, TST, HST: Lowstand systems tract, Transgresive systems tract, Highstand systems tract.

Figure 4.1. The inflection points of the systems tracts in a sequence corresponds to a cycle of sea level change (following to Tran Nghi, 2012).

4.2. SEQUENCE STRATIGRAPHY

Based on the facies analysis and correlating with sea-level change in terms of sequence stratigraphy, the Middle Cambrian - Lower Ordovician sedimentary rocks of the Dong Van area were proposed of 9 third-order sequences in corresponding to 9 cycle of sea level change. The describing the sequences in ascending order (Fig 4.2, 4.3, 4.4, 4.5):

4.2.1. Sequence S_1

In the Dong Van area, sequence S_1 was not observed at the lowest part because they were destroyed by the fault in the Lung Cu II section, while they could be visible in the Chang Pung section in the China. Thus, this sequence was observed the TST and HST systems tracts.

The TST is characterized by the offshore, shallow marine carbonate facies association yielding trilobite *Damesella* sp. of late Middle Cambrian age (Pham Kim Ngan et al., 2008). The lower boundary of the TST is maximum regressive surface (MRS), which is not observed because of fault. The upper boundary of the TST is maximum flooding surface (MFS). This boundary is marker by the change from facies Ltb to facies L-M of the HST (SS. 95). The HST consists of the shoreface and inner shelf, shallow marine oolitic limestone facies association and the bioclastic limestone facies deposited in foreshore and inner shelf, shallow marine (BL). The upper boundary of the HST is equivalent to the boundary between the sequence S_1 and sequence S_2, which is drawn at the SS. 97 in Lung Cu. This boundary is subaerial unconformity, which is marker by the wackestone to grainstone facies reflects deposition in foreshore and inner shelf, shallow marine (W-G) to the calcareous sandstone - siltstone facies deposited in foreshore and inner shelf, shallow marine (IA).

4.2.2. Sequence S_2

Sequence S_2 is distributed from the Xeo Lung Village to the Lung Cu flag Tower (Lung Cu II section). This sequence does not expose in the Chang Pung section due to fault.

The LST contains the foreshore and inner shelf, shallow marine calcareous siliciclastic sediments facies association. The lower boundary of the LST is equivalent to the boundary between the sequence S_1 and sequence S_2 above. The upper boundary of the LST is MRS at SS.97/1 in Lung Cu. This is change from facies IA to facies W-G. The TST consists of the offshore, shallow marine carbonate facies association. The upper boundary of the TST is not observed due to fault. The HST is characterized by the foreshore and inner shelf, shallow marine bioclastic limestone facies association and the shoreface and inner shelf, shallow marine oolitic limestone facies association. The upper boundary of the HST is equivalent

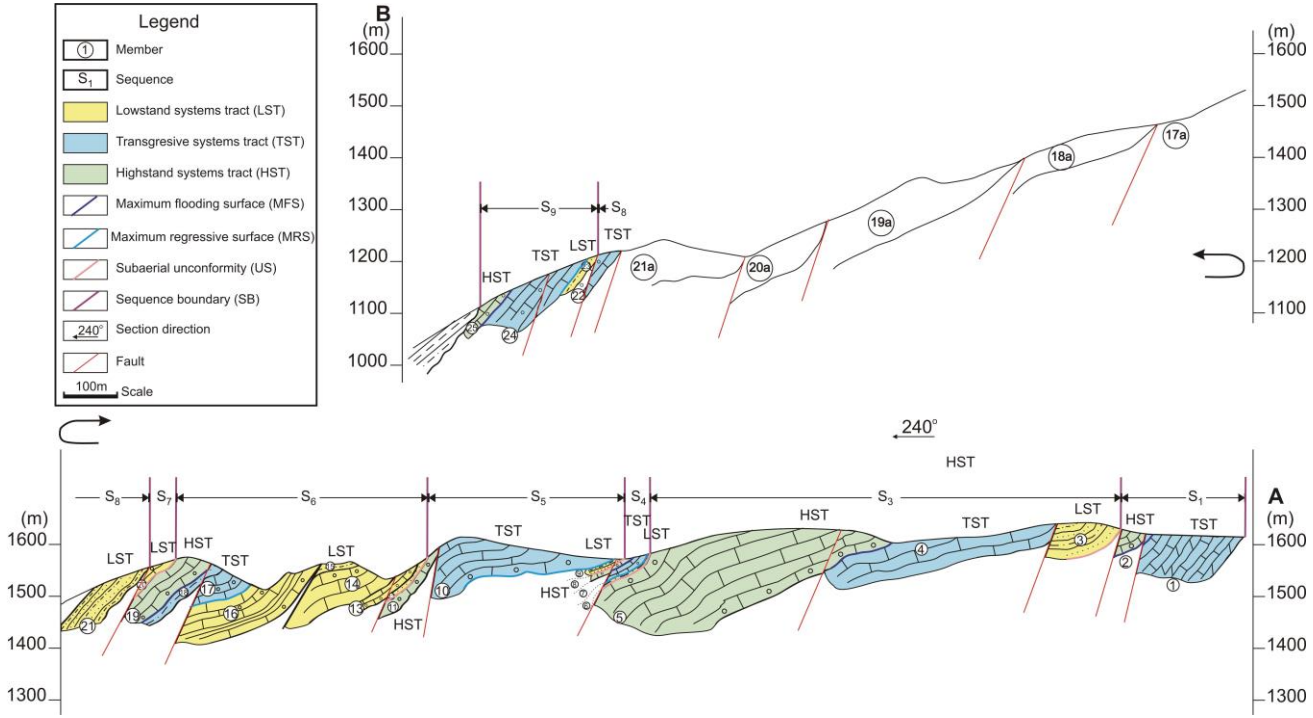


Figure 4.2. Sequence stratigaphic of the Chang Pung section.

