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Karst poljes in Viet Nam – The Relationship between Terrain and Geological Structure

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ABSTRACT: The karst formations are widely distributed in the world. In Vietnam, karst occurs in an area of approximately 60,000 km^2. This is an important geological formation. In karst, there are many different types of terrain such as blind valleys, dolines, karst valleys, through valleys, ponor and karst poljes, carren, microcarren. Although there have been many research works in karst areas, they only focused on karst geomorphology, karst water, and karst related catastrophes. In this paper, the author addresses the connection between geomorphology and geology. More specifically, the relationship between the terrain and the geological structure of the karst poljes, explain the relationship of karst process with modern tectonic motion. The Karst area is very complicated and difficult to go to. But with determination and Love my job, the author has completed the task.

Accordingly, the author concludes that the karst poljes are all distributed on the folded structures and the karstization process is strongly influenced by modern tectonic movements. The formation and development of karst poljes commences with the vertical karstification, then the horizontal development. The karst process is mostly intense in karst areas dominated by tectonic activities and uplifting in the continental environment.

Keywords: karst, karst poljes, karstification, limestone, structural, fold.

I. INTRODUCTION

There have been many geologists in Vietnam and in the world interested in karst research [1], [2], [3], [4], [5], [6], [7], [8], [9], [10], [11], [13], [14], [15], [16],[17], [18], [19], [20], [21]. The study area is the karst distribution area of the North Vietnam (Fig.1). There are many special terrains in karst areas such as blind valley, doline, karst valley, through valley, ponor and karst polje, carren, microcarren. Among them, karst polje is one of the most important types of terrain since there are many factories on the karst poljes, which are populated areas and socio-economic centers.Even karst poljes became the capital of some provinces such as Lai Chau, Lang Son and Moc Chau.

There are many karst poljes in the Vietnam karst area, however, they are not large. Most karst poljes have an area of only few km2 (Chiềng La karst polje – Lang Sơn province, Na Pai and Ban Hau karst poljes- Lang Sơn province, Yen HoaYên Hoà karst polje- Quang Binh provinceetc). The author chooses threekarst poljes (Tam Duong karst polje, Moc Chau karst polje, Lang Son karst polje). Those are three of the largest karst poljes in Vietnam (Fig. 1).

II. MATERIALS AND METHODS

- The author has collected and done research on a huge amount of documents covering the territory of Vietnam. These are all 1/200,000, 1/50,000 scale geological mapping documents, in-depth studies on karst such as the Northwest karst geological study, of which the author was a participant between 1994-1998.

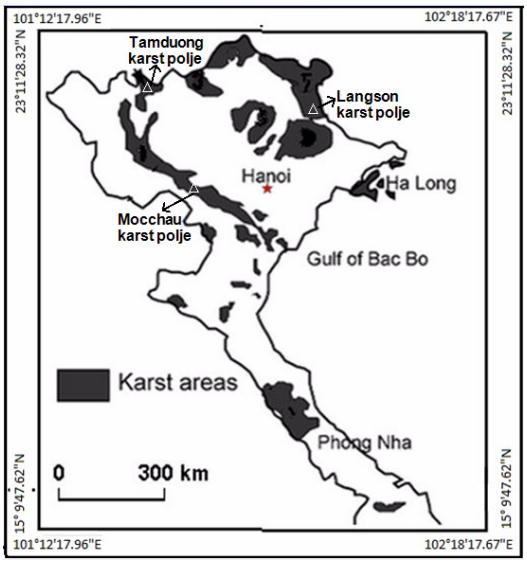

Fig. 1. Distribution of karst areas in Vietnam.

- The author's research results from 1994 to present, especially articles on the karst in recent years. Based on the scientific application between theory and practice, in particular, results of the analysis of satellite images, air photos and topographic maps have been verified by the Author at the site. Choosing locations for accurate results as the "key" area for analysis and interpretation of other regions. Because the distribution area of karst

is very large andmany areas have not been able to conduct field surveys.

