

GEOLOGICAL STRUCTURAL CONTROL OF KARST WATER IN THE PROPOSED NGOC SON-NGO LUONG NATURE RESERVE, HOA BINH PROVINCE, VIETNAM

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Abstract. The Feasibility Study on “Establishing the Ngoc Son-Ngo Luong Nature Reserve” has been proposed by the Hoa Binh Provincial People’s Committee and supported by FFI/LLINC. The Study has been carried out under the main responsibility of the Northwestern branch, Forestry Inventory and Planning Institute (FIPI). Contributions by RIGMR’s geoscientists, within LLINC project, were to conduct additional geological research and surveys, so as to form a basis for other studies and to add more values to the Nature Reserve. On the basis of available geological data, the authors try to characterize the main geostructural features of the proposed Nature Reserve in an attempt to understand the karst water resources of the area.

Keywords: nature reserve, geology, stratigraphy, tectonics, karst landform.

1 Location

FFI (Fauna & Flora International) Vietnam, together with its Vietnamese national counterpart, the Forest Protection Department (FPD, under the Vietnam’s Ministry of Agriculture and Rural Development, MARD), is currently undertaking a project on the possibility of establishing a continuous protected karst area, including the existing Cuc Phuong National Park and the Pu Luong Nature Reserve (PLNR) to its northwest. According to the initial proposal, the project area consists of 6 communes belonging to the districts of Lac Son and Tan Lac (Hoa Binh province). The 6 communes are Ngoc Lau, Ngoc Son and Tu Do (Lac Son district, Vu Ban map sheet, F-48-127-D) and Bac Son, Nam Son and Ngo Luong (Tan Lac district, Mai Chau map sheet, F-48-127-A). However, this geological study indicates a possibility to expand the boundaries of the proposed project area to include some neighbouring communes possessing analog physiographic characteristics and hence create a project area

delimited by natural boundaries. Thus the geological characteristics and values of the proposed Nature Reserve will be presented here in the “expanded version”.

2 Geological characteristics

In the general geological context, being located in the same major tectonic zone, the project area has more similarity to the Cuc Phuong National Park than the Pu Luong Nature Reserve. The most prominent and clearly visible feature is the intercalation and/or alternation between limestone and non-limestone (terrigenous) rock belts, forming strips stretching NW-SE, i.e. in accordance with the general structural direction of the area. However, unlike the Cuc Phuong National Park, where limestone prevails, in the Ngoc Son-Ngo Luong area a better balance between these rock types can be observed. Nevertheless, being located adjacent to the Pu Luong Nature Reserve, research on geology and other natural characteristics of the area of interest can not be carried out separately and viewed independently from those for the Pu

Luong Nature Reserve.

2.1 Topography

The project area is part of the NW-SE plateau-like, limestone range of Northwest Vietnam, being the southeastern continuation of a series of famous karst regions e.g. Moc Chau, Son La etc. In essence, it can also be considered a plateau highly rising above the surrounding areas. The plateau is dissected into parallel strips, where relics of planation surfaces at different altitudes can still be observed, which make the plateau both linear and stair-like. The plateau scarp also stretches in the NW-SE direction, serving as its natural boundary with the low hill and plain landscape underneath.

The absolute altitude of the area ranges between 100 m and more than 1000 m, increasing from SE to NW. The averagely low (300-500 m) to high (800-1000 m) mountainous topography prevails upon the hilly lowland and stream valleys. Peaks correspond to limestone rocks, with rugged and complicated topography. The summit areas show up to 200-300 m vertical denivellation and considerable, up to 0.5-0.8 km/km² lateral extent. An exception is the central part of the Ngoc Lau and part of the Ngoc Son communes, where the topography is relatively level at the average altitude of 500 m.