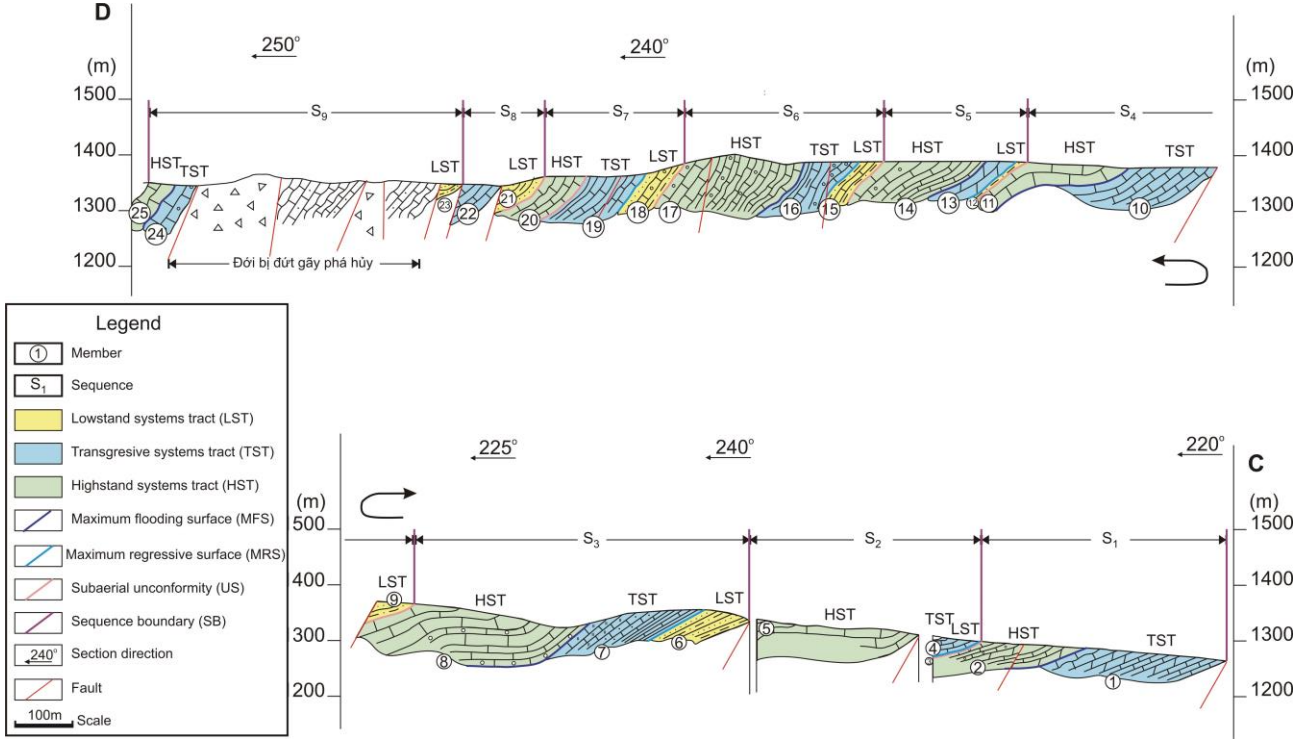


Figure 4.3. Sequence stratigaphic of the Lung Cu II section.

to the boundary between the sequence S_2 and S_3, which is not exposed due to fault.

4.2.3. Sequence S_3

The LST consists of the foreshore and inner shelf, shallow marine calcareous siliciclastic sediments facies association. The occurrence of the trilobite *Cyclolorenzella - Blackwelderia - Drepanura* bed at Chang Pung is early Late Cambrian age (Pham Kim Ngan et al., 2008). In this thesis, trilobite *Blackwelderia* sp., and Brachiopods *Lingulella* sp. are the first time found in the Lung Cu II section. The upper boundary of the LST is MRS at Lung Cu. This surface is change from facies IA to W-G. The TST contains the shoreface and inner shelf, shallow marine marlstone facies association and the bioclastic limestone facies deposited in foreshore and inner shelf, shallow marine (BL). The upper boundary of the TST is MFS. This boundary is marker by the facies WB above and facies L-M below in Lung Cu, while is facies L-M below and facies OG of the HST above in Chang Pung. The HST is characterized facies associations, the foreshore and inner shelf, shallow marine bioclastic limestone, the shoreface and inner shelf, shallow marine marlstone and the shoreface and inner shelf, shallow marine oolitic limestone facies association. The upper boundary of the HST is subaerial unconformity, which is equivalent to the boundary between the sequence S_3 and S_4. This boundary is marker by facies W-G to IA (LC.440) in Lung Cu and facies OG to IA (SS.2028) in Chang Pung.