- The result of cooperation between the Institute of Geosciences and Mineral Resources and Leven University of Belgium between 1993 - 2004. The Author joined with Belgian experts to survey caves in Huong Son, Thay Pagoda (Hanoi), Thuan Chau, (Son La), Sin Ho (Lai Chau) from 1994 to1998.
- Collecting and synthesizing all relevant geological documents along with selecting the formations containing carbonate rocks. All research documents about karst, especially the results of karst research of the author from 1994 to the present, are taken into account.
- Researching the karstization process based on the theory of Derek and Paul (2007) and Petar (2018) [1,8]. The theoretical basis is the dissolution of limestone and dolomite related to the pH and CO_2 concentration of the environment and the activity of the biological world. The carbonate rock dissolution process is described by the following reaction (Fig. 2).

$$Ca,Mg\ (CO_3)_2 + 2CO_2 + 2H_2O \Leftrightarrow Ca^{2+} + Mg^{2+} + 4HCO_3^{2-}$$

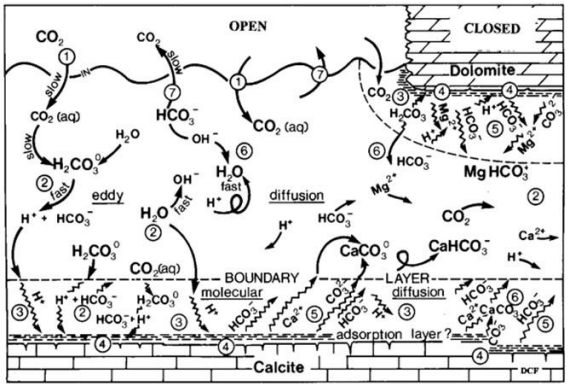

Fig. 2. Limestone dissolution process in karstization (Derek and Paul 2007)[1].

- Analyzing satellite images, air photos, UTM topographic maps at the scale of 1/50,000 to determine the distribution of karst areas and the location of the karst poljes.
- Reconnaissance at the site, measurement of parameters such as bedding of rocks. The focus is on karst poljes. Verifying the results analyzed in the 2nd step.

Fig 3. Lang son fold is destroyed by the karstification process to form Lang Son karst polje (Field investigation 2019).

Field investigation checks and compares with room research results to determine the accuracy of topographic map analysis, satellite image analysis, air photo analysis. The results of testing the karst polje distribution in the field completely fit with the research results in the room (Fig. 3).

III. RESULTS AND DISCUSSION

A. Geological settings

Karst formations in Vietnam are distributed in 31 provinces and cities, but concentrated in the North and the North of the Central Region (Fig 1). They are distributed in many different strata. Research results of Nguyen Xuan Khien, Chu, SK., (2005) [6] suggest that karst formations in Vietnam belong to four groups including pre-Cambrian Limestone Group; Middle Cambrian - Middle Devonian Limestone Group; Devonian - Permo-Carboniferous Limestone Group, and Permo-Carboniferous - Middle Triassic Limestone Group. The distribution area and the thickness of those four groups of limestone are not the same. Researching and analyzing the 1/200,000, 1/50,000 geological maps of the General Department of Geology and Minerals of Vietnam [2], the author has established the main carbonate rock formations of Vietnam. Below is a description of those stratigraphic units.

The oldest carbonate formation in Vietnam is Ham Rong limestone formation (€ $_3$*hr*). With a thickness of 400-720m, its composition is mainly limestone, dolomite limestone and oolitic limestone. The limestone is greenish-gray containing Trilobita fossils [2].

The thickness of Lutxia Formation (O_1*lx*) is from 200-400m and its composition consists of limestone interbedded with shale and lime clay containing fossil Trilobite (*Isotelus stenocephalus, Hysterolenus sp.,*).

The thickness of Na Quan Formation (D_1-D_2*nq*) is between 230-400m and its composition consists of black limestone and limestone containing corals: *Coenites. vermicularis, Favosites goldfussi, Fav. stellaris, Parastriatopora sp.*

Ban Cong Formation (D_2*gv*-D_3*bc*) consists of fine-grained limestone weakly recrystallized and sometimes dolomitized, with a thickness of 600-800m containing fossilStromatoporoidea Frasni: *Clavidictyon (?) cf. milcreckense, Parathurammina sp., Bisphaera sp., Vicinesphaera sp., BrachiopodaGipidula sp., Devonoproductus sp.*

Bang Ca Formation (D_3fr*bc*) consists of bright limestone and fine-grained limestone bedded with thick or massive structure, with a thickness of 220m containing fossil: *Stromatoporoidea, Tabulata, Rugosa, Brachiopoda.*

Toc Tat Formation (D_3fr-C_1? *tt*) consists of banded limestone with motley, violet-red and greenish-gray colors interbedded with many layers of siliceous clay, with a thickness of 300-350m containing fossil: *Palmatolepisglabra, P. glabrapectinata, Uralinellabicamera, Uralinella sp.*

Pho Han Formation (D_3 - C_1*ph*) consists of dark gray fine-grained limestone and dark gray limestone containing Foraminifera fossils: *Endospiroplectamminavenusta, Endothyraparakosvensis, Septabrunsiina:endothyroides, Tournayella sp. ...* 200m thick.

