Journal of Mining and Earth Sciences Vol.56 (2016) 38-48

Journal of Mining and Earth Sciences

Website: http://tapchi.humg.edu.vn

Application of digital elevation model for interpretation of geological structures: a case study of the Dien Bien area, Northwestern Vietnam

Hung The Khuong*

Faculty of Geosciences and Geoengineering, Hanoi University of Mining and Geology, Vietnam

ARTICLE INFO

Article history:
Received 03 Sep. 2016
Accepted 25 Oct. 2016
Available online 20 Nov. 2016

Keywords:
Digital Elevation Model
Lineaments
Geomorphology

ABSTRACT

This paper present a preliminary result of the application of digital elevation model (DEM) and Shaded Relief Image in interpretation geological structure of the Dien Bien area. The application of this data set has led to the identification of lineaments and recognition of correlation between the lineaments and geological structures directed in the study area. The interpreted lineaments derived from various enhancing techniques show that the lineaments trend in east south (ESE) – west north west (WNW), south south east (SSE) – north north west (NNW), north north east (NNE) – south south west (SSW), and east north east (ENE) – west south west (WSW) directions. The interpreted lineament map demonstrates that the NNE-SSW system is correlated with the Dien Bien - Lai Chau fault system, which is interpreted as a strike-slip structure. It is also visualized that the Cenozoic pull-apart basin formed by extensional tectonics along the fault is dominated in this area. The results of this study also demonstrate that mapping of structural features using DEM can provide adequate geological information dependent on scale of interest and data quality.

1. Introduction

Lineaments are more or less rectilinear alignments that can be seen on satellite images, aerial photographs and digital elevation models in (Ollier, 1981; Panizza et al., 1987). These linear features may represent natural morphological alignments or those of anthropogenic nature (roads, aqueducts, crops, etc.). Structural discontinuities of rocks and other features related to tectonic activity often results in morphological lineaments (fault scarps, joints, fold axis in (Ramsay and Huber, 1987). These lineaments can be expressed as linear valleys, linear slope breaks or linear

*Corresponding author
E-mail: khuongthehung@humg.edu.vn

ridgelines (Jordan et al., 2005).

There are many specific landforms associated with faults which allow the fault type recognition (Burbank and Anderson, 2001; Keller and Pinter, 1996). Fault scarps are the most clear fault features (Ollier, 1981). They are very steep slopes with the same aspect parallel to the fault trace. The size of fault scarps could vary between a few meters up to hundreds of kilometers of length (Burbank and Anderson, 2001) and between fraction of meter and hundreds of meters of height. As normal and strike slip faults usually present high dip angle they are not affected by topography and tend to be a straight line in plan view, although they may be curved or sinuous (Burbank and Anderson, 2001; Ollier, 1981). Thrust and reverse faults have low dip angles and in this way they present more complex topographic expressions and they are more difficult to recognize in remote sensed images (Burbank and Anderson, 2001; Ollier, 1981).

The purpose of this study is to provide the three-dimensional model and image topographical patterns in preparation for a land of northwestern Vietnam. Similar methods of remote sensing (aerial photographs, satellite and radar), digital elevation models are also based on the registration process and interpret numerical data, and there are some widely used in research mapping (Phan and Hoang, 2004).

In the present work,it was set initially lineament course in the Dien Bien area. This is one example of possible applications of digital elevation model. The results of this modeling were compared with some of already existing materials such as geological map of the Dien Bien area (Tran, 2005), as well as the effects of the own field work.

Area for which the digital elevation model (DEM) covers a part of the northwestern Vietnam. This analysis consisted of examination of some the Splot images at 1:100,000 scale, and 1:100,000 topographic maps. Most lithologies of the Dien Bien area are Mesozoic sedimentary sequences including acidic volcanic rocks, and carbonates and terrigenous sedimentary rocks. Proterozoic, Paleozoic and Cenozoic rocks consisting of flysch, carbonates sedimentary rocks, schists, phyllites and basalts, and Quaternary sediments also occur therein. Generally, the Proterozoic, Paleozoic and Mesozoic lithologies were intruded by the Paleozoic, Mesozoic and Cenozoic intrusive bodies, as shown in Figure 1