4.2.4. Sequence S_4

The LST contains the foreshore and inner shelf, shallow marine calcareous siliciclastic sediments facies association. The upper boundary of the LST is MRS. This boundary is marker by facies IA to OG (SS. 2028/1) in Chang Pung. It is not exposed due to fault in Lung Cu. The TST is characterized the foreshore and inner shelf, shallow marine bioclastic limestone facies association, the shoreface and inner shelf, shallow marine oolitic limestone facies association and the offshore, shallow marine carbonate facies association. The upper boundary of the TST is MFS. This boundary is marker by the facies L-M to WB of the HST in Lung Cu. In while is drawn by facies Ltb below and LC above in Chang Pung. The HST contains facies associations, the foreshore and inner shelf, shallow marine bioclastic limestone, the shoreface and inner shelf, shallow marine marlstone, the shoreface and inner shelf, shallow marine oolitic limestone and the offshore, shallow marine carbonate. The upper boundary of the HST is equivalent to the boundary between the sequence S_4 and S_5. This boundary is subaerial unconformity, which is marker by facies W-G to IA (SS. 3032) in Lung Cu.

4.2.5. Sequence S_5

The LST consists of the foreshore and inner shelf, shallow marine calcareous siliciclastic sediments facies association yielding brachiopods *Billingsella tonkiniana* of middle Late Cambrian (Pham Kim Ngan et al., 2008) in the Chang Pung section. The upper boundary with the TST is MRS, which is marker by the change from the foreshore and inner shelf, shallow marine calcareous siliciclastic sediments facies association to facies DL. The TST contains the offshore, shallow marine carbonate facies association. The upper boundary with the HST is MFS, which is marker by facies L-M above and facies Ltb below in Lung Cu. The HST is characterized the foreshore and inner shelf, shallow marine bioclastic limestone facies association and the shoreface and inner shelf, shallow marine oolitic limestone facies association. The upper boundary of the HST is equivalent to the boundary between the sequence S_5 and S_6, which is subaerial unconformity. This surface is drawn by facies LC below to IA above at SS.3061 in Lung Cu and facies OG to IA in Chang Pung.

4.2.6. Sequence S_6

The LST is characterized three facies association, including the foreshore and inner shelf, shallow marine calcareous siliciclastic sediments facies association, the foreshore and inner shelf, shallow marine bioclastic limestone facies association and the shoreface and inner shelf, shallow marine oolitic limestone facies association. There are two zones trilobites *Prochuangia mansuyi* and *Irvingella* - *Pagodia* of Late Cambrian age (Pham Kim Ngan et al., 2008). The upper boundary with the TST is MRS, which is marker by the facies OG below and IL above. The TST consists of the offshore, shallow marine carbonate facies association and facies LC. They contain trilobites *Prosaukia angulate*, *Haniwa* sp. of Late Cambrian age (Pham Kim Ngan et al., 2008). The upper boundary of the TST is MFS. This boundary is marker by facies L-M above and facies SH below in Lung Cu. This is not exposed due to fault destroying the beds on top of facies IA in Chang Pung. The HST consists of facies associations, the shoreface and inner shelf, shallow marine marlstone, the shoreface and inner shelf, shallow marine oolitic limestone, and the shoreface and inner shelf, shallow marine conglomerate limestone. The upper boundary of the HST is equivalent to the boundary between the sequence S_6 and S_7. This boundary is subaerial unconformity, which is drawn by facies OG to IA at SS.3080 in Lung Cu.

4.2.7. Sequence S_7

Sequence S_7 is mainly distributed in the Lung Cu II section, including three systems tract (LST, TST and HST). Due to fault, this is only observed

the LST in Chang Pung. The LST is characterized three facies associations, including the foreshore and inner shelf, shallow marine calcareous siliciclastic sediments, the shoreface and inner shelf, shallow marine marlstone and the shoreface and inner shelf, shallow marine oolitic limestone. There are two zones trilobites *Dictyella mansuyi*, *Tsinania* sp., *Prosaukia* ? sp. of Late Cambrian age (Pham Kim Ngan et al., 2008). The *Dictyella mansuyi* is additional found in the Lung Cu II section. The upper boundary with the TST is MRS. This boundary is marker by the facies IA below to facies OG above at SS.3082 in Lung Cu. The TST contains facies associations, the shoreface and inner shelf, shallow marine marlstone, the shoreface and inner shelf, shallow marine conglomerate limestone, shoreface and inner shelf, shallow marine oolitic limestone, and the foreshore and inner shelf, shallow marine calcareous siliciclastic sediments. The upper boundary of the TST is MFS. This boundary is marker by the facies L-M below and IA above. The HST consists of facies associations the foreshore and inner shelf, shallow marine bioclastic limestone and the shoreface and inner shelf, shallow marine marlstone. The upper boundary of the HST is equivalent to the boundary between the sequence S_7 and S_8. This boundary is subaerial unconformity, which is drawn by facies WB to IA at SS.3088 in Lung Cu.