Lung Nam limestone formation (C_1t-v*ln*) consists of dark gray - light gray limestone and dark gray micro-small-grained limestone containing foraminiferal fossils: *Tournayelladiscoidia, Planoendothyrasp; Endothyrasp; Endothyraantiqua; Septabraniinakarakubensis; Septatournayella sp.* 130m thick.

Bac Son Formation (C-P_3*bs*) consists of marmorized limestone, oolithic limestone, marble and dolomitized limestone with gray and light gray colors. With the thickness of 600-880m, it contains fossil: *Triticites paramontiparus, T. sp., Occidentoschwagerina sp., Schwagerina cushmani, Neoschwagerina simplex, Pseudodoliolina ozwai, Cancellina sp..*

Dong Dang limestone formation (P_3*đđ*) is gray, light gray, massive structure or ataxitic structure, micro- small grained texture, bedded thick to massive. With the thickness of 280m, it containsfossil: *Palaeofusulina prisca, Colaniella ex.gr. lepida, Colaniella parva, Reichelina pulchra, Codonofusiella kwangsiana, Neoendothyra compressa, Pachyphloia sp., Lasiodiscus sp., Neodiscus sp.*

Dong Giao Formation (T_2a*đg*) is gray, light gray, microgranular limestone, bedded structure. With the thickness of 800-1200m, it contains fossil: *Anisi Paraceratites subtrinodosus, Mentzelia mentzelii and Daonella sturi, Costatoria proharpa,etc.*

Carbonate rocks are characterized by fossil richness. The carbonate formations in Vietnam are mostly formed in shallow coastal warm waters.

Above are the typical formations containing carbonate rocks in Vietnam. It would be more if taking into account carbonate rock formations in the form of interfringer layers, lenses or impure limestones.

B. Distribution of karst fields

In the karst area, there are many karst poljes of different sizes. The karst fields have regular distribution, easily recognized on satellite and aerial photos. The karst poljes are identified by photographic tone, texture, pattern, shape, combinations of recognition elements.

The karst fields feature closed valleys which are lower than the surrounding terrain with a horizontal bottom. For example, Lang Son karst polje and Tam Duong karst polje is densely populated along with headquarters and factory (Fig. 3). In the satellite image, karst fields and limestone distribution areas have a different structure from those of non-karst rocks. The locations, which are karst fields are covered by a dense population, transportation systems, buildings, and houses. Recognized in the image as squares, surrounded by bright fine dots. Around the karst fields are carbonate mountains with very few hydrological systems (Fig. 3. Tam Duong karst polje is an example).

The study and determination of the distribution of karst poljes were conducted by the Author from general to detail, analyzing the relationship between geomorphology and geology to find out the rule. The author chooses the three largest karst poljes in Vietnam located at different positions in the vertical movement speed (Fig. 4).

Fig. 3. Tam Duong karst polje [22].

The research results show that all karst poljes are developed in the direction of the geological structure and located on the folded structure. See structural lithography (Fig. 5, Fig. 6, Fig. 7) and cross-sectional structures across karst poljes.

