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Pattern and determinant agents of the debris and mud flash flood in Lay Nua Commune area, the Former Muong Lay District, Dien Bien Province

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Abstract. This paper discusses debris and mud flash flood, which is a widespread phenomenon with different levels of damaging effects and repetition in the mountainous areas of Vietnam. There are some sites where the flash flood with severe debris components has recurred many times and it has always caused heavy loss of human and materials, such as Lay Nua Commune, the Former Muong Lay District, Dien Bien Province. During the 1990s, this kind of severe hazard is recorded to occur every two years in the town of Former Muong Lay District. This leads to the government's decision to relocate the town to another place. Some characteristics of physiographical conditions such as climate, relief, lithologic and tectonic features, which are considered relevant to debris and mudflows activities, are analyzed, and then come to the conclusions on determinant agents of debris and mud flash flood in this area.

Keywords: Muong Lay; Landslide; Mud flow; Debris flow; Mud flash flood.

1. Introduction

Debris and mud flash flood is a specific form of the flash flood, which presents a very dangerous hazard for the mountainous inhabitants. Finding out its appearance mechanism and determinant factors allows us to make an appropriate warning of the risks that can occur in specific areas.

This phenomenon is rather widespread in mountain regions of Vietnam, but its damaging effect level and repetition appears very different. There are some sites where the flash flood with severe debris components has recurred many times and always causing heavy human and material losses, especially in the Lay Nua Commune, the Former Muong Lay District, Dien Bien Province. During 1990s, every two years it has to mention the name of the town of Former Muong Lay District with information about this kind of severe hazard. The situation has been so grave that the government has been obliged to make a decision to relocate the town to another place at distance of several dozens of kilometers towards Dien Bien Phu City.

Our study within the framework of Fundamental Research Project 702806 on the section of Nam Lay river valley from Lay Nua

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to Former Lai Chau Town (about 10 km) enables us to make some important conclusions about the mechanism and determinant factors of the debris flow formation that can be considered as the specific indicators of the mountainous areas very sensible to the debris and mud flows.

2. Some characteristics of physiographical conditions of the study area relevant to debris and mud flows activities

In previous publications [1, 2], the author has indicated the need and sufficient conditions for debris and mud flows to appear as a particular case similar to one of the Bac Ha Tableland SW slopes. The case of Lay Nua shows us another important factor of debris and mud flows forming.

2.1. Climatic conditions

Evidently, it is necessary to have a situation that causes a rainfall abundant enough to form a runoff with high intensity and great amount of flowing water mass.

Following the data collected in Lai Chau meteo-hydrological station (Muong Lay Town), the study area in one of the most pluvious regions of the country. The rainy season is from April to September, getting the peak in June, July and August, with annual average rainfall of 2,000 - 2,500 mm. In the middle of rainy season, there are usually 20 rainy days per month; every year there are generally 5-10 days with heavy rainfall of more than 50 mm and 1-2 days of more than 100 mm per day. In the summer, intensive rains can occur continuously during 2 to 6, even more than 10 days.

Such rainfall and precipitation regime explain the eventful activities of all kinds of flash flood, debris and mud flows in the former Muong Lay District during the last decade of the 20th Century.

2.2. Relief of the region

The relief of the region is middle mountainous (1200-1700 m of height in the west and 1500-2000 m in the east part). Note the writing that the east slope of the Nam Lay Valley is simultaneously steep slope (above 25^0), almost escarpment, of the Tua Chua Tableland which is divided into 5-6 steps.

The valleys show some anomalous features, such as the bed of Nam Lay River in the section of about 10 km in length from its confluence with Nam He River to its outfall into Da River presenting a particular lineament oriented towards N-E 15^0 with a regular width of 500-600 m except one within the Lay Nua Commune, where its width has doubled (1200 m, Fig. 1). From Lay Nua upstream the river adopts the direction of N-E 40^0 and its width reduces quickly.

