Neotectonic and Geomorphological Characteristics of the Ma Pi Leng Area (Ha Giang Province, North Vietnam): Implications for Improving the Worth of Vietnamese Geological Heritage

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Abstract. Ma Pi Leng area is the core part of Dong Van karst plateau geopark, and is a region of high diversity of geology and tectonics in Vietnam. This region has experienced strong uplift motions that have created three grades of regional relief: 1400–1600 m; 1100–1200 m and 500–600 m. This geomorphology is in turn strongly eroded by the stream systems and divided into different structural blocks controlled by the faults. During the neotectonic stage, several modes of faulting have occurred in Ma Pi Leng such as strike-slip, normal, extension, riverse faults. The NW–SE fault system had a decisive role in determining the structural pattern of the region. The tectonic fractures, at the largest scale, are hundreds of meters high and up to a kilometer long. Tectonic activities, together with exogenic processes, have made regional relief strongly diverse with strips of horsts and grabens as well as ladder-steps-shaped escarpments, inverse topography, high cliffs and deep canyons. Besides that there are also the caves at varying levels of height, chains of sinkholes, and pyramidal mountainous peaks. Ma Pi Leng area is truly majestic and worthy of tourist attractions both in terms of scientific value and natural landscape. **Key words** – Ma Pi Leng, neotetonics, active fault.

1 Introduction

The Ma Pi Leng area (MPL) of Vietnam is situated within 105°17′22″ and 105°29′13″ longitude, 23°10′05″ and 23°20′22″ latitude (Fig. 1). It covers a part of the Dong Van and Meo Vac districts, and is the central part of Dong Van plateau in the northeast of Ha Giang province. Generally Dong Van, Meo Vac districts, and the MPL area in particular, have a special tectonic position. Lying in the southern edge part of the South China block, tectonic activity is quite stable in the central part, but its edge part is significantly disordered [5]. On the other hand, the MPL area is connected with the northeast edge of Indosinian moutainous belt by the Red River Fault Zone, and so the MPL is also affected by common tectonic

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processes. Because of these reasons, the MPL area has a specific geomorphological landscape and is very diverse in topographical, geological and tectonic form [1, 2]. However, it is still not paid due attention regarding its geomorphological and tectonic activities. Moreover, the MPL has been considered as a global geopark, and therefore it is extremely necessary to elucidate its tectonic characteristics for the purpose of improving the worth of geological heritage, and value for tourism and scientific activities.

Fig. 1. Sketch-map showing the location of the study area

This paper presents new results on tectonic activities and their worth on geological heritage in the MPL.

2 Materials and methods

The present investigation has been conducted based on observations at 115 geological exposures in order to document the geomorphological, geological and tectonic data, with field work conducted in 2016. A number of important features have been systematically documented, including: geological and geomorphological anomalies (deformation of geological strata, change of river and spring channels, watershed line, alluvial fan, terraces, battures along faults and their distribution) and tectonic structural patterns. Based on the method of analysis of tectonic physics [9], stress field and characters of fault activity were reconstructed. In addition, our field-based studies were supported by powerful satellite images with high solution (landsat and Spots), maps of DEM (scale 1: 100000 and 1: 50000), and geological maps (scale 1:100000 and 1: 200000).

3 Results

3.1 Geomorphological characteristics

3.1.1 Category of relief

The MPL area includes three main topographical types: *Erosion-solution mountainous relief* in massive form developes on limestones, observed in the northwest of the study area, represented by caves, sinkholes, and solution grooves on its surface; *Erosion-solution mountainous relief* in linear-massive form develops on terrigenous rocks and thinly-bedded limestones, encountered in the central part of the study area. It is very common, presented as verticle-sloped cliffs, and small-scale caves; *Erosion-denudation mountainous relief* with lenearment-form is distributed in the NE part of the study area, and created in large ranges with the NW–SE direction. It is typical by linear and cuesta topography with peaks being cone-shaped, pyramid-shaped in form.