4.2.8. Sequence S_8

Sequence S_8 is exposed in the high part of two sections and destroyed by fault, thus, observed two incomplete systems tract (LST and TST). The LST contains the foreshore and inner shelf, shallow marine calcareous siliciclastic sediments facies association of the Chang Pung Formation, which yields trilobite *Calvinella walcotti* and brachiopods: *Eoorthis* sp. of lalest Late Cambrian (Pham Kim Ngan et al., 2008). The *Calvinella walcotti* is additional found in the Lung Cu II section. The lower boundary is subaerial unconformity, which is placed at top of the sequence S_7. The upper boundary is observed because of fault. The TST consists of the shoreface and inner shelf, shallow marine marlstone facies association and the shoreface and inner shelf, shallow marine oolitic limestone facies yielding brachiopods: *Oligorthis* sp. and Crinoid *Ramulicrinus* sp. of Early Ordovician age (Pham Kim Ngan et al., 2008). Due to fault, the boundary of the TST is observed in Dong Van area.

4.2.9. Sequence S_9

The sequence S_9 is destroyed by fault like to the sequence S_8, thus, which is not observed complete systems tract. The lower boundary of the sequence S_9 is not exposed in two sections. The upper boundary of the sequence S_9 is limited by the Lower Ordovician - Lower Devonian regional

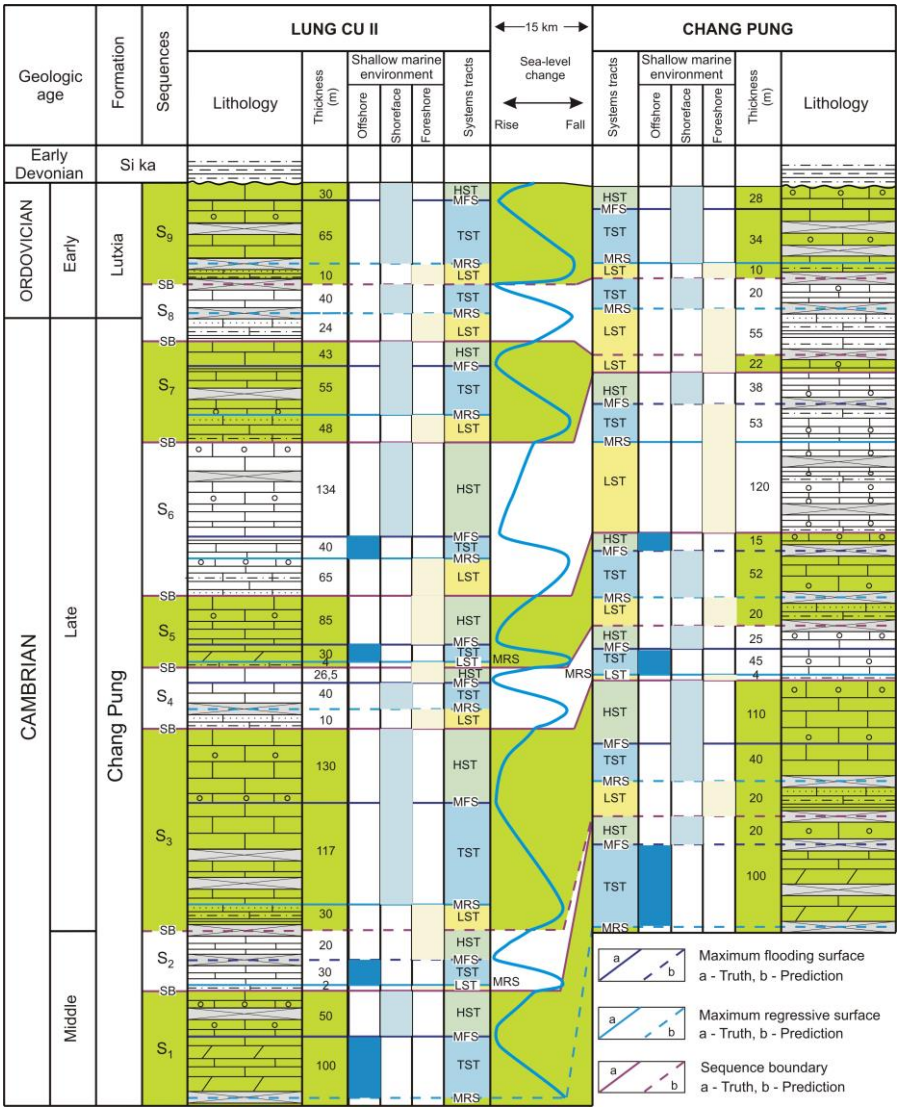


Figure 4.4. The sequence stratigraphy of the Middle Cambrian - Lower Ordovician of the Dong Van area.

unconformity. The LST contains the foreshore and inner shelf, shallow marine calcareous siliciclastic sediments facies association yielding trilobite *Hysterolenus* sp. Early Ordovician age (Pham Kim Ngan et al., 2008). The boundary of the LST is not exposed by fault. The TST is

characterized by the foreshore and inner shelf, shallow marine bioclastic limestone facies association and the shoreface and inner shelf, shallow marine oolitic limestone facies association containing conodont *Cordylodus angulatus, Semiacontiodus* sp., *Iapetognathu* sp., and *Chosonodina* sp. and trilobite *Conophrys* sp. of Early Ordovic age. In addition, Pham Kim Ngan (2008) was collected brachiopods *Oligorthis* sp. of Early Ordovic age in Chang Pung area. The upper boundary of with HST is MFS. This boundary is placed the facies L-S to L-M in Lung Cu, and L-M to LC in Chang Pung. The HST contains the foreshore and inner shelf, shallow marine bioclastic limestone facies association yields conodont *Cordylodus* sp. of Early Ordovic age. The upper boundary of the HST is equivalent to the upper boundary of the sequence S_9. This boundary is Lower Ordovician - Lower Devonian regional unconformity.