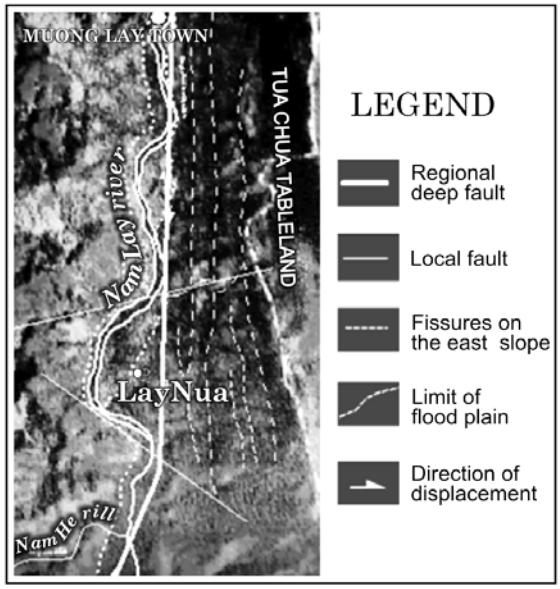

Fig. 1. Photographic sketch showing tectonic faults and fissures in the Muong Lay area.

All of the streams and numberless ravines on the east slope are altogether short and steep

in comparison with one of the opposite slopes. It is also noticeable that in the examined section of this slope there are only 4 small streams and they are concentrated totally within the Lay Nua Commune (section 'B' of 4 km in length in Fig. 2).

Such a particular topography is favorable for reception of rainy air mass coming from NW- and Da River side. The east slope with its important elevation and steepness, like a grandiose wall, and in addition of activities of 4 mentioned streams on narrow space of the Lay Nua Commune presents a good premise for a quick rain water concentration which is at one favorable for creation of ordinary flash flood and causing mass landslide leading to apparition of debris and mud flows.

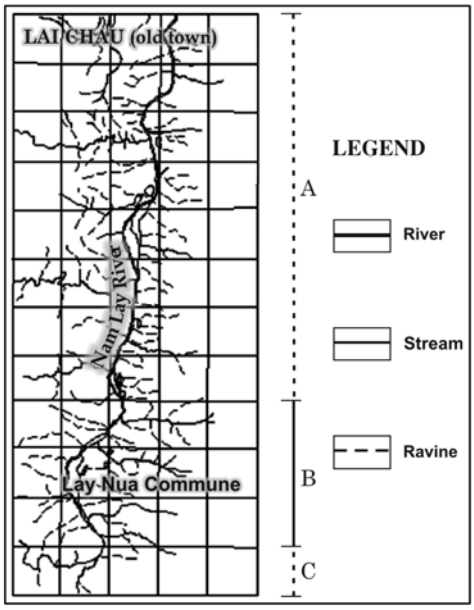

Fig. 2. Sketch of hydrographic network.

2.3. Geological features

Geological features have been examined in two aspects, namely lithologic and tectonic structures.

2.3.1. Lithologic structure

Lithologic structure of the study region is composed of several rock complexes rather contrast from the viewpoint of selective erosion. On the top of watershed area, there are predominantly hard bedrocks, as limestone of the Ban Pap Formation ($D_{1\text{-}2}$ *bp*), aphyric basalt, porphyritic basalt, basaltic agglomerate of the Cam Thuy Formation (P_3 *ct*); the middle section of the east slope of the Nam Lay valley consists of metamorphic schists of the Pa Ham Formation (O_3 -D_1 *ph*) and limestone of the Ban Pap Formation ($D_{1\text{-}2}$ *bp*); the foot of this slope and all the west side of the Lay Nua valley are built with very tender black clay shales and silty sandstone of the Lai Chau Formation ($T_{2\text{-}3}$ *lc*). This basement of bedrock is overlaid by a cover of quaternary loose sediments of a very remarkable thickness. They are mainly slope deposits (colluvium, deluvium) on the valley – side slope, fluvial and alluvial fan deposits at the river bottom.

2.3.2. Tectonic structure

The study region is situated in the Dien Bien - Lai Chau fault zone, the most seismically active one in Indochina. It is composed of two subparallel main faults forming a narrow graben with sediments of the Triassic, Lai Chau Formation ($T_{2\text{-}3}$ *lc*) at the bed. According to geophysical data, the described faults plunge abruptly eastwards with a dip of 85^0 and the destruction zone of 1-2km in width [3]. The fault zone is oriented in general north-south and characterized by left-lateral regime in Pliocene-Quaternary time. Every time, when it changes slightly the direction one can see more or less clearly the presence of a shattered belt or even small basins. In the site of Lay Nua Commune, all of these features morphologically manifest themselves in form of 4-5 parallel slope steps corresponding to the longitudinal fissures and many transversal ones which have been exploited as lines of weakness by 4 above-mentioned streams and in particular a trapezium - shaped anomalous enlargement of the Nam Lay valley floor (Fig. 1, 2). Among the slope steps the highest nearby watershed has an

aspect of an escarpment.