2.2 Stratigraphy

The study area is covered mostly with Mesozoic rocks which belong to the Co Noi (T₁cn), Dong Giao (T₂a dg) and Nam Tham (T₂l nt) formations. To a limited extent, loose Quaternary sediments accumulate along streams.

a. Co Noi Formation (T₁ cn)

These rocks are observed mainly at the NE and SW edges of the study area, especially in the Tu Do and Ngo Luong communes, forming NW-SE striking narrow belts. Totalling 650-700 m in thickness, the formation consists mainly of shale, siltstone, sandstone with interbeds and lenses of calcareous shale and limestone. The rocks conformably underlie limestone beds of the Dong Giao formation. Their terrigenous composition suggests that whole formation is in general, an aquitard.

b. Dong Giao Formation (T₂a dg)

This formation extensively develops in the study area, forming rigorous limestone belts that stretch in NW-SE direction. Totalling about 1000 m in thickness, the formation

consists of siliceous, clayey and mostly pure limestone, thinly bedded at the lower part to massive structured at the upper part. Based on their bedding structure and clay content, therefore 2 sub-formations can be distinguished.

c. Nam Tham Formation (T₂l nt)

Conformably overlying the Dong Giao limestone, the formation develops in the central part of the study area, forming NW-SE belts. It can be divided into 2 sub-formations. The lower sub-formation is mainly observed at Ngoc Son-Ngoc Lau communes, forming a NW-SE trending syncline. Totalling 430-660 m in thickness, it consists of shale, micaceous and calcareous shale, limestone lenses and siltstone that are strongly pressed into micro-folds. The upper sub-formation consists of mainly siliceous limestone and massive limestone, alternating at some places with shale and micaceous shale, totalling 170-340 m in thickness. The lithological composition indicates that the lower sub-formation is an aquitard while the upper one can be a water bearing layer.

2.3. Tectonic setting

Tectonic structure

In general, the study area, along with other adjacent areas such as the Cuc Phuong National Park, the Pu Luong Nature Reserve is located at the interaction between two major tectonic zones i.e. the ancient Ma River anticlinorium at the SW and the younger Da River synclinorium at the NE. Both develop in a NW-SE direction and are separated by the Son La deep-seated fault.

Similar to the Cuc Phuong National Park, the Ngoc Son-Ngo Luong area is located wholly in the Da River tectonic zone, with Mesozoic rocks of the Co Noi, Dong Giao and Nam Tham formations as described above. They form a big, NW-SE trending synclinorium with total thickness up to 1900-2900 m. The central axis of this synclinorium consists of rocks of the Nam Tham formation, but in addition, there are other synclines, which terminate with the upper Dong Giao sub-formation.

Further to the NE, near Kim Boi, are located the basalt massif of the Cam Thuy formation (P₂ ct) and granitic bodies of the Phia Bioc complex (γT₃n pb). Subsequent folding and faulting activities, especially in late Triassic (T₃n) when the area became under

continental regime, has generated the NW-SE trending strip form of the area, that is furthermore a bit concave to the NE, surrounding the above mentioned magmatic massifs. These tectonic movements are strongly reactivated in the Himalayan neotectonic stage (about 54 Ma until now). Pulsating uplift alternated with relatively quiet periods, resulting in a series of ancient planation surfaces at altitudes of 900-1200 m, 700-900 m and 300-500 m.

Stratabound units

With regard to the water bearing properties, the following stratabound units can be identified:

- the Early Triassic non-carbonate stratum, Co Noi formation ($T_1\text{cn}$);
- the Middle Triassic carbonate stratum, Dong Giao formation ($T_2\text{adg}$);
- the Middle Triassic non-carbonate stratum, Lower Nam Tham sub-formation ($T_2\text{lnt}_1$);
- the Middle Triassic carbonate stratum, Upper Nam Tham sub-formation ($T_2\text{lnt}_2$);
- the Cenozoic non-carbonate, loose Quaternary sediments.

All these strata display an interbedding and alternation between carbonate and non-carbonate rocks both vertically and laterally in the SW-NE direction. Thus hydrologically, there could be two separated, water bearing carbonate strata i.e. the Dong Giao ($T_2\text{adg}$) formation and the Upper Nam Tham sub-formation ($T_2\text{lnt}_2$), interbedded with the Co Noi ($T_1\text{cn}$) and Lower Nam Tham ($T_2\text{lnt}_1$) non-carbonate aquitards.

Folding and faulting characteristics

Rocks of the Co Noi formation crop out only along the NE and SW edges of the study area, forming a basal aquitard for the whole area. Field surveys found some exsurgences only along the boundary between these underlying rocks and the overlying limestone of the Dong Giao formation.