Based on the correlation of sequences and sea - level change in both Lung Cu II and Chang Pung sections can be defined the sequence stratigraphic framework for the Middle Cambrian - Lower Ordovician strata of the Dong Van area (Fig. 4.1).

4.3. THE SIGNIFICANCE OF STRATIGRAPHIC DIVISION AND CORRELATION

The Middle Cambrian - Lower Ordovician sedimentary rocks of the Dong Van area can be divided into 2 lithostratigraphic units, including the Middle - Upper Cambrian Chang Pung Formation and Lower Ordovician Lutxia. The Chang Pung Formation can be preliminarily divided into 4 members, Xeo Lung, Cang Tang, Lo Lo and Then Van members.

4.3.1. Xeo Lung Member

The Xeo Lung Member is characterized by alternations of the dolomitic limestone facies deposited in offshore, shallow marine (DL) and the thin-bedded lime mudstone facies formed in offshore, shallow marine (Ltb) in the lower part, and the shoreface and inner shelf, shallow marine oolitic limestone facies association and the foreshore and inner shelf, shallow marine bioclastic limestone facies association in the upper part. Thickness is about 120 - 150m. The lower boundary of the Xeo Lung Member was not exposed because of faulting. The upper boundary of the this member is subaerial unconformity which separates the wackestone to grainstone facies reflects deposition in foreshore and inner shelf, shallow marine (W-G) from the calcareous sandstone - siltstone facies deposited in foreshore and inner shelf, shallow marine (IA). Based on the trilobite *Damesella* sp. (Pham Kim Ngan et al., 2008) of the Xeo Lung Member indicates a late Middle Cambrian age.

4.3.2. Cang Tang Member

The Cang Tang Member is subdivided into three members in ascending order: The Lower Member consists of the foreshore and inner shelf, shallow marine calcareous siliciclastic sediments facies association yield abundant the trilobites *Blackwelderia* sp., *Damesella* sp., *Cyclolorenzella tonkinensis, Damesella brevicaudata, Drepanura premesnili, Pseudagnostus douvillei, Stephanocare richthofeni, Paracoosia deprati* in the Chang Pung section (Pham Kim Ngan et al., 2008). The Middle Member mainly characterized by alternations of the limestone - marlstone alternation facies reflects sedimentation in shoreface and inner shelf, shallow marine (L-M) and the wackestone to grainstone facies reflects deposition in foreshore and inner shelf, shallow marine (W-G). The Upper Member consists of the oolitic limestone facies indicates deposition in shoreface and inner shelf, shallow marine (OG) interbedded with the foreshore and inner shelf, shallow marine bioclastic limestone facies association. Thickness is about 170 - 329m. The lower boundary of the member is subaerial unconformity underlain by the Xeo Lung Member. The upper boundary is subaerial unconformity which draws the the wackestone to grainstone facies reflects deposition in foreshore and inner shelf, shallow marine (W-G) from the calcareous sandstone - siltstone facies deposited in foreshore and inner shelf, shallow marine (IA). The Cang Tang Member is early Late Cambrian in age based on the trilobites above (Pham Kim Ngan et al., 2008).

4.3.3. Lo Lo Member

The Lo Lo Member is composed mainly of the limestone - marlstone alternation facies reflects sedimentation in shoreface and inner shelf, shallow marine (L-M) interbedded with dolomitic limestone. Especially, the stromatolitic limestone occurs in the middle part of the member. It is a marker layer to correlate the Lo Lo Member between the Lung Cu II and Chang Pung sections. In addition, in the middle part of Lo Lo Member, the siltstone layers of the foreshore and inner shelf, shallow marine calcareous siliciclastic sediments facies association yields brachiopod *Billingsella tonkiniana* in middle Late Cambrian age (Pham Kim Ngan et al., 2008). Thickness is about 161 - 200m. The boundaries of the Lo Lo Member are subaerial unconformities. The lower boundary is underlain by the Cang Tang Member. The upper boundary is overlain by the Then Van Member.

4.3.4. Then Van Member

The Then Van Member is characterized by the calcareous sandstone - siltstone of the foreshore and inner shelf, shallow marine calcareous siliciclastic sediments facies association interbedded with facies of