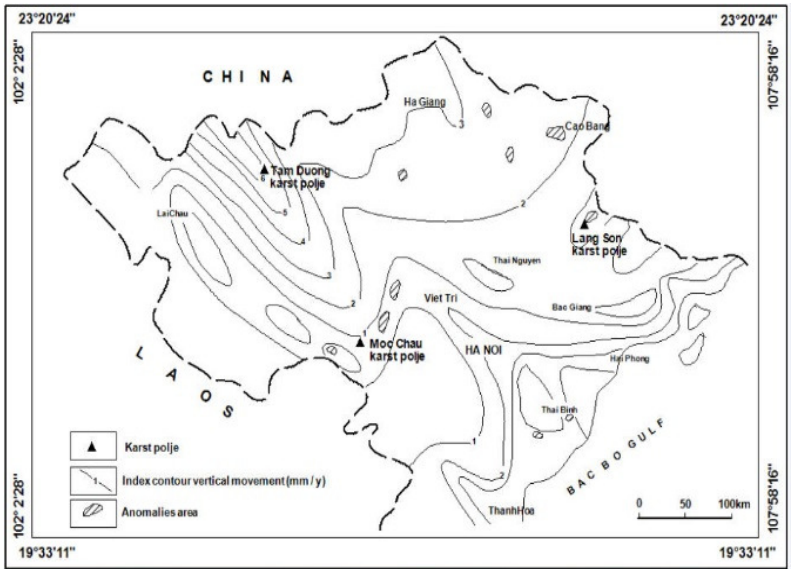

Fig 4. Position of 3 karst poljes on the Neotectonicvertical movement speed (To, T.D., yem. N.T., 1991)[12].

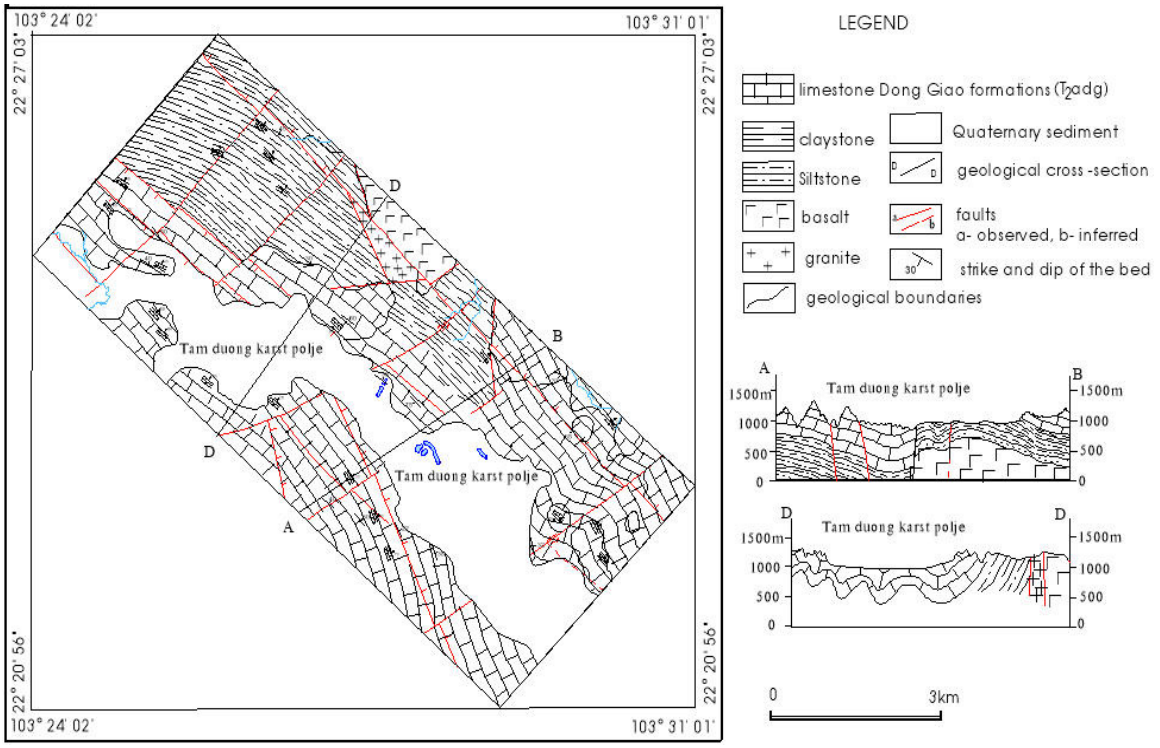

Fig. 5. Lithologic structural diagram of Tamduong area.

