Characteristic of Lang Son Karst Poljes in Vietnam and Geohazards

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Abstract

In the karst regions of Vietnam, there are many different terrains. The most important one is karst polje. Because there are a lot of residential areas and important economic regions. Based on the study of Geomorphology, geological structure analysis, Geophysics document analysis, and karstification process research at Lang Son karst polje. The author gives conclusions: Lang Son karst polje was formed from the limestone of Bac Son Formation, 700 – 800 m thick. Lang Son karst polje was formed from anticline structure, the limestone of Bac Son Formation that has high karstification level. Lang Son karst polje has only one karst aquifer which is a water supply source for residential areas in Lang Son city. This karst aquifer distributes in limestone blocks of the Bac Son Formation. Geohazards on Lang Son karst polje include collapse, sinkhole, flood, and pollution of water. Among them, the most dangerous one is the collapse of the underground karst caves.

Keywords: Karst; Lang Son karst polje; Karstification; Geohazards; Collapse; Structural; Fold

1. Introduction

Studies of karst (in general) or karst poljes (in particular) have been of interest to many geologists (Buru, 1988, Derek et al., 2007, Hiba et al., 2021, Thinh et al., 2022, Nghia, 2000, Petar et al., 2018, Tam et al., 2005, Thanh, 1995, Thuy, 2001, Tuan, 2009a, Tuan, 2009b, Tuan, 2009c, Tuan, 2020). Karst poljes are a special type of terrain that is only found in karst regions. In Vietnam, there is very little research on karst poljes.

Up to now, the documents about Geology, Geomorphology, Geophysics, the results of research on the structure, the borehole documents at Lang Son karst polje have been complete. This research goal serves the sustainable development of the territory in Vietnam. The author of the article will mention some geohazards related to Lang Son karst polje. The study area is located in the karst region of northern Vietnam (Fig.1).

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Fig. 1. Lang Son karst polje location

2. Materials and Methods

Materials to complete the article include:

- Research documents on Geology, geomorphology, tectonics, structure, hydrogeology, geophysics are available at Hanoi University of Mining and Geology, Center InFormation of Geological Archives, General Department of Geology and Minerals of Vietnam.

- Documentation of the author's doctoral thesis study.

- Analysis results of air photos, satellite images, topographic maps: surveying the study of structure and landforms before going to the field.

- The research results show that, from 1952 up to now, the Lang Son karst polje area not only changes in topography but also has huge fluctuations in population and infrastructure.
The results of analyzing aerial photos in 1952, 2000, satellite images in 2021 show that: In 1952 (Pic.1), there was very little population, almost no industrial zone. Currently, the population is very densely populated, a lot of industrial zones are developed (Pic.3)

Geophysical research documents have helped geologists locating boreholes for groundwater.

Borehole monitoring documents, analysis results of surface water and groundwater samples are the basis for conclusions about the relationship between groundwater in the karst aquifer and surface water of the Ky Cung river.

In order to obtain the aforementioned objectives, we used the following study methods:

- Collecting research materials on karst, especially karst polje studies.
- Researching the karstization process based on the theory of Derek and Paul (2007), (Petar and Milanovíc., 2018). The theoretical basis is the dissolution of limestone and dolomite (Fig. 4) related to the pH and CO₂ concentration of the environment and the activity of the biological world. The carbonate rock dissolution process is described by the following reaction (Fig. 3).

\[
Ca,Mg(CO_3)_2 + 2CO_2 + 2H_2O \Leftrightarrow Ca^{2+} + Mg^{2+} + 4HCO_3^- \quad (1)
\]

- Analyzing satellite images, air photos in 1952, 2000, 2020 to study the changes in population and infrastructure in Lang Son karst polje.
- Field investigation checks and compares with room research results to determine the accuracy of topographic map analysis, satellite image analysis, air photo analysis.

Fig.3. Limestone dissolution process in karstization (Derek and Paul, 2007)

Fig.4. Limestone along Ky Cung river, lots of cracks and holes, surface water flows straight down (Field investigation, 2020)
• Field investigation, determining the distribution of boreholes, karst caves, water flowing in caves, water flowing out of caves, sinkholes, etc. Use drone to survey the area.
• In fact, drone supports very well for field surveys. A drone provides us with vast, panoramic photos of the most obvious study area (Fig. 5).
• Field investigation, identifying rocks, analyzing relationship, measure strike and dip of the bed. Attaching strike and dip of the bed into the map (Fig. 6). Linking lying positions, mapping structural petrography maps (Figs. 7 and 8).