3.1.2 Form of topographic surfaces

- *Planation surfaces*: The MPL area has three levels of topography corresponding to three different planation surfaces: 1400–1600 m; 1100–1200 m and 500–600 m. Planation surfaces which are developmental on limestone rocks are composed of mountainous peaks with roughly similar elevation. The other with flat surfaces are narrow in width and the NW–SE elongated trends are developed by terrigenous rocks.
- *Caves*: These are concentrated in the SW part of our study area (Figs. 2A, B, C). There are two levels of cave at altitudes of 1000–1200 m and 700–800 m. They are presently dry and inactive. Caves that are located at altitudes of 500–600 m are currently developing and their surface contains active water streams.

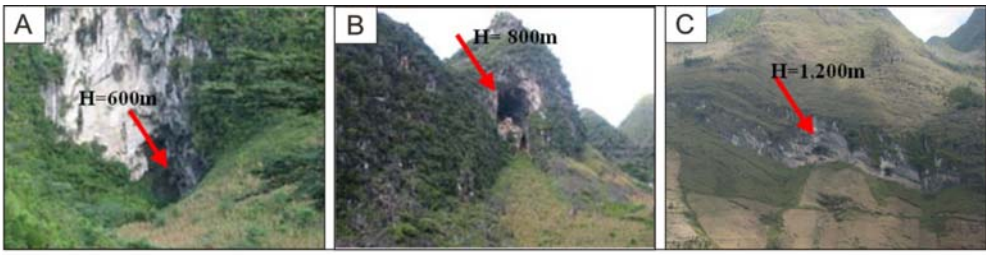

Fig. 2. A – Cave at 600 m with active water streams; B – Dry cave at 800 m; C – Dry cave at 1200 m

- *Sinkholes:* They have circular and ellipsoidal shapes. Their bottoms with small-sizes are cavities. They are distributed in large ranges from 200 m to several kilometers according to the NE–SW, sublongitude and sublatitude direction to creat a karstic valley.
- *Tectonic cliffs*: They are built not only by limestones rocks, but also by the terrigenous rocks. Cliffs which are developed in limestones are of several meters to tens of meters in height and tens of meters to hundreds of meters in length, creating a series elongated with a NE–SW, NW–SE, sublongitudinal and sublatitudinal directions. The Nho Que river valley is the most typical example of this morphology, and nearly 800 m in height and 400 m in length.
- *Rock desert:* The whole area has been strongly uplifted, together with a dense development of fissures and faults, and differences in the altitude of erosional basement; therefore, it is completely exposed by bedrocks in the dry seasons.
- *Residual mountains:* In the MPL, topographical form clearly represents geological structures and tectonic activity. Cuesta relief is displayed by the monoclinal *attitude* of associated rock beds, while the others form roof-shaped, cone-shaped, ladder-step and pyramid-shaped forms, reflecting the presence of tectonic faults.
- *River terraces:* The second-order terraces are encountered in the Meo Vac town and Pa Vi commune. They are hills with flat peaks, 5–7 m in height, composed of polimictic conglomerates interbeded with sandstones and clayey sandstones. The first-order terraces are distributed in Meo Vac, Dong Van towns and along sides of the Nho Que river. They are situated at 2–3 m in height, and exist in the form of small and narrow plains along sides of rivers and their tributaries. They are built by sand and clayey sand.
- *Alluvial battures:* These are distributed at a height of 0.5–1 m along the Dong Van spring-sides and the Nho Que river-sides. They are built by gravel and coarse-grained sand.