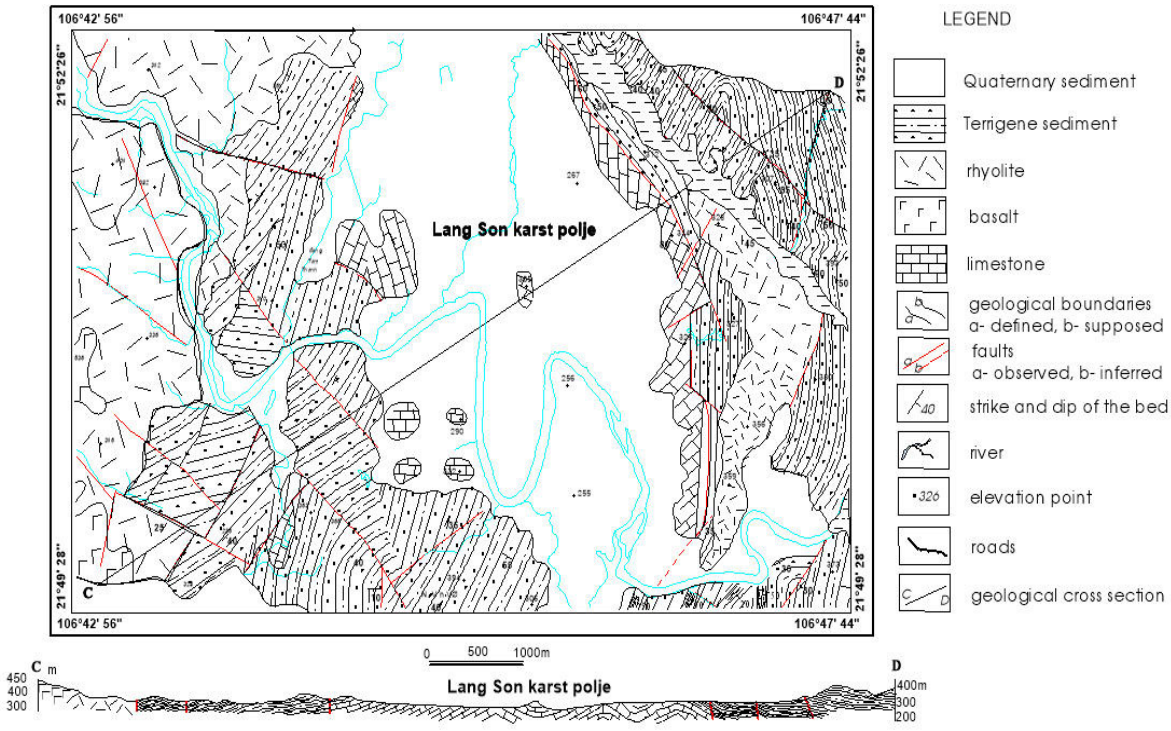

Fig. 6. Lithologic structural diagram of Langson area.