Looking at the absolute altitude of the Co

Noi outcrops, one tends to conclude that the Ngoc Son-Ngoc Lau plateau has been uplifted considerably compared to the NE plain strip underneath. On this plain there are still some relics of the Dong Giao limestone overlying the Co Noi rocks, indicating the vast majority portion of the younger Dong Giao and Nam Tham formations have been eroded while they are still preserved in higher position on the Ngoc Son-Ngoc Lau plateau. The absolute altitude of the plain along the road from Tu Do via Ngoc Lau to the district center is about 100 m while that at the Co Noi-Dong Giao terrigenous-carbonate boundary often reaches 300-400 m, implying at least a 200-300 m uplift of the plateau compared to its NE marginal plain. Similarly, compared to the limestone belt at the SW edge, the same plateau might have been uplifted by 100-200 m.

Limestone of the Dong Giao formation forms NW-SE stretching belts. However, its tectonic structure appears more complicated. At Ngoc Lau commune, the strata grade into the rocks of the Nam Tham formation, forming a perfect, 3 km wide x 15 km long syncline (Fig. 1). On the contrary, to the NW, at Ngoc Son, Ngo Luong, and even Nam Son and Lung Van communes, the Dong Giao limestone appears strongly faulted to leave only small, narrow strips for the Nam Tham formation. Around Bac Son commune, these small and narrow strips spread widely and the Nam Tham rocks no longer keep a belt-shape form.

At Tu Do commune, rocks of the Co Noi and Dong Giao formations form a big NW-SE anticline. A fault (partly followed by the Mon stream), however, runs along the axis of this structure and considerably destroyed its SW flank. There could be a major displacement along this axial fault as terrigenous rocks of the Co Noi formation crop out on the NE flank while the SW flank is still composed of the Dong Giao limestone.

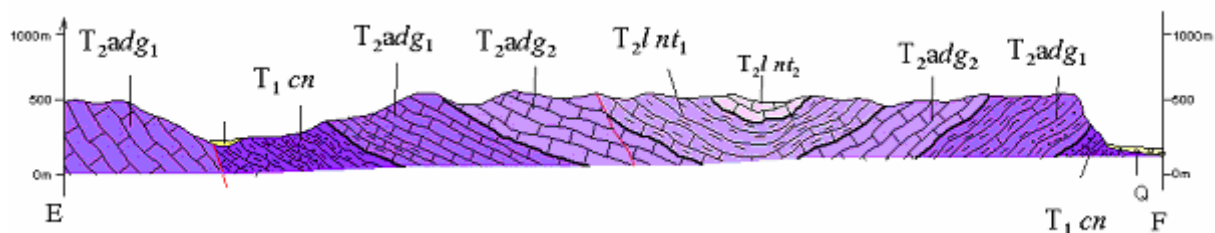


Fig. 1: Perfect synclinal structure through Co Noi, Dong Giao and Nam Tham formations at Ngoc Lau commune.

A SW-NE cross section from Tu Do commune to the district center reveals some repetition of these terrigenous-carbonate rock belts, forming a series of alternating anticlines and synclines, to result in a huge synclinorium with the core made up of rocks belonging to the Nam Tham formation which outcrops around Ngoc Son and Ngoc Lau communes.

Faults and shear zones are frequent, serving as the boundary between tectonic zones, geological formations, or destroying and/or complicating folding structures. They all can be grouped in four regional systems of NW-SE, NE-SW, sub-meridian and sub-parallel directions (Fig. 2). Being the predominant system, the NW-SE faults can be further divided into 2 sub-systems, i.e. the NNW (320-330°) in the NW part, around Bac Son, Nam Son and Lung Van communes, and the WNW (300°) in the SE part, around Ngo Luong, Ngoc Son, Ngoc Lau and Tu Do communes. This shift in the overall structural direction is thought to be due to the big, sub-meridian, left lateral strike (up to 4 km relative displacement) Ban Cong-La Han fault (just to the west of the study area).