Just in this dynamic situation, the rock have been squeesed, crushed and broken taking the imbrications and leaflike polish structure (eg. black clay shales and silty sandstone of the Lai Chau Formation) and the valley - side slope has become very instable. Furthermore, that is a best circumstance causing the slope deposits to slide and fall down when it rains continuously and strongly.

3. Debris and mud flows in Lay Nua Commune

Lay Nua Commune, location site of the town of Former Muong Lay District, is known as an area of consternated disaster because of debris and mud flows. Here happened violent debris and mud flows in 1945, 1958, 1974, and during the 1990 decade three ones in succession with an interval of two years were happened (Table 1).

Regarding to the spatial distribution, at the whole studied valley section of 10 km in length, the Lay Nua Commune area along of about 4 km has to bear terrible attacks of debris and mud flows, though the former Lai Chau Town area has also suffered heavy losses, but because of an another catastrophe, namely the called "breach flash flood" on mountain river.

So in this segment of Nam Lay valley, the section of 4 km in length at the east slope distinguishes itself as a rare impression anomaly: the debris and mud flows repeat frequently in the time and concentrate extremely in the space: every time debris and mud flows have occurred simultaneously in the all 4 streams here (Fig. 3). A reasonable interpretation of this fact should bring us effective criteria for hazards warning works.

Table 1. Flash flood with important detrital component happened in Lay Nua area during the 1990 decade.

Year	Precipi-tation mm/year	Events	Moment of getting culminant point	Loss and damage
1990	2440	Big landslide in the nearby Nam He confluent valley, two important consecutive flash floods during 4 days at the Nam Lay section of Lai Chau Town, debris and mud flash flood in Lay Nua Commune - the town of Former Muong Lay District.	30- 40 min.	People: 82 dead, 200 wounded; properties: 607 households were lost totally, 15 enterprises and offices were destroyed, 113 ha of rice field were damaged heavily, 243 ha of arable soil buried under cover of 40cm of mud and debris, 5 major bridges and 15 irrigation works were destroyed; the amount of mud and debris were about several million m^3; estimated total loss: 22 billion VND.
1994	2490	Big landslide, catastrophic debris and mud flash flood in Lay Nua Commune - the town of Former Muong Lay District	Suddenly	- Stream Huoi Lo: 18 houses swept away, 11 people dead; 20 wounded; - Stream Huoi Phan: many houses were collapsed, swept away, 6 people dead; 14 wounded; hundreds of arable soil buried under mud and debris; estimated total loss: 25 billion VND.
1996	2415	Innumerable landslide on whole east valley slope from Lay Nua to Lai Chau Town, catastrophic debris and mud flows in Lay Nua Commune; big flash flood at the Nam Lay section of Lai Chau Town	Suddenly	- In Lay Nua Commune: 55 deaths, more than 400 households were evacuated, suspension bridge and many irrigation works were swept away, hundreds of thousands cubic meters of mud and debris buried the fields

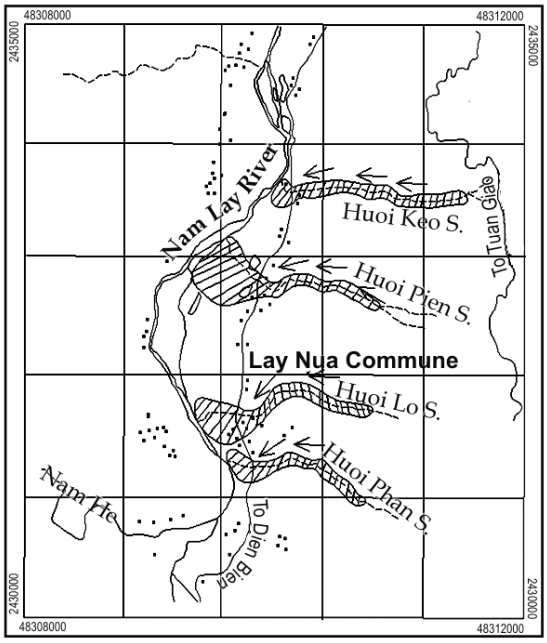

Fig. 3. Location of the debris and mud flash flood in the area of Lay Nua Commune.