Fig. 5. Lang Son karst polje is occupied with residential areas (2020)

• Monitoring, sampling water in boreholes, sampling surface water on Ky Cung river.
• Research on geological structure: the author has researched and linked geological documents in a scientific and systematic way. The documents are geological maps, geomorphologic maps, tectonic maps, hydrogeological maps. One of the most important conclusions is that Lang Son karst polje are located on an anticline structure, complicated by the activities of the fault. Therefore, Lang, Son karst polje has the structure of a horst.

Fig. 6. Strike and dip of the bed at the south-east of Lang Son city

Fig. 7. The lithologic structural map at the south-east of Lang Son city
**Fig. 8.** Determine bedding at the south-east of Lang Son city

- Geophysics method: The geophysics method is very effective for studying deep structures. It is done after the geological survey finishes. At Lang Son karst polje, we use a combination of resistivity survey to determine distribution locations of underground karst caves (Fig. 9). The geophysics method measures Rn- Hg to identify active faults and also determines the broken zone width of the Cao Bang-Tien Yen fault. Radon detects 16 anomalies with amplitude from 154 to 921 pCi / l compared with the average background of 41 pCi / l. Hg vapor measurement detected 23 anomalies with a measure of 104 to 252 mgHg / m3 compared with the average background of 36 mmHg / m3 (Figs.10 and 11).

**Fig. 9.** Section geophysics at Lang Son karst polje
Research the borehole: Currently in Lang Son karst polje, there are many boreholes (water supply boreholes, hydrogeological research boreholes, engineering geology serving the socio-economic development of Lang Son province). During the drilling process, Geologists have identified 3 floors of underground karst caves.

3. Results

3.1. Geological-Geomorphology General

Lang Son karst polje is located on an anticline structure. Strong tectonic activities, combined with karstization destroyed most of the limestone area in Lang Son city. Currently, Lang Son city's topography is lower than the surrounding terrain. Therefore, people often name it "Lang Son basin", the geomorphologic term called "Lang Son karst polje". Participating in the geological structure of Lang Son karst polje region includes the following rocks (Fig.2) (Nghia, 2000, Tam et al., 2005, Tuan, 2009a)

Bac Son Formation (C-P3bs) consists of massive limestone, oolitic 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. Bac Son Formation is the oldest in the region.

Dong Dan Formation (P3dlf) is gray, light gray, massive structure or ataxitic structure, micro-small grained texture, bedded thick to massive. With a thickness of 280m, it contains fossil: Palaeofusulina prisca, Colaniella ex.gr. lepida, Colaniella parva, Reichelina pulchra, Codonofusiella kwangsiana, Neoendothyra compressa, Pachyphloia sp., Lasiodiscus sp., Neodiscus sp.
Lang Son Formation (T₁ls): light-gray sandstone with some interbeds of dark-gray, black-gray clay shale, and siltstone; 200-300 m thick. It contains fossil: Columbites cf. parisianus, Tirolites ex gr. cassianus, Prenkites sp., Preflorianites sp. together with bivalves Gervillia exprorecta, Eumorphophis cf. spinicosta, Entolium discites microtis.

- Ky Cung Formation (T₀kc): black-gray, thin-bedded limestone, 250-400 m thick
- Khon Lang Formation (T₂kl): rhyolite, rhyodacite, and their tuffs, 200-250m thick.
- Mau Son Formation (T₃ms): siltstone, silty sand, sandstone, alternating layers of shale. 550-750m thick.
- Tam Lung Formation (J₁-K₁l): conglomerate, sandstone, siltstone, porphyritic rhyolite, tuff.
- Na Duong Formation (N₁nd): conglomerate, gritstone, sandstone, siltstone, claystone. 80-100m thick.

Quaternary sediments (ap,aQ): silt, sand, gravel, grit. Thickness 10-20m. They contain fossil: Lygodium sp.; Gleichenia sp.; Cyathea sp.; Pinus sp.; Castanea sp.; Quercus sp.; Cystopteris sp.; Polypodiaceae gen.indet.; Castanopsis sp.; Aralia sp.; Poaceae gen.indet.; Sapindaceae gen.indet.; Compositae gen.indet.; Thaeeaeae gen.indet.; Lithocarpus sp.; Davalia sp.; Sellaginella sp.,

Lang Son karst polje was formed from the limestone of Bac Son Formation (C-P₃bs), characterized by karst landform. Currently, the bottom of Lang Son karst polje is filled by Quaternary sediments about 20m thick (Nghia, 2000). The composition of Quaternary sediments are mainly clay, sand, pebbles, gravel…. Surroundings of Lang Son karst poljes are limestone mountains (west, east). The sedimentary rocks of Lang Son Formation, sedimentary-eruptive rocks of Tam Lung Formation are distributed in the West and the North (Fig.12).