3.2 Neotectonic characteristics

3.2.1 Characteristics of neotectonic structure

We have identified 4 Neotectonic structural zones in the MPL and adjacent area (Fig. 3):

- A very strongly uplifted zone with amplitude 1400–1600 m is located in the NE part of the study area in the NW–SE oriented range (Fig. 3). Its basement is built by PZ_1 rocks (Cambrian-Ordovician period) including claystones, limestones and *quartzites* [4]. During the Pliocene-Quaternary period, this structure was desconstructed strongly by faults. Currently, only residual mountains remain at elevations of 1400–1600 m and dry caves at 1300 m.
- A strongly uplifted zone with amplitude 1100–1300 m is located in the SE part of the study area, oriented the NW–SE direction (Fig. 3). Its basement is composed of PZ_3 rocks (Carboniferous-Permian age) including thickly bedded and massive limestones [4]. During the Pliocene-Quanatery, this zone was strongly uplifted. Currently, it is presented by a large range of surfaces and dry caves at an elevation if 900–1200 m with openings of 10–20 m wide and 15–30 m high (Fig. 2C).
- A medium uplifted zone with amplitude 450–600 m is located in the central part of the study area (Fig. 3). The basement is built by PZ_2 rocks (Devonian age), including claystones, siltstones, clayish limestones and thinly-bedded limestones [4]. During the Pliocene-Quaternary, this structure was moderately uplifted, resulting in a massive-linear form. Currently, its surface is at 450–800 m. Solution-leaching and erosion-denudation are precise processes thet created the NW–SE oriented cliffs and many active caves at around 450 m in height.
- Spreading-formed structure is evidenced in the Dong Van and Meovac valleys (Fig. 3). The Dong Van valley forms an acute triangle surrounded by ranges of high mountains and filled with Quaternary deposits. It was formed by lateral-slip movement of the Dong Van-Thuong Phung Fault. The Meo Vac valley is of a graben geometry and elongated in the roughly an N–S direction. Its cliffs are built by limestones. This valley is created by lateral-slip movement of the Thai Pin Tung-Pa Vi Fault.

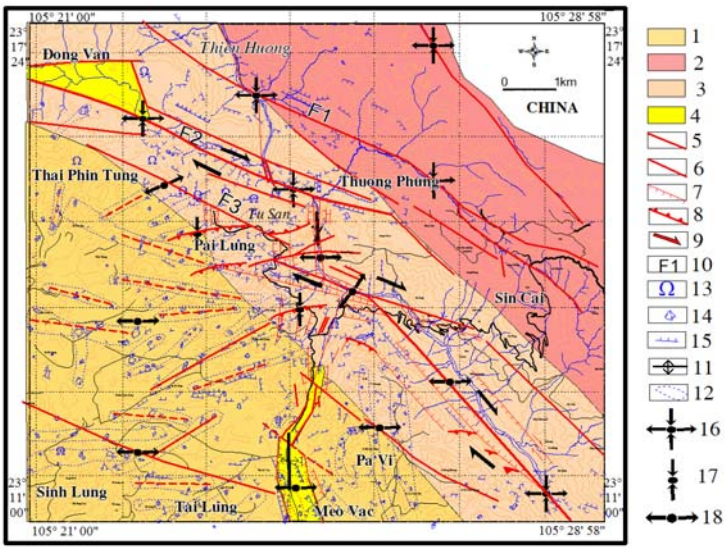

Fig. 3. Map of distribution of Neotectonic faults in the MPL and adjacent area: 1 – Structure of medium uplift in massive form with amplitude 500–800 m; 2 – Structure of strong uplift in massive form with amplitude 1000–1300 m; 3 – Structure of very strong uplift in arch-line form with amplitude 1400–1600 m; 4 – Spreading-formed structure; 5 – Main fault; 6 – Subsidiary fault; 7 – Normal fault; 8 – Inverse fault; 9 – Direction of movement of fault; 10 – Name of fault; 11 – Spreading axis; 12 – Karst valley; 13 – Karst cave; 14 – Sinkhole; 15 – Tectonic cliff; 16 – Lateral stress; 17 – Compression stress; 18 – Spreading-formed tress

3.2.2 Characteristics of tectonic fault

In the study area, main faults are orientated the NW–SE direction, playing an important role in controlling Neotectonic structures. The other faults are developed in the sublongitudinal, NE–SW and sublatitudinal directions (Fig. 3).