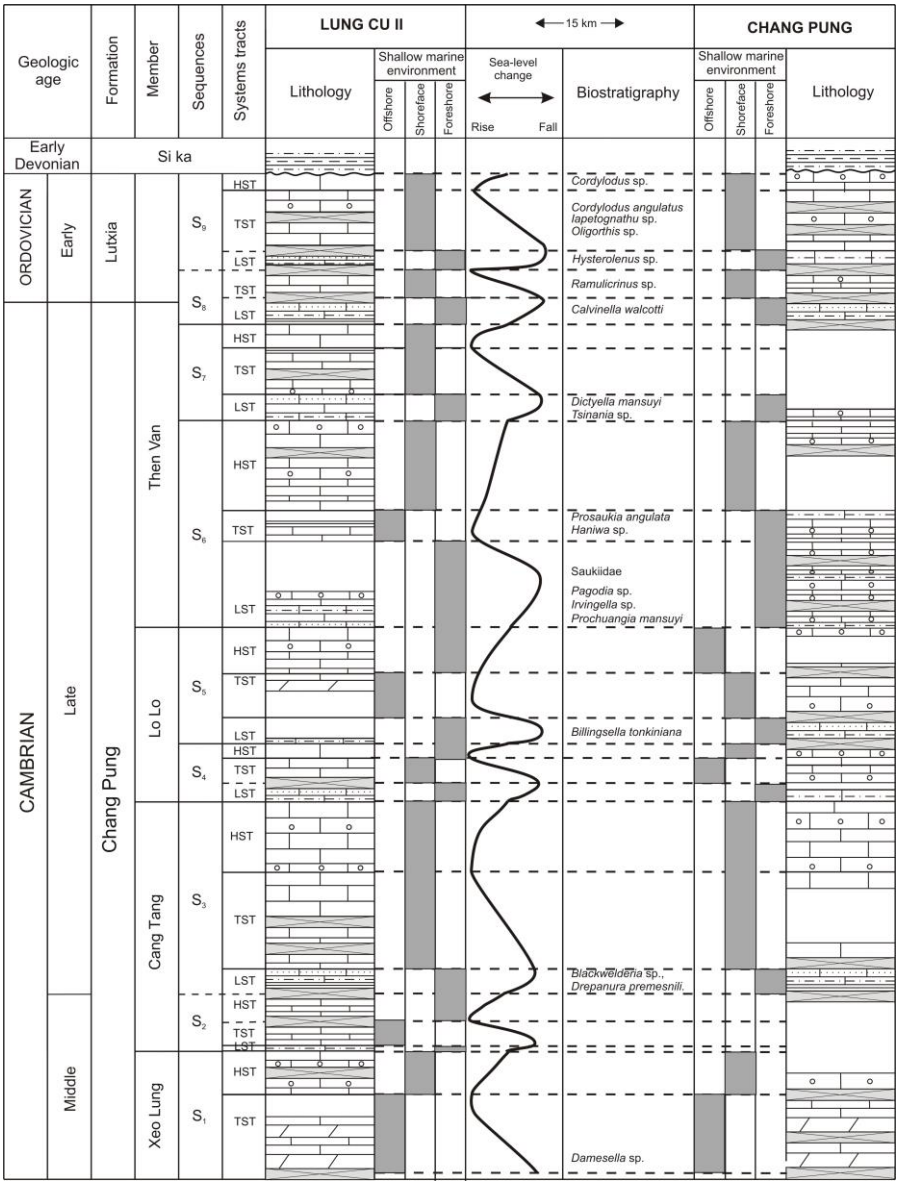


Figure 4.5. The chronosequence stratigraphic framework of the Middle Cambrian - Lower Ordovician of the Dong Van area.

different carbonate facies association. The Then Van Member is subdivided into three members in ascending order: The Lower Member consists of the

presence of small size trilobites *Prochuangia mansuyi*, *Caulaspina* sp., *Pagodia* sp., *Irvingella* sp., of Late Cambrian age (Pham Kim Ngan et al., 2008) in the calcareous sandstone - siltstone interbedded with the cross-bedding limestone facies deposited in shoreface and inner shelf, shallow marine (CL) and the intraclastic limestone facies reflects deposition in shoreface and inner shelf, shallow marine (IL). The Middle Member mainly characterized by alternations of the limestone - marlstone alternation facies reflects sedimentation in shoreface and inner shelf, shallow marine (L-M) and the oolitic limestone facies indicates deposition in shoreface and inner shelf, shallow marine (OG). Especially, in this part, the ash-gray, yellowish and pink yellowish weathering, thin-bedded calcareous sandstone - siltstone yields trilobites *Dictyella mansuyi, Prosaukia angulate, Haniwa* sp. of Late Cambrian age (Pham Kim Ngan et al., 2008). The Upper Member characterized by disappearance of facies of carbonate facies association, mainly consists of the calcareous sandstone - siltstone yielding trilobites *Calvinella walcotti* and brachiopods *Eoorthis* sp. of lastest Late Cambrian age (Pham Kim Ngan et al., 2008). Thickness is about 288 - 407m. The lower boundary is subaerial unconformities, which is overlain by the Lo Lo Member. The upper boundary of the Then Van Member is not exposed by fault, which is placed at the boundary of the Chang Pung and Lutxia formations. The Then Van Member is late Late Cambrian in age based on the trilobites above.

In summary, based on the fossil record, the correlation of sequences and formations with sea - level change in both Lung Cu II and Chang Pung sections can be defined the chronosequence stratigraphic framework for the Middle Cambrian - Lower Ordovician strata of the Dong Van area (Fig. 4.2).