4. Pattern and determinant agents of the debris and mud flash flood in the Lay Nua Commune area

4.1. The determinant agents

There were some attempts to find relationship between the formation of flash flood and rainfall regime including precipitation amount, type, and intensity, duration of rainfall and phase of rainy season as well. Using statistical methods, some scientific have found interesting relation between the mentioned parameters [3]. In any case, one must agree that a special meteorological circumstance is required. In the case of our study, we realized that the influence of climatic conditions and vegetation cover are almost homogeneous for all interested section, while, on the contrary, the difference becomes evident concerning lithological, tectonical, topography structures and the geomorphological processes. Therefore, considering a specific torrential rain as a prerequisite for flash flood forming we have concentrated on investigating the two most important aspects, namely source of detritus material supply for flash flood and slope stability propitious for triggering the landslide and collapse in order to push this detritus material into the water course.

As mentioned above, in order that an ordinary flash flood should occur it is necessary to have a sufficient precipitation amount and a particular rainfall regime, while a flash flood with important mud and detritus component requires in addition a presence of abundant amount of detrital material apt to slide or collapse into the water course and enough to create there a temporary dam with followed breach leading to a flowage of the mixture with high percentage of mud and detritus.

4.1.1. The source of detritus material

Analyzing the nappe of quaternary superficial deposits, we found that the east slope of Nam Lay River valley is covered with a layer of loose slope deposits (coluvium and deluvium) and weathering debris with a thickness of often more than 10 m (Fig. 4). This nappe of loose superficial deposits is in particular well developed in Lay Nua Commune area. Its abundance is due to an important role of the escarpment situated on the transitional zone from the Nam Lay valley slope to the edge of the tableland Tua Chua. This escarpment has an origin tectonic owing to the Dien Bien - Lai Chau left-lateral fault. Because of the presence of hard and brittle rocks on the top (limestone of the Ban Pap Formation ($D_{1\text{-}2}$ *bp*), aphyric basalt, porphyritic basalt, basaltic agglomerate of the Cam Thuy Formation (P_3 *ct*)), and of the remarkable original height of slope (nearly 700 m for a distance of 1200 m), maybe during periods of *rhexistasis* the escarpment has evolved according to a model termed *parallel retreat of slopes*. In the studied case, as the theory

supposes, the escarpment has conserved constantly its form, and on its foot slope has been accumulated enormous amount of debris furnishing endlessly detrital material for landslide and collapse processes.

On the geomorphological profile we find this loose detrital cover to be broken into 5-6 steps by a series of parallel tectonic fissures (Fig. 1 and 4) creating a significant alternation of steep and gentle slope segments. Such a structure of slope is very favourable for accumulation of energy in the superficial material nappe which will turn into rapid mass movement when having appropriate situation (heavy and persisten rain, earthquake,...).

Thus, that may be one of most determinant factors which cause such an anomalously high level of flash flood with important detrital component on the Lay Nua area. In consequences, every lineament in form of escarpment with remarkable relative height and length must be considered as an important warning sign about landslide and flash flood with high percentage of debris component hazards.

4.1.2. About the slope stability

As it have been proved above, on the east slope of Nam Lay valley there12 are all-necessary conditions for forming and maintaining a thick and abundant cover of superficial deposits. In order to move these loose materials downwards towards the stream, it requires a weakening of slope stability. Such is indeed the case of our study: the area where the phenomenon of debris and mud flash flood is anomalously frequent is perfectly coincided with the fractured zone, i.e. the zone of tectonically low slope stability.

As is well known for the incohesionless materials, slope angle is the only geometric control on slope stability and very dry soils rely on their interparticle frictional strength for stability. In cohesive soils, the height of slope is as important as the slope angle. All these parameters are concurred to create here, on the examined area, very low slope stability, in particular when it rains persistently and thereby the debris materials become saturated with water.