– The Thien Huong-Sin Cai Fault (F1) is oriented the NW–SE direction (130°). It is inclined to the NW direction and coincides with fissile surfaces of calcareous-terrigenous rocks. It shows evidence of dextral strike-slip faults (Fig. 4A). Its NE side is uplifted more strongly than the SW one. Sub-faults cut through ranges of mountains to create step-formed terrains, which decrease in height in the SW direction. Each topographic step is seperated by a vertical-sloped rock cliff. In the Sin Cai village, there is a compression zone approximately 10–15 cm wide, and which contains clay reflecting the young activity of the F1 (Fig. 4B).

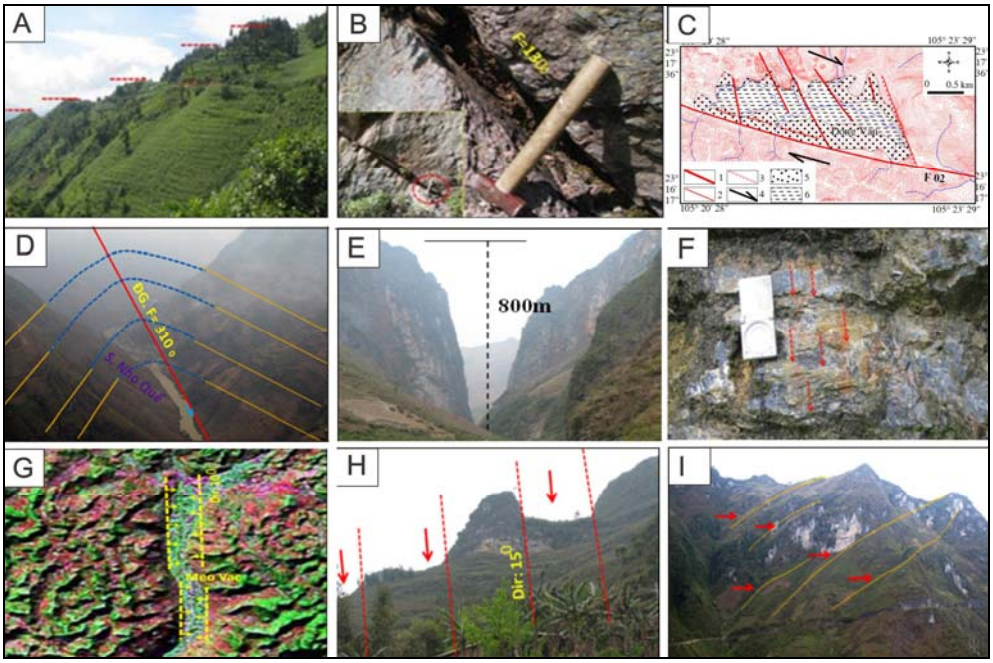

Fig. 4. Tectonic evidences in the study area: A – System of faults with the NW–SE direction (Thuong Phung village); B – Compression zone in the NW-SE direction (Sin Cai village); C – Structural pattern reflects right lateral-slip movement of the F2; D – Inverse terrain; E – The Nho Que valley; F – Shear surface and striations in the sublongitude direction (Pa Vi village); G – The Meo Vac valley on the satellite image; H – Subsidence zones with sublongitude direction; I – Movement of faults in the NE–SW direction

– The Dong Van-Thuong Phung Fault (F2) is oriented in the NW–SE direction (115–130°) (Fig. 3). On the satellite images it represents a band with approximately 1000 m wide. Its sub-faults cut the topographic surfaces to form a complex of horsts and grabens, which are around 200–300 m in width. Besides this, the fault is also represented by young firsts-order springs with strongly eroded V-shaped channels without Quaternary deposits. Along the fault zone, a chains of sinkholes has developed with vertical cliffs. Evidence for the Dong Van trough is from the strike-slip activity of the F2. The main fault combines with the roughly S–N faults to form structural patterns deflecting a right-lateral-slip mechanism of the F2 (Fig. 4C).