The syngenetic NE-SW faults are often short and small. There are only a few sizeable faults that cut the NW-SE mountain ranges

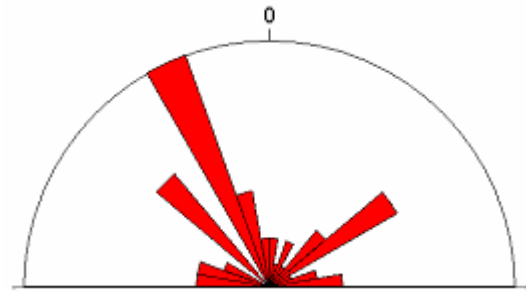


Fig. 2: Rose diagram of principal fault directions.

into blocks. One fault is observed near Ban Ho village of Bac Son commune.

Other faults of the sub-meridian and sub-parallel systems are less abundant, often cutting and displacing NW-SE and NE-SW faults, implying they are more active in later tectonic stages.

3 Karst development and hydrological characteristics

3.1 Karst development

Initial speleological surveys and a cumulative cross-section representing the surface topography and cave development show that caves develop mostly at 3 altitude ranges (Fig. 3) i.e.:

- higher than 1000 m;
- between 850-900 m;

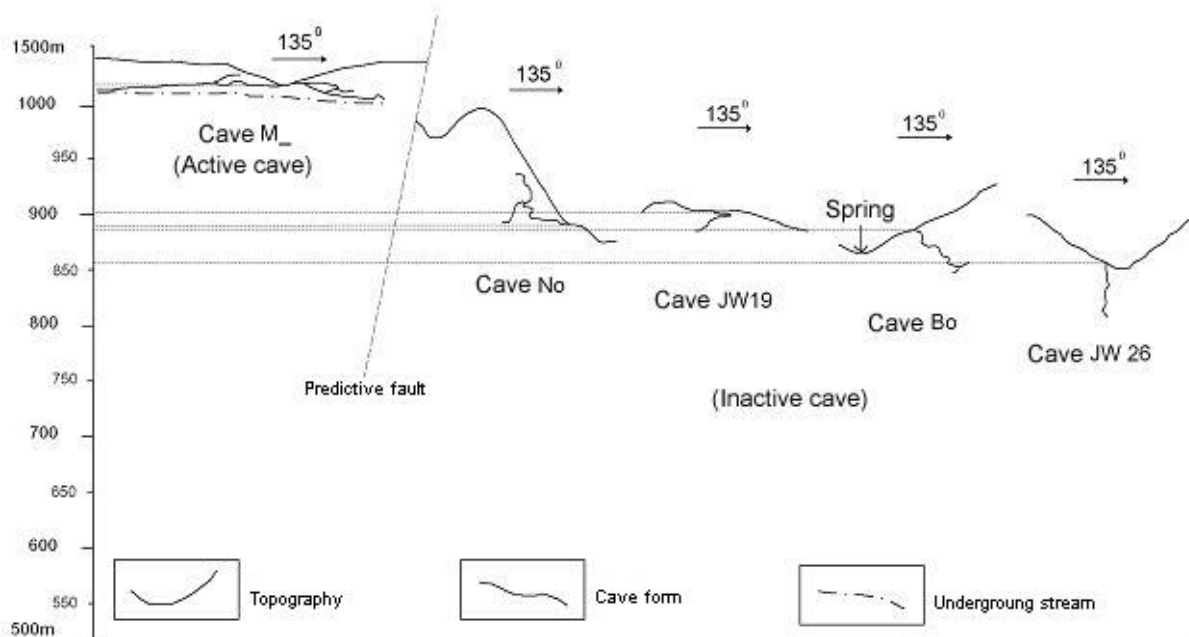


Fig. 3: Cumulative schematic cross-section showing stages of cave development, showing fault-bounded independent aquifer systems.

- between 650-800 m.

In addition, caves mostly develop in the Dong Giao limestone and to a much lesser extent in the Nam Tham limestone. Most of them not only are located along NW-SE faults but also develop in this direction. Fossil caves are mostly at the altitude of 780-900 m but at the same time, some active caves (e.g. Hang My and Hang Ton caves in Nam Son commune) are found with considerable discharge at similar or even higher altitudes. This again confirms the fault governed block tectonic settings of the study area.

It can be noticed that the current depth of karstification is at the altitude of about 650-700 m, i.e. comparable to the highest point of the roof of the Co Noi formation. This implies that in case of further karstification the uneven roof of the Co Noi formation could serve as an underground water divide.