4.1.2.1. The role of lithologic agent

As stated above, there are two noticeable features to be emphasized:

- Firstly, the surface of main valley as well as the small tributaries is covered with a very thick layer of loose debris;

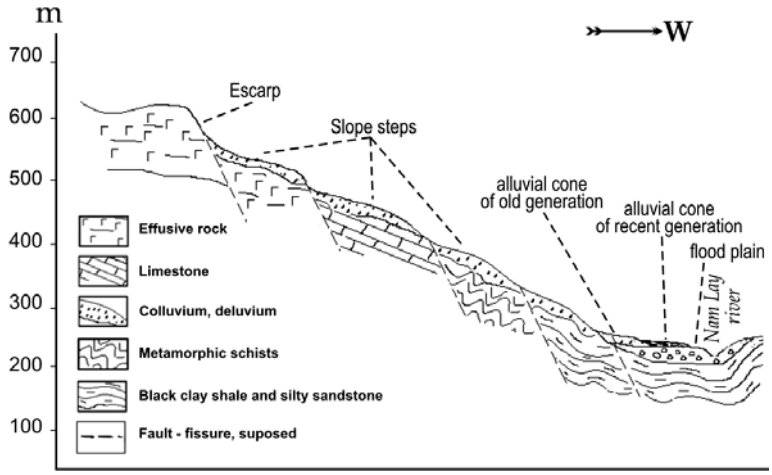

Fig. 4. Geomorphological transversal section
for the Lay Nua Commune area (esquisse with free horizontal scale).

- Secondly, in the cross section of the slope (Fig. 4 and 5), there is a series of tender black clay shales and silty sandstone of the Lai Chau Formation ($T_{2\text{-}3}$ *lc*). They are the ones rocks which are easy to be crushed and shattered forming weathering products rich in clay material. Such a mixture every time after being imbued with water becomes mobile and incites important landslides. It is to be accentuated that in the cross sections this member of so-called weak rock layers is situated always in the lower part easy leading to a slope disequilibrium and triggering the landslides in series (Fig. 6).

4.1.2.2. The level of tectonic fracturing

The Lay Nua Commune area is situated completely in a strongly fractured zone that causes the slopes stability here to become very precarious.

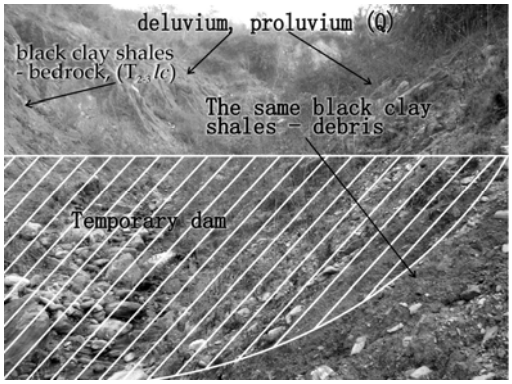

Fig. 5. The black clay shales $T_{2\text{-}3}$ *lc* (Huoi Lo Stream).

Fig. 6. A number of landslides on the east Nam Lay valley side slope at moment of debris flash flood, 1996.

- In addition to the common influence of the Lai Chau - Dien Bien left-lateral fault, the east side slope of the Nam Lay valley has been dismembered by several secondary longitudinal fissures forming 4 - 5 parallel steps (Fig. 1). As proofs of these longitudinal fissures we can see frequently within the four present here tributary streams (streams Huoi Lo, Huoi Pien, Huoi Moi, Huoi Phan) small falls and cataracts somewhere of more than 10 m in height corresponding to the hard bedrock exposures (mainly schists, basalt agglomerate and limestone) (Fig. 7).

- These secondary tectonic longitudinal fissures can be observed clearly on the east valley side up to surrounding of the former Lai Chau Town, but the area of Lay Nua Commune along besides had been divided into smaller fragments by a system of transversal ones. To prove this remark we can indicate the existence of numberless ravines and the four cited streams which morphologically manifest themselves the lines of weakness following the most important transversal fissures (Fig. 1). Using the method of tectonic fault striation analysis, we had found these significant transversal fissures to be a type of normal fault with a component of lateral displacement (Fig. 1 and 8). Consequently, the area of Lay Nua Commune presents at the same time two anomalous features, both the most significant transversal fissures and the 4 remarkable tributary streams (Fig. 2, section 'B').

Fig. 7. A waterfall of 15 m high in Huoi Pien Stream.

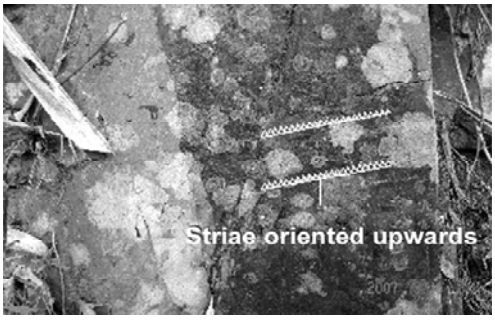

Fig. 8. Tectonic stria showing a normal fault, Huoi Pien Stream.