- Thai Phin Tung-Pa Vi fault (F3) represents segmental feature according to different trends (120°, 110°, 135°) (Fig. 3). It is recognized by a number of features, such as canyons, karst valleys, ranges of sinkholes, intensive density of fractures, limestones cliffs of several hundreds meters in height, grabens, shear surfaces, strongly broken strata and step-shaped reliefs, and land-slides. They represent a right strike-slip mechanism of this fault. Especially, an inverted relief was observed, which was created by the F3 cut through a large anticline. Currently, it is represented by the valley of the Nho Que river (Fig. 4E).
- The sub longitude oriented faults scatter in the MPL area, with length from hundreds of meters to several kilometres (Fig. 4F). They were recognized based on grabens infilling Quaternary deposits, slipped evidences and striations, presented normal separation or normal slip (Figs. 4E, G, H).
- The system of NE-SW and sub latitude oriented faults is about several kilometres long, concentrated mainly in the west part of MPL. They coincide with subsided belts. Both its sides are built by ranges of limestone mountains. On its floor appears many sinkholes. The NE-SW oriented fault represents normal sinistral strike-slip (Fig. 4I).

4 Discussion

During the Neotectonic period, uplift movement has created three main levels of relief corresponding to three planation surfaces at the different elevations: 1400–1600 m; 1100–1200 m; 500–600 m, respectively. Their ages coincide with three uplift phases, but this is still debatable. An (2008) has considered that two planation surfaces occurred in the Dongvan plateau: at elevations 1200–1400 m with late Miocene age; at 1500–1700 m with early-middle Miocene age. According to Bao (2008), the planation surfaces have been recognized at 1400–1600 m and 1200–1300 m during late Miocene; the other of 500–600 m and 800–1000 m were dated to Pliocene. However, the dating of planation surfaces has still been lacked satisfactory data.

Based on analyses of topographic sections and distribution of cave steps, three main levels of relief in the MPL were recognized, including: 1400–1600 m, 1100–1200 m, 500–600 m. By correlation between deposits in filling the Dong Van and Meo Vac valleys, formation of the levels of relief was elucidated. The valleys were filled with Quaternary deposits with 2–5 m in thickness, including alluvial and alluvial-proluvial sediments. In the Meo Vac valley, three sedimentary budgets were determined corresponding to three stages of terraces and battures forming along the Meo Vac river. Based on An's data (2008), we have agreed age of terraces and battures as the following: The second-order terrace was formed during the early-middle Pleistocene (Q_1^{1-2}); The first-order terrace occured in the late Pleistocene (Q_1^3); and battures were of the Holocene (Q_2). These ages of the terraces and battures are connected with the three topographic levels which were decribed above.

The MPL is situated in the S–W edge of the South China plate, which is linked with the Indosinian mountain belt by the Red River Fault Zone. This connection leads to activities of the faults being very complicated and affected by tectonic activities from the Indosinian terrane [5]. The faults are of small-scale because they are almost intra-plate destructions [6]. Earth-quake occasionally occurs as a result of this. During the Cenozoic, from 25 to 30 milions years ago, in Vietnam, tectonic activity is divided into two main phases [8]: Eocene-early Miocene phase and Pliocene-Quaternary phase. The evidence for first phase is given by strongly broken rock strata to form a cataclastic, brecciated zone. The second phase is represented clearly on current relief's surfaces by topographical bands, planation surfaces, cave steps and tectonic cliffs. Its stress-field has compression axis more or less in the N–S direction. The NW–SE oriented fault system is right-lateral slip, the NE–SW oriented one is left-lateral slip; and roughly S–N and E–W fault systems are of reverse slip. This is suitable with the rule of distribution of faults and geodynamic model in the MPL.

Therefore, reliefs in the MPL are clearly formed during Quaternary period, with some maybe forming earlier in the Pliocene. The Late Pliocene-Quaternary tectonic compression phase is divided into three sub-phases with different directions of uplift corresponding to the three relief's levels.