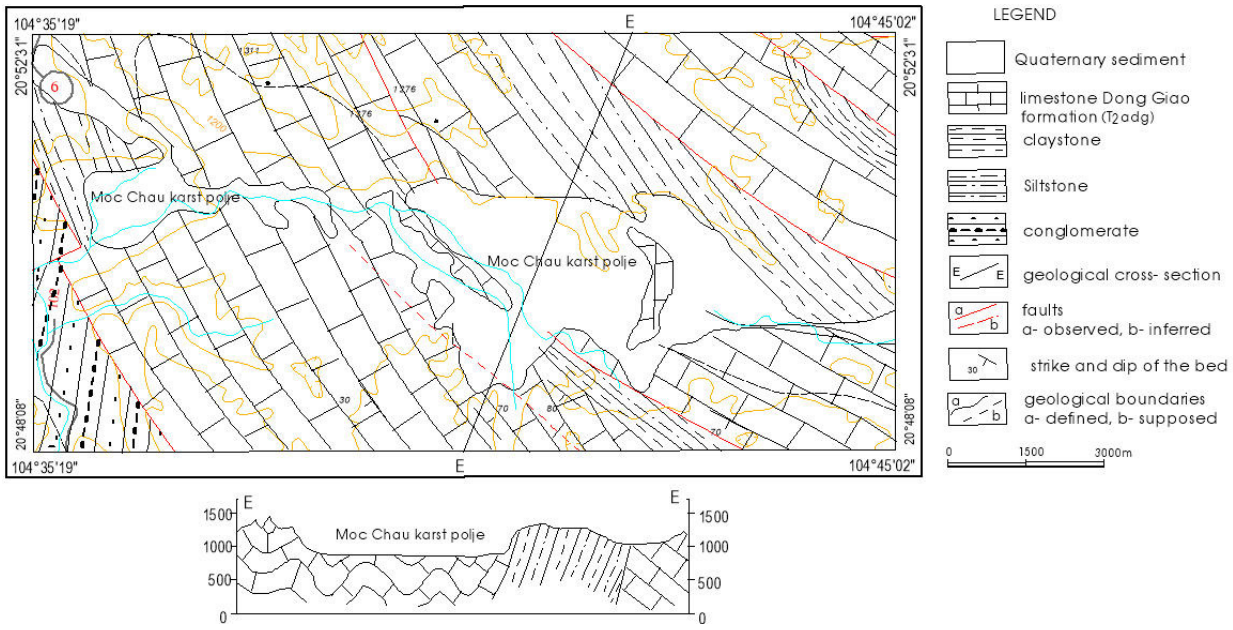

Fig. 7. Lithologic structural diagram of Mocchau area.

Tam Duong karst polje is distributed at an altitude of about 900m, extending in the NW-SE direction, with a length of about 20 km and a width of about 7 km. Tam Duong karst polje formed on Dong Giao limestone formation.

The geological activity created the fold system, promoting karstification. Southwest limb bedding measured 220-250 ∠ 30- 80, Northeast limb bedding measured 60- 80 ∠ 25-55.

Lang Sơn karst polje. Lang Son karst polje has a rhombus shape, the long axis developed according to the meridians. The area of Lang Son karst polje is about 20 km^2. There are some tectonic activities on formation of Bac Son limestone, forming a fold structural system. The section line cross to Lang Son karst poljes shows: Northwest limb measured bedding: 300- 310∠25-50, Southeast limb bedding measured 120-14∠ 20-50.

Moc Chau karst polje. Moc Chau karst polje is distributed at an altitude of over 1000m, developing in the Northwest - Southeast direction, an area of about 70 km^2. The section line cross to Moc Chau karst poljes shows: Southwest limb bedding measured 240-260∠30-70, Northeast limb bedding measured 50- 80∠ 25-70. Karst polje formed on Dong Giao limestone formation. Tectonic activities have created the fold system.

C. Discussion

The studies on karst in Vietnam have been interested by many Authors (Derek, F., Paul, W., 2007, DGMVN, Do, v., 1979, Gams, I. ,1978, Jan, M., Rudy, S., Khien, X. N., 2003, Khien, X. N., Chu, S.K., 2005, Nang, D.T., 1979, Petar (2018), Research karst landscape for tourism. Project KT-01-07, Sweeting M.M., 1972, Thuy, N.T., 1972, To, T.D., yem. N.T., 1991, Tuan, C.L., 2012, Tuan, C.L., 2009, Tuan, C.L., 2019, Tuan, C.L., 2020, Tuyet, D., *et al.,* 2003, Tuyet, D *et al.,* 2002, Tuyet, D *et al.,* 1998, Yuan, D. X., 1991). These projects mainly researched geomorphology, cave characteristics. In particular, Do Tuyet and Dao Trong Nang had descriptions for karst poljes.

Derek & Paul (2007) have contributed a lot in karst research. In his work "Karst Hydrogeology and Geomorphology", he focuses on areas such as:

The Karst Rocks, Dissolution: Chemical and Kinetic Behaviour of the Karst Rocks, Distribution and Rate of Karst Denudation, Karst Hydrogeology, Analysis of Karst Drainage Systems, Speleogenesis: The Development of Cave Systems, Cave Interior Deposits, Karst Landform Development in Humid Regions, The Influence of Climate, Climatic Change and Other Environmental Factors on Karst Development, Karst Water Resources Management, Human Impacts and Environmental Rehabilitation (Derek & Paul 2007).

When studying karst poljes, Gams (1978) gave 3 typical criteria of karst poljes:

- Flat floor in rock (which can also be terraced) or in unconsolidated sediments such as alluvium;
- A closed basin with a steeply rising marginal slope at least on one side;
- Karstic drainage

Nang, (1979), described and partitioned karst in Vietnam and explained some of thenatural phenomena that often occur in karst areas in “Karst topography in Vietnam” (Nang, 1979).