- Perhaps this is the main reason that causes the Nam Lay River to widen its valley flat, making here a big trapezium - shaped meander (Fig. 1 and 2): on the one hand because of high level of tectonic fissuration, on the other hand owing to the presence of the erodible shales and silty sandstone ($T_{2\text{-}3}$ *lc*) in the both river banks. This enlargement itself, its form and the presence of the two system of fault and fissures suggest that here we possibly have a small "pull-apart" basin or at least an young shattered belt. This hypothesis will become more reasonable, if we note the change of the Lai Chau - Dien Bien fault direction at the confluence of Nam He and Nam Lay rivers from N-E 40^0 to N-E 15^0.

- The geomorphological features are also concurred to prove classically that the studied area is actually under influence of neotectonic differential movements: the east valley side slope is uplifted more than the west one. One of undeniable proofs is the fact that at the mouth of the all four cited tributary streams exist alluvial imbricate cones (nested cones) of two generations (Fig. 4) among them the youngest extents progressively towards the river channel causing the last to move to the opposite bank (Fig. 1). Concurrently, on the east valley side slope there are a lot of landslides whose head scarp parallels the Nam Lay River, similar to the rents in the slope detrital cover.

The above mentioned data present the persuasive proofs of the existence in the Lay Nua Commune area of a tectonic shattered belt situated perpendicularly to the main axis of the Lai Chau - Dien Bien fault zone. This situation explains such a very high level of instability of the east slope of the Nam Lay valley and consequently why within the studied area only the section corresponding to the territory of the Lay Nua Commune had to suffer frequently the wave of landslides which provide the detrital materials for the frightened flash flood with important detrital component.

So, a high level of rock crushing in the tectonic shattered belt presents one of the most important warning signs for the phenomenon of landslides and flash flood with important detrital component.

4.2. The pattern of the debris and mud flash flood in Lay Nua area

All of the Vietnamese researchers have a common opinion that the flash flood with important detrital component can occur when it is obligatory to happen a sudden breaking the dam of temporary impounded lakes in order to create a flow of great velocity.

However, the factors creating the bar on the stream's line and the way of its break may be different. For example, the results of the studies in Bac Ha region [1] show a very specific manner of the temporary dam formation. That is the presence of a beaded valley, within which there is an alternation of broadened and constricted sections deeply due to a particular geological structure. Therefore, the tectonic fissures disposed perpendicularly to the strike of a monoclinal structure predetermine the direction of the valley axis. On the other hand, the monocline is composed of two members of resistant and less-resistant strata, so as the stream erodes the less-resistant member the valley bottom becomes broad and in the contrary case, it is narrow. When it rains persistently from the slopes of the broadened section, occur intensively the landslides whose detrital material will create at the site of valley constriction an obstacle in form of a temporary dam.