Chapter 5

DEVELOPMENTAL HISTORY OF SEDIMENTARY ENVIRONMENT OF THE MIDDLE CAMBRIAN - LOWER ORDOVICIAN STRATA OF THE DONG VAN AREA

The Middle Cambrian - Lower Ordovician sedimentary rocks of the Dong Van area in northeast Vietnam, is composed of 9 sequences (S_1 - S_9) is equivalent to 9 developmental stages of sedimentary environment on cause - effect relationship within 9 cycle of global sea level change (John W. Snedden và Chengjie Liu, 2010), including 1 cycle in the Middle Cambrian, 2 cycles in the Middle - Late Cambrian, 4 cycles in the Late Cambrian, 1 cycle in the Late Cambrian - Early Ordovician, 1 cycle in the Early Ordovician. The sequences in Dong Van area can be correlate to sequences of Hardenbol et al. (1998) during Middle Cambrian - Early Ordovician (Fig 5.1).

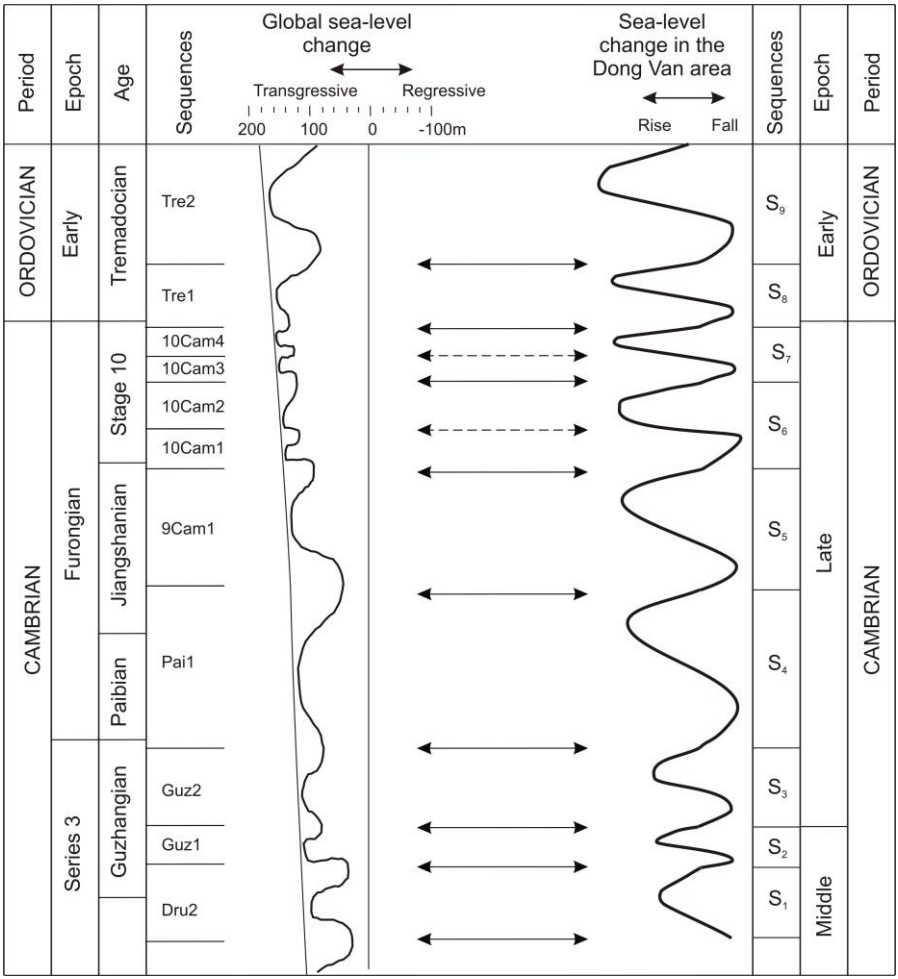


Figure 5.1. Correlation of the curve of global sea-level change (following to John W. Snedden and Chengjie Liu, 2010) and sea-level change of the Dong Van area during Middle Cambrian - Early Ordovician period.

The Middle Cambrian period, the global sea level is relatively raised with high level, and then is the period of sea level falling, forming a sedimentary cycle is equivalent to the sequence (S_1), which is related to the global third-order sequence Dru2.

The Middle - Late Cambrian period, forming two sedimentary cycles are corresponding to two sequences (S_2 related to Guz1 và S_3 related to Guz2).

The Late Cambrian period, the sea was developed and expanded during the relatively stable tectonic regime, forming four sedimentary cycles are corresponding to four sequences, S_4 related to Pai1, S_5 related to 9Cam1, S_6 related to 10Cam1 and 10Cam2, and S_7 related to 10Cam3 and 10Cam4.

The Late Cambrian - Early Ordovician period, forming a sedimentary cycle is equivalent to the sequence (S_8 related to Tre1).

The Early Ordovician period, forming a sedimentary cycle is equivalent to the sequence S_9, which is related to Tre2.

CONCLUSION

1. This study is the analysis to the application of the suitable sequence stratigraphic model to the Middle Cambrian - Lower Ordovician sedimentary rocks in the Dong Van area in northeast Vietnam.