Tuyet *et al.,* (1998), based on the classification of Gams (1978) to describe karst poljes in the Northwest of Vietnam. In addition, he has divided Vietnamesekarst into seven regions, describing topographic forms and

referring to karst hydrology. More in depth are cave research findings in karst areas in the Northwestern of Vietnam. This is the result of research cooperation between the Vietnam Institute of Geosciences and Mineral Resources, and Belgium LeuVan University (Tuyet, *et al.,* 2002, 2003)

Regarding the intensive research on karst, there is Petar (2018) with the work “Karst hydrogeology”. In this book, he mentioned 2 parts Petar (2018) [8].

- Part 1: Hydrogeology of karst terranes
- Part 2: Methods of hydrogeological investigations of karst characterizes

There are many issues presented by Petar (2018) in the above two parts. In it, in Chapter 8, Item 8. 5 (Structural analysis, page 194), the importance of faults and cracks in the movement of water was mentioned. Petar (2018) made the following comment:

“The fracture genesis classification (tensile, shear, and release); Statistical analysis of space position or only elongation of earlier classified fractures according to genesis or size; and Correlation of basic parameters of fracture systems with the remaining parameters that are essential for determination of hydrogeological characteristics of the region under study” (Petar (2018)[8].

Karst is widely distributed in China, over area of ~200.000km^2. Chinese scientists have been investing a lot of research in this field. Professor Yuan Dao Xian has many studies on karst. In his work "Karst of China," the issues related to Chinese karst are studied by him such as (Yuan, D. X., 1991,):

Basic Features and Background for Development of Karat in China

Major Karst Types in China

Cave in China

Karst Environmental Problems in China

Karst Water Resources in China

Mineral and Oil- Gas Resources in Karst Regions of China

Karst Scenery Resources

Thus, the book of Professor Yuan Daoxian also does not care about the relationship of karst poljes with geological structure.

In summary, although not listed all studies on karst in the World and in Vietnam, with the in-depth karst studies mentioned above, there has not been any work mentioning the relationship between topography and geological structure in karst areas. Especially, the relationship between karst poljes and geological structure - a terrain form is very important for human life and socio-economic development in Vietnam.

To explain the relationship of karst poljes with geological structure, the author has established structural lithography schema, geological sections across karst poljes.

Tuan, (2012) discussed the relationship between topography and bedrock in Chapter 8 of the "General Geology" textbook, referring to 5 rock groups including carbonate rocks [13].

Later, Tuan, (2020) mentioned "Characteristics of karst polje in Vietnam and associated geohazards". Accordingly, the process of formation and development of karst poljes in the areas of Tam Duong, Moc Chau, Mai Son, Lang Son, Ban Hau, Yen Hoa has gone through 5 stages [17]

- The Carboniferous-Triassic period, the Tam Duong, Moc Chau, Mai Son, Lang Son, Ban Hau, Yen Hoa area was subsided in the sea. This is the time to produce a limestone platform. Initially, these limestone formations have horizontal bedding (Fig. 8A).
- Since the Late Cretaceous, due to tectonic inversion, the Tam Duong, Moc Chau, Mai Chau, Lang Son, Ban Hau, Yen Hoa areas have been gradually uplifted and hence the pre-existing rocks have experienced a strong ductile deformation to produce folding structures (Fig. 8B).
- The endogenous geological process continued affecting the rock layers, making them deform continuously and translated from ductile to brittle deformation. As a result, fractures, cleavages and faults have been produced during this period (Fig. 8C).
- Over time, joints, fractures and broken zones have been enlarged by water infiltration corrosion, dissolution. Finally the primary structure of carbonate have been destroyed by combination of endogenous and exogenous processes. The process of chemical dissolution associated with invasion mechanism in the valleys, the basin is expanding. The unconsolidated sediments have been deposited on the valley floor, along with the surface flow system development. Finally, fold structural breakdowns and create reversed topographic forms like today (Fig. 8D, Fig. 8E).

The author believes that the concept on karst poljes of Gams (1978), Derek and Paul (2007), Petar (2018) and Tuyet *et al.,* (1998) are not comprehensive. That definition is only true for early and adolescent karst poljes. As the karstization process is continuous, the carbonate is dissolved until the carbonate distribution areas are no more. This fact has happened on some karst poljes in Vietnam. It is Lang Son karst polje. In the Lang Son karst polje, the carbonate rocks surrounding Lang Son karst polje have been mostly destroyed by karstization process, leaving only the East, Southwest, and some limestone blocks in the Chua Tien and PhaiVe. (Fig. 6). In the Tam Duong karst polje, the karstization process happened very strongly in-depth, reaching the bottom of the Dong Giao limestone bed, revealing on the surface of the terrigenous sediments of the Tan Lac Formation (T1*tl*) in the North-Eastern north of the Duong karst polje (Fig. 5).