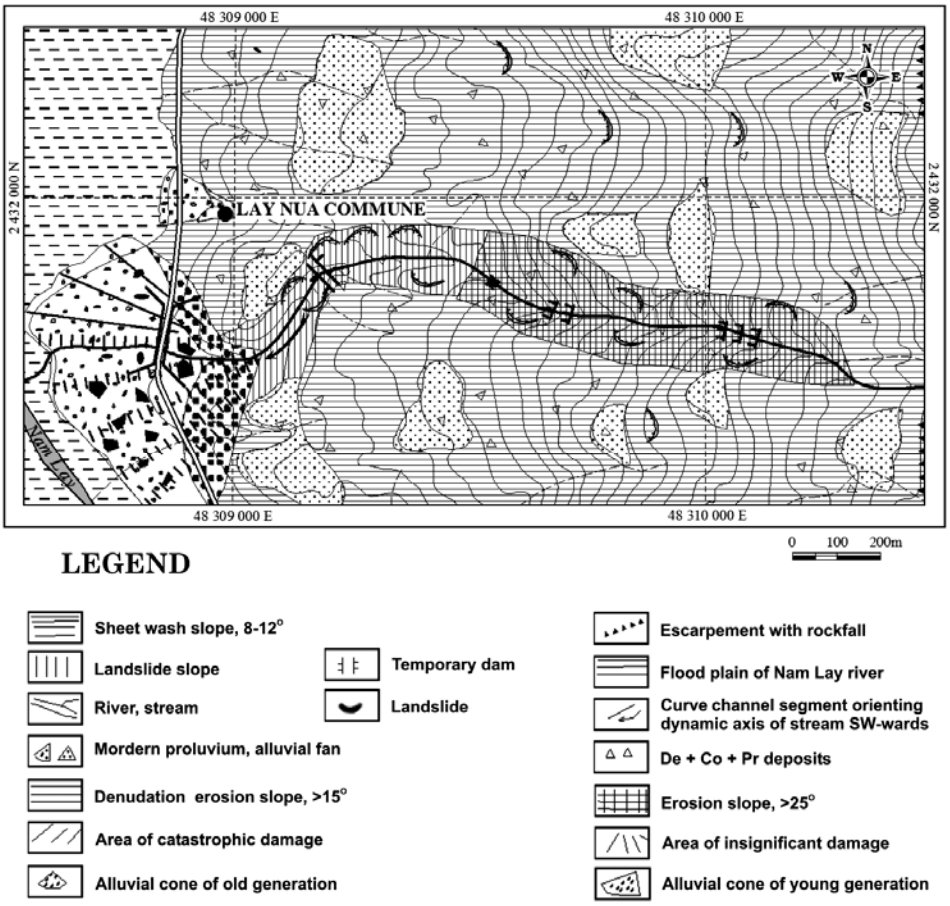

Fig. 9. Geomorphological map presenting the debris and mud flash flood in Lay Nua Commune.

The case of our study in Lay Nua Commune area presents another mechanism of debris and mud flash flood formation that merits particular consideration. Here there is neither water gap nor beaded valley, nor monocline, but there is a very high level of tectonic fracturing, a relief of considerable steepness, intensively dissected and in particular the slopes abundant in debris material. These local conditions themselves made the east of valley side slope within the Lay Nua Commune area so unstable that causes a large number of landslides to occur when suitable meteological situations are met (Fig. 6). In a similar case, the massive detrital materials slide or collapse into the streams may easy create temporary dams impounding the watercourse. In the valley of Huoi Lo Stream one can see clearly the vestiges of the same "barrage" (Fig. 4, 7, and 9) in form of destroyed temporary dams or the huge rock blocks and boulders which are lying now across the stream valley, as well as a number of landslides on the slopes. Over a short period, the temporary dams will be breached and forming the debris and mud flash flood. The flowage of the mixture can be name as *"breach debris and mud flash flood"*.

So, we can conclude that the debris and mud flash flood in Lay Nua Commune area belong to the type of breach flash flood in the small slope stream, which evolves following the sequence of events:

Persistent torrential rain → intense landslides → impounding the stream → breaching the dam.

5. Conclusions

- The debris and mud flash flood in the Lay Nua Commune area, Former Muong Lay District, Dien Bien Province evolves in accordance with the pattern of breach flash flood in the small and steep slope stream;

- The determinant agents that cause the debris and mud flash flood to occur in the Lay Nua Commune area with such a high intensity, a notable spatial concentration and a remarkable reiteration frequency, besides the appropriate meteorological situation, are as follows:

+ An abundant source of detritus material accumulated at the foot slope dominated by an escarpment of remarkable relative height and length, in particular which has evolved in accordance with the model of *parallel retreat of slopes;*

+ High level of tectonic fissuration of rocks in the local shattered belt, particularly in the shear zones.

These factors, together with ones we have found in the study at south-west slopes of Bac Ha Tableland [1], belong to a group of lithological, structural and geomorphological agents and can be used as the credible and effective indicators for warning the debris and mud flash flood.

Acknowledgments

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References

[1] Dao Dinh Bac, Pham Tien Sy, Mud flows and their warning signs deducted from the study on the South-West slope of Bac Ha Tableland, *VNU Journal of Science, Natural Sciences and Technology* No. 4AP / XX (2004) 1 (in Vietnamese).

[2] Dao Dinh Bac, Using GIS for warning the mudflow hazard and determining the area of small hydrology power construction, key study in Lao Cai Province, *VNU Journal of Science, Natural Sciences and Technology* No. 4AP / XXI (2005) 10 (in Vietnamese).

[3] Vu Cao Minh, *Investigation, assessment of the landslides and mudflows problem in Lai Chau Province and suggest the prevention method,* Final report of the Fundamental Research Project, Institute of Geological Sciences, VAST, Hanoi, 1997 (in Vietnamese).