2. The Middle Cambrian - Lower Ordovician sedimentary rocks of the Dong Van area in northeast Vietnam, are composed of six facies association types and fifteen facies types: The offshore, shallow marine carbonate facies association: (1) The thin-bedded lime mudstone facies formed in offshore, shallow marine (Ltb) and (2) The dolomitic limestone facies deposited in offshore, shallow marine (DL); The shoreface and inner shelf, shallow marine marlstone facies association: (3) The limestone-shale alternation facies indicates deposition in shoreface and inner shelf, shallow marine (L-S) and (4) The limestone - marlstone alternation facies reflects sedimentation in shoreface and inner shelf, shallow marine (L-M); The shoreface and inner shelf, shallow marine conglomerate limestone facies association: (5) The intraclastic limestone facies reflects deposition in shoreface and inner shelf, shallow marine (IL) and (6) The limestone conglomerate facies formed in shoreface and inner shelf, shallow marine (LC); The shoreface and inner shelf, shallow marine oolitic limestone facies association: (7) The cross-bedding limestone facies deposited in shoreface and inner shelf, shallow marine (CL), (8) The oolitic limestone facies indicates deposition in shoreface and inner shelf, shallow marine (OG) and (9) The oncolitic limestone facies reflects sedimentation in shoreface and inner shelf, shallow marine (OL); The foreshore and inner shelf, shallow marine bioclastic limestone facies association: (10) The bioturbated wackestone facies formed in foreshore and inner shelf, shallow marine (WB), (11) The wackestone to grainstone facies reflects deposition in foreshore and inner shelf, shallow marine (W-G), (12) The bioclastic limestone facies deposited in foreshore and inner shelf, shallow marine (BL) and (13) The stromatolitic limestone facies reflects deposition in foreshore and inner shelf, shallow marine (SL); The foreshore and inner shelf, shallow marine calcareous siliciclastic sediments facies association:

(14) The calcareous shale facies formed in foreshore and inner shelf, shallow marine (SH) and (15) The calcareous sandstone - siltstone facies deposited in foreshore and inner shelf, shallow marine (IA).

3. The sequence stratigraphic framework is proposed for the Middle Cambrian - Lower Ordovician sedimentary rocks of the Dong Van area in northeast Vietnam, which is composed of 9 sequences (S_1 - S_9). The each of sequence includes three systems tracts: lowstand systems tract (LST), transgressive systems tract (TST) and highstand systems tract (HST).

+ The lowstand systems tract (LST) is characterized by foreshore and inner shelf, shallow marine calcareous siliciclastic sediment facies association.

+ The transgressive systems tract (TST) consists of limestone facies association deposited in foreshore and inner shelf to offshore, shallow marine.

+ The highstand systems tract (HST) contains the thin-bedded lime mudstone formed in offshore, shallow marine and foreshore and inner shelf, shallow marine limestone facies association.

4. The chronosequence stratigraphic framework is proposed for the Middle Cambrian - Early Ordovician period of the Dong Van area in northeast Vietnam.

5. The Middle - Upper Cambrian Chang Pung Formation occurring in the Dong Van area is divided into 4 members, including Xeo Lung, Cang Tang, Lo Lo and Then Van members, for geological mapping and regional stratigraphic correlation.

6. The reconstruction of sedimentary environment of the Middle Cambrian - Lower Ordovician strata of the Dong Van area in northeast Vietnam is preliminarily clarified, which is mainly controlled by global sea-level changes, including 9 developmental stages in corresponding to 9 cycle of sea level change.

7. The curve of sea-level change of the Dong Van area in northeast Vietnam is preliminarily correlated with global sea-level changes during Middle Cambrian - Early Ordovician period.

SUGGESTION

- To study on the high resolution stratigraphy of biostratigraphy, sequence stratigraphy and chemostratigraphy for establishing the premise, criterion and prospect assessments of related minerals.

- To study the application the sequence stratigraphic method for revising, division and stratigraphic correlation the pre-Cenozoic strata for geological mapping and mapped linkage in Vietnam.

RESEARCHER'S PUBLICATIONS RELATED TO THE THESIS

1. **Phong Nguyen Duc**, Jerzy Dzik, Mark Williams, Toshifumi Komatsu, 2017. *Early Ordovician conodonts and graptolites in northeast Vietnam*. IGCP 653 'The onset of the Great Ordovician Biodiversity Event' annual meeting, Yichang, China.

2. Jerzy Dzik, **Nguyen Duc Phong**, 2016. *Dating of Cambrian - Ordovician boundary strata in northernmost Vietnam and methodological aspects of evolutionary biostratigraphic inference*. Stratigraphy, vol. 13, no. 2, 83–93.

2. **Nguyen Duc Phong**, Nguyen Viet Hien, Nguyen Thi Thuy, Nguyen Huu Manh, Jerzy Dzik, Toshifumi Komatsu, Ryota Urakawa, 2016. *Lower Ordovician conodonts Cordylodus from the Lutxia Fomation in the Lung Cu area, northeastern Vietnam*. Palaeontological Society of Japan. Abstracts with Programs, the 2016 Annual Meeting.

4. **Nguyen Duc Phong**, Tran Nghi, Tran Tan Van, Rudy Swennen, Toshifumi Komatsu, Tran Huu Dan, Nguyen Xuan Phong, 2015. *The presence and significance of carbonate grains in sediments of the Chang Pung Formation in Lung Cu area, Dong Van, Ha Giang*. Geology and Mineral Resources, Volume 11, 50th anniversary of Vietnam Institute of Geosciences and Mineral Resources (1965-2015), 1-7p, Ha Noi.

5. Tran Tan Van và **Nguyen Duc Phong**, 2011. *Stratigraphy of Paleozoic carbonate rocks in North Viet Nam*. Workshop on Palaeozoic Limestone of South-East Asia and South China, Malaysia.