On the bottom of Lang Son karst polje there are remnant of limestone mountains in Chuatien, Phaive. There are also Ky Cung river and streams such as Nao Ly, Ki ket, Ngoc Tuyen... Caves, sinkholes, water coming in the cave, water coming out of the cave, terraces, alluvial sediment along a river.

**Fig.12.** Geological map of Lang Son karst polje (Nghia, 2000, Tam, et al., 2005, Tuan, 2009a)
3.2. Characteristics of Lang Son Karst Polje

3.2.1. Shape Lang Son karst polje

Lang Son karst polje has a rhombus shape, the long axis developed according to the meridians of longitude. The area of Lang Son karst polje is about 18 km². There are some tectonic activities on Formation of Bac Son limestone, forming a fold structural system. The section line cross to Lang Son karst polje shows:

Northwest limb measured bedding: 300-310° 25-50, Southeast limb bedding measured 120-140° 20-50. The northeast of Lang Son karst polje is Cao Bang- Tien Yen fault. This is a deep fault, active fault (Nam et al., 2005). The bottom of Lang Son karst polje has many sinkholes, wells, water coming in the cave, water coming out of the cave. Currently, on Lang Son karst, remnant of limestone mountains are small in the center of the city (Phai Ve, Tam Thanh, Nhi Thanh, Chua Tien). East of Lang Son karst polje is the range of limestone Bac Son Formation and Dong Dang Formation, running in an arc in the direction from northeast to southeast, closely related to Cao Bang -Tien Yen fault. West of Lang Son karst polje is Bac Son Formation limestone and sedimentary rocks of Lang Son Formation (T ils).

Previous studies often referred to Lang Son karst polje as Lang Son Valley or Lang Son basin. Before 1998, many sinkholes, wells, water coming in the cave, water coming out of the cave on Lang Son karst polje (Fig.13). Nowadays, Lang Son has developed into an urban area, sinkholes, wells, water coming in the cave, water coming out of the cave has been filled up (Fig.14).

Fig.13. Distribution of sinkhole, Well karst, water exploitation boreholes in Lang Son karst polje (Thanh, 1995 and Thuy, 2001)
3.2.2. Border polje

Surrounding Lang Son karst polje are not only karst rocks, but also non-karst rocks and faults. During the rainy season, the water of the Ky Cung River is high, in addition, water from the non-karst rocks flows into Lang Son karst polje. Lang Son karst polje is flooded (Fig. 15).

3.2.3. Structure of Lang Son karst polje

Lang Son karst polje was formed from Bac Son Formation limestone aged C-Pbs. Currently, the karstification process has destroyed most of the limestone area, leaving only the center and the edge of Lang Son karst polje an area of about 2.5 km² of limestone. Observing the topography, we see that the area of Lang Son city is located at the lowest position (253m) compared to the surrounding terrain (320-390m). Therefore, Lang Son karst polje is also known as Lang Son valley. Thus, in terms of geomorphology and geology, these are opposite to each other. In terms of the geological structure, Lang Son karst polje lies on the anticline structure, The axis of the anticline has sub- meridians of longitude.

The lithological map of Lang Son karst polje structure, and the cross-section is the convincing proof of the structure of Lang Son karst polje. (Fig.16)
4. Discussion

To form karst polje and karst caves, first of all, limestone is required. Limestone must have a high CaCO₃ content, which is convenient for karstification. Also, it must take into account the conditions of climate and rainfall. Especially the role of endogenous geological processes. At that time, a chemical reaction occurred:

\[
\text{Ca}_2\text{Mg}(\text{CO}_3)_2 + 2\text{CO}_2 + 2\text{H}_2\text{O} \leftrightarrow \text{Ca}^{2+} + \text{Mg}^{2+} + 4\text{HCO}_3^- \tag{2}
\]

Since the Formation of limestone collections C-P₃bs (about 300 million years ago), the rock layers with T, J, K, E, N age have been completely eroded, respectively. Currently, limestone C-P₃bs is exposed on the surface. The karstification process took place very strongly, forming today's Lang Son karst polje.

Research results show that, 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. The role of vertical motion greatly affects the karstization process. It determines the development trend of the karst polje.