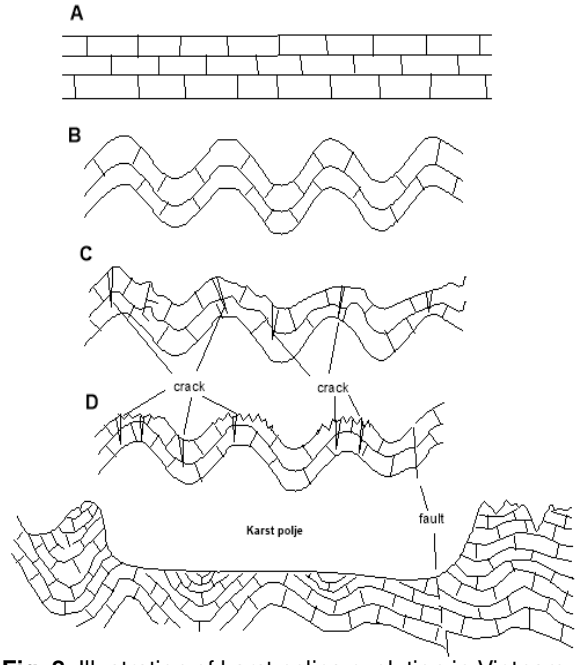

Fig. 8. Illustration of karst poljes evolution in Vietnam.

Analyzing and comparing the distribution position of karst poljes on the Neotectonic vertical movement speed shows that, in areas with strong vertical movement speed, the karstization process happened strongly in-depth (see the section of Tam Duong karst polje- Fig. 5). In stable areas, the karstization process happened very strongly in horizontal direction (see the section of Lang Son karst polje, Moc Chau karst polje – Fig. 6, Fig. 7). The karstization process happened firstly at the positions of faults, fracture zones, fissures, etc,then spread out horizontally, combined with the lifting and lowering movements of the Earth's crust to form the current terrain.

Thus, the role of vertical motion greatly affects the karstization process. It determines the development trend of the karst poljes. The results of this study can be applied for prospecting water and mineral resources in karst areas. In addition, it helps with land use planning in karst poljes. To be more specific, in the Northeast of Tam Duong karst polje, the karstization process, which was strongly influenced by vertical movement, causing Dong Giao Formation's limestone to be completely destroyed, and the terrigenous sedimentary rocks of the Tan Lac Formation have been exposed. There will be no karst water source.

All karst poljes develop in the direction of the geological structure. The position of karst poljes always lies in the fold. The karst formations in Vietnam are distributed in many different strata, but karst poljes are mainly formed in Carbon-Permian limestone and Triassic limestone.

IV. CONCLUSIONS

Approximately 20% of Vietnam's territory, Vietnam is a country with a humid tropical climate, the dissolution process of carbonate rocks happens very strongly, creating many typical terrain types such as blind valley, dolines, karst valleys, through valleys, ponor and karst poljes, carren, microcarren. Among them, only karst polje is favorable terrain for socio-economic development. People have chosen karst polje as a place to live for a long time. Research results have confirmed that in Vietnam, karst poljes are associated with carbonate rocks of the Carbon - Permian and Triassic periods.

The karst poljes formed and developed in five stages. The karst poljes have a close relationship with the geological structure. It can be asserted that all karst poljes in Vietnam are on the fold structure. This view can be generalized to *"On karst areas in Vietnam, the distribution positions of karst poljes are fold structures".* This result can be used for studying the geological structure, prospecting groundwater, and related mineral resources in the karst areas. Besides, this comment can be considered as a "key" to apply to geological and geomorphological research in the karst areas.

Karst terrain is very rugged, which makes travelling very difficult. Hence, choosing the method of studying satellite images, aerial photos as the support methods will be favorable. In particular , if we have a high-resolution satellite or aerial images, for example, satellite images five spot with resolution up to 2.5m, IKONOS (1m & 4m), and QUICK BIRD (0.6m & 2.5m).

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