The NW–SE oriented fault system is of a large-scale, playing an important role in forming and controlling types of relief's architecture with distinct features: strongly uplifted architecture with massive form is orientated in the NW–SE direction in the NE part; and the massive-form one is in the SW part, commonly as a border between different geological formations such as PZ_1, PZ_2 and PZ_3. The activities of these faults also brought about typical architectures developed along the fault zones. For example, the Dong Van valley is formed by normal-lateral-slip mechanisms of the F2; The roughly N–S oriented valley of Nho Que river and the NW–SE oriented graben Tu San occurred due to normal-lateral slip mechanism of the F2; The graben Trang Huong is created by normal separation of the F2.

The sub-meridian faults are of a smaller scale. They are formed later, caused by the activity of NW–SE oriented faults. They are distributed in a system with parallel lineament-forms. They cut topographic surface to create two main types of relief, including ladder-step-formed terrains and graben. The NE–SW oriented faults are less-developed, but their activity is represented clearly by shear surfaces, tectonic striations, and topographic shift along both sides of faults. They are combined with the NW–SE oriented fault system to create a system of fractures and conjugate faults reflecting the sub-meridian oriented force.

5 Conclusion

Ma Pi Leng is a very diverse area in Geology-Tectonics, representing a large asymmetric syncline. It is fully reflected through old to young geological formations (Cambrian-Triassic formations) which were arranged in temporary and spatial orders. Many geological boundaries of this area were discovered in accordance with the international stratigraphic chart. During the Neotetonic period, the MPL area represented a strongly uplifted regime with unstable amplitude to create topographic orders at different elevations such as 1400–1600 m, 1100–1200 m and 500–600 m. It was strongly cut by rivers and streams leading to subdividing its area into three architectural blocks controlled by regional faults.

The faults developed in different directions with typical active features (strike-slip, normal and reverse). Tectonic fractures are approximately 100 m in height, 1000 m in length, and on the largest scales compared with other regions in Vietnam. Tectonic activities brought about a strong anomaly in terrain to form horsts, grabens, ladder-step-formed or inverted terrains, large cliffs, and deep valleys. Furthermore, there are cave steps, karst funnel-formed holes, pyramid-shaped and cone-shaped mountains. Tectonic activities, together with exogenic processes, have brought the MPL area a variety in geomorphologic landscape, deserved of an international geomorphological heritage.

References

1. L.D. An, *The Dong Van-Meo Vac plateau A precious geomophorgical heritage of karst. Dong Van stone plateau: Striking values, orientation for conservation and sustainable development Ha Giang*, 6–27 (2008)
2. D.V. Bao, *Geomorphology of the Dong Van Meo Vac area, striking values and orientations for preservation and rational use. Dong Van stone plateau: Striking values, orientation for conservation and sustainable development Ha Giang*, 81–99 (2008)
3. V.V. Chinh, *Some active faults during the Neo-tectonic period in the NE Vietnam*. Resour Geol, 1, 22–32 (1996)

4. H.X. Tinh (ed.), *Geology of the Bao Lac Map sheet at 1: 200,000 scale*. General Dept. of Geol. & Min. of Vietnam, (2001)
5. T.T. Thang, N.V. Vuong, V.V. Tich, N.D. Chinh, H.H. Hiep, *Process of deformation, geodynamic evolution of the Red River Fault Zone and their significance in interaction between the South China Plate and the Indochina Plate. The results of basic researches on The Red River Fault Zone (2001–2003)*. Hanoi Scien. & Tech. Publish. House, 75–107 (2004)
6. P.T. Trinh, H.Q. Vinh, N.D. Tuc, B.T. Thao, *The modern tectonic activity of the Red River Fault Zone*. J. Earth Sci, **22**, 325–336 (2000)
7. N.T. Yem, *Regimes of tectonic stress-field during Cenozoic period in the Vietnam territory*. J. Geol., Ser. A, **236**, 1–6 (1996)
8. N.T. Yem, O.I Gusenko, L.M. Quoc, A. Motrikov, *Modern stress-field and deformation mechanism of the SE Asia crust*. Resour Geol., **2**, 8–13 (1996)
9. П. Н. Николаев, *Методика тектоно-динамическогоанализа*, Изд. Недра, Москва, **295с** (1961)