4.1. The Risk of Karst Caves Collapsing

- The exploitation of water in the limestone layer is increasing due to the daily needs and infrastructure construction.
- Continuous population growth, now the residential and industrial areas have filled Lang Son karst polje, putting pressure on the surface of Lang Son karst polje.
- Cao Bang- Tien Yen fault in the northeast of Lang Son karst polje is an active fault that will contribute to increasing the risk of geological catastrophe on Lang Son karst polje. (Nam, et al., 2005).
- The study of boreholes in Lang Son karst polje shows that, there are at least 3 levels of karst cave in the underground. The karst caves and fractured zones are most developed at depths less than 50m.
(Nghia, 2000). Lang Son karst polje, has only 1 aquifer karst in the Carbon-Permian limestone (Fig. 17).

Fig 17. Hydrogeological section of lang Son karst polje (Nghia, 2000)

4.2. Pollution of Ground Water under Karst Polje

Groundwater pollution will occur because:
- The streams that flow into the Ky Cung river are polluted (Ngoc Tuyen stream, Lao Ly stream,...), there is a lot of rubbish in the Ky Cung river (Fig.18).

Fig. 18. Nao Ly Stream (left), Ky Cung River (right) there is a lot of garbage. They flowing into Lang Son karst polje.
- There is a circulation between the surface water of the Ky Cung River and the groundwater aquifer (Thuy, 2001)
- The surface water of the Ky Cung river has been polluted
- People discharge waste into the environment.

This is the most outstanding threat in the Lang Son karst polje. Nao Ly, Ngoc Tuyen springs produce short-lived surface streams flowing over a short distance before they are recycled into groundwater aquifers through sinkholes, dolines, and ponor. The in-flow water may carry sufficient contaminant to pollute the groundwater sources. The thickness of sediment overlying Lang Son karst polje is very thin, it is < 20m thick. In residential areas and industrial areas, there is a lot of garbage on Lang Son karst polje. Source of pollution immediately follows into the cracks and caves without any filtering process, a direct circulation between surface and groundwater is established; Consequently, once the surface source is polluted by the living wastes, hospital rubbish, industrial sewage, pesticide, and fertilizers... the karst aquifers are immediately vulnerable and polluted.

4.3. Risk of Water Shortage

Langson city will water shortage for the following reasons:
- The demand for water is increasing.
- Population increasing day by day.
- Industrial zones are increasingly developing.
The reserve of groundwater is increasingly declining, now the groundwater mirror in the wells has been lowered by about 0.8m.

4.4. Flood

Karst polje are convenient places to accumulate water when it rains, water flows very quickly, often causing flooding. Depending on the rainfall, flash floods may occur. On the karst regions, floods only occur on the karst with special positions, normally on the slope or foot of the denuded mountain ranges or plateaux that composed of the non-karst rocks. Floods often occur in the rainy season in Lang Son karst polje. In order to limit and mitigate the loss by the floods, it is first to be planned; building the houses and constructions avoid the flood path; organising the monitors and early alarm of possible floods to people, settling away from the floods to ensure a safety of life and properties of the civilians.

4.5. Sinkhole

In Lang Son karst polje, underground cavern systems are very developed. The residential area on karst polje is using from karst cave underground system. Collapses and subsidence of the karst underground spaces are dangerous and disadvantageous phenomenon to the constructions and economy. The builders therefore must be learned of a nature and potential of collapses and subsidences and have the prevention ensuring a safety to the constructions. Currently, the sinkholes in Lang Son karst polje are filled by residential areas. These are dangers that need to be warned.

6. Conclusions

The research results show that, from 1952 up to now, the Lang Son karst polje area not only changes in topography but also has huge fluctuations in population and infrastructure. One of the most important conclusions is that Lang Son karst polje is located on an anticline structure, complicated by the activities of the fault. Lang Son karst polje formed by Carbon-Permian limestone, Bac Son Formation, is located on the structure of anticline. Lang Son karst polje is the metropolis of Lang Son province, there are many residential and industrial areas. On the bottom of Lang Son karst polje there are many karst caves, sinkholes, springs, and drainage networks. Currently, it is mostly covered with Quaternary sediments. The capacity of exploiting groundwater in the Carbon-Permian limestone is increasing. Most concerned is the catastrophe related to the collapse of underground karst caves. In addition, the process of flooding, pollution of domestic water, and lack of domestic water are unavoidable. Lang Son province must move towards new technology solutions. It's purifying water from the air, like this model currently available in Israel.

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