3.2 Hydrological characteristics

Geological characteristics determining the regional hydrology are:

- The Ngoc Son-Ngo Luong terrigenous-carbonate rock belt, 7-10 km wide, 35-40 km long, stretching without interruption in NW-SE direction from Mai Chau district town toward the Cuc Phuong National Park, has been uplifted 100-300 m as a tectonic block relative to the surrounding areas.
- There is an alternation and/or interbedding between aquitards (terrigenous rocks of the Co Noi (T_1 cn) formation and Lower Nam Tham (T_2 l nt₁) sub-formation) and aquifers (limestone of the Dong Giao (T_2 a dg) formation and Upper Nam Tham (T_2 l nt₂) sub-formation) both vertically and laterally in the SW-NE direction. The Co Noi formation serves as the basal aquitard, preventing

groundwater seepage to deeper levels. Moreover, all these strata form a large synclorium that also assists in preserving water in the area. Thus, just a few low-lying exsurgent points are found at the top boundary with the Co Noi strata.

- The lateral alternation between terrigenous aquitards and carbonate aquifers in NW-SE direction is expressed by emerging limestone ranges and submerging terrigenous valleys. This feature can result in locally independent hydrological systems that run parallel to each other and become interconnected only at the intersections with other, e.g. NE-SW, sub-meridional and sub-parallel fault systems.

As a result, the karst hydrology is quite complicated as proven by the following features:

- Some very important resurgent points from limestone ranges, with discharge rates ranging ca. 5-20 m³/s, as seen in Ban Mu and Xom Hung villages, may suggest a quite sizeable recharge area. In addition, there may be some inter-connection between different aquifers and/or local hydrological systems, which complicates the general NW-SE structure-controlled flow pattern of the area. Well-developed travertine terraces downstream of these resurgences indicate the CO₂ rich mineralised water has been in contact for quite long time with limestone, which may also imply a long journey of the water in limestone underground and consequently, a sizeable recharge area.
- There are some sizeable resurgent points at relatively high altitudes (300-400 m) along the NE slope of the plateau, adjacent to some big, ancient travertine terraces near Xom Lo, Xom Khua villages. This may indicate that the NE slope in the past might have been the major

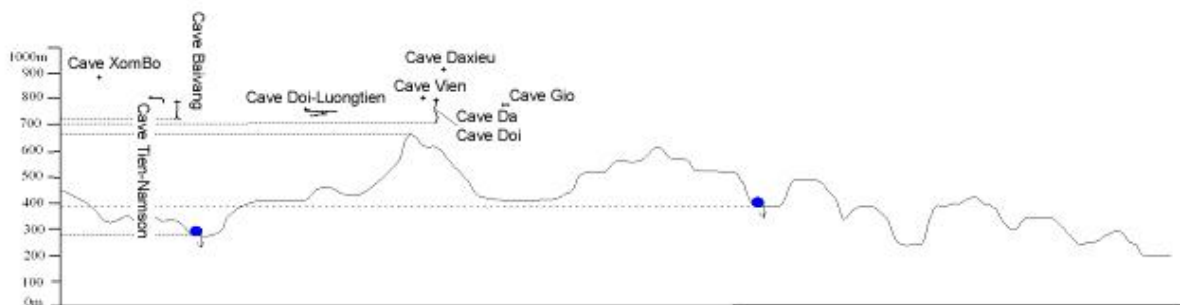


Fig. 4: SW-NE topographical cross section showing location of major exsurgence points (vertical scale exaggeration 10x).

discharge point of the whole area, a hypothesis that very well fits with the formation of the Ngoc Son-Ngoc Lau karst field also in this part of the study area (Fig. 4).

- In addition, there are quite a few small resurgent points at even higher altitudes (right on the surface of the Ngoc Son-Ngoc Lau karst field, i.e. about 500 m), just next to sinkholes at the foot of limestone ranges. This strongly confirms the idea that independent, parallel local hydrologic systems co-exist without local interconnection, which may result in local artesian resurgences. Meanwhile, major underground flows still develop at the foot of limestone ranges, along major fault zones, where among large-sized and deep valleys, sinkholes often develop.

In brief, with regards to the area karst hydrology, one may conclude that there could be several (at least two) separate karst aquifers in the vertical section. Laterally, there could also be locally independent hydrological systems, which may become interconnected at some fault-controlled interaction points.

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