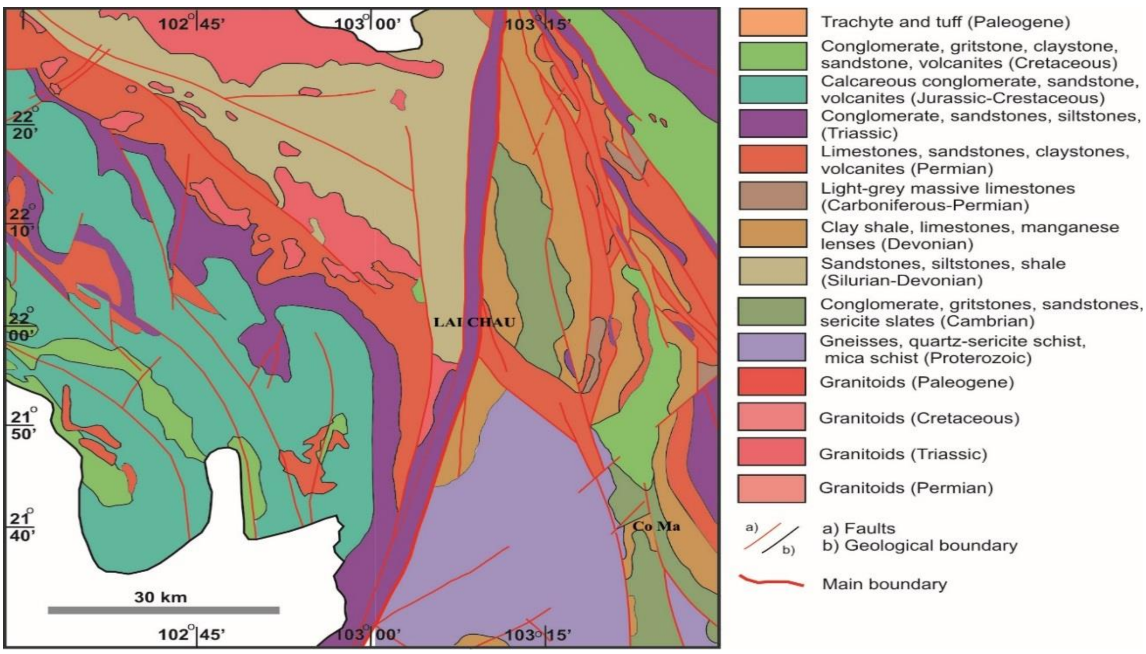

Figure 1. Geological map of the Dien Bien area (compiled from geological maps of the northern Vietnam at 1:200,000 scale and modified by (Tran, D. T., 2005)

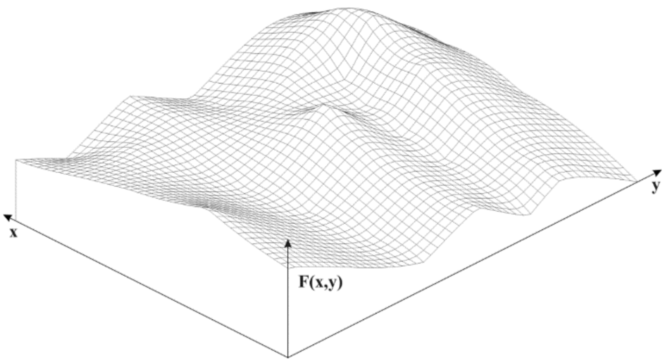

Figure 2. Digital elevation model, regular grid composite of X, Y, Z point system

2. Research methods and data

2.1. Digital elevation model and remote sensing image

Digital elevation model (DEM), also called digital terrain model is a representation of the surface topography of a region of the Earth's surface, normally in vector format (i.e. stored like an image). DEMs are often obtained by digitizing map contours, or by stereo matching aerial photographs or satellite images. DEM construction is based on scanning the maps and digitization of contour line, or other elements of the terrain and then transformation from target point to the X, Y, Z coordinate system and save data in files. Computer software, such as Surfer program, is designed for these purposes.

Table 1.Parameters of digitized values and digital elevation model (DEM) interpolation.

Parameters	Lai Chau-Muong Lay
Number of digitized parameters	87080
Z Minimum	110.77
Z Maximum	2048.7
Z Mean	833.3
Z Median	802.04
Z Standard Deviation	389.48
Interpolated type	Kriging point
Drift	linear
Grid Size	100/97

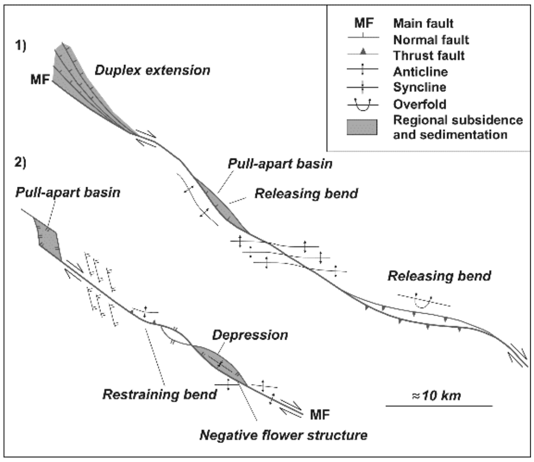

Figure 3. Geological structrures in combination of the faults

DEM representation of data is done using a regular grid, which is described as a density function Z = F(x,y) (Keckler, 1994), as shown in Figure 2. Surfer program is used to create a grid from X, Y, Z data. Interpolation and filling empty space between digital points is carried out by Kriging algorithm.

The remote sensing image analysis is carried out on SPLOT image and other images (http://earth.google.com) combined with DEM analysis. To better understand the lineaments and recognize tectonic boundaries. Analysis of remote sensing images is performed in order to classify areas where geological features are very difficult to read. When remote sensing data are available in digital format, digital processing and analysis may be performed using a computer. Digital processing may be used to enhance data as a prelude to visual interpretation. Digital processing and analysis may also be carried out to automatically identify targets and extract information completely without manual intervention by a human interpreter. However, rarely is digital processing and analysis carried out as a complete replacement for manual interpretation. Often, it is done to supplement and assist the human analyst.

2.2. Structural analysis

The combination of the faults can form typical structures in Figure 3. Constructional or restraining bends and offsets are local zones of convergence where material is pushed together by the dominant fault movement. The linkage of adjacent fault segments is typically through the development of P-shear splay faults. At a constant volume of the deforming transpression zone, local shortening will produce vertical lengthening and thus surface uplift. This push-up area will be eroded.

Extensional, releasing or dilatant bends and offsets are local zones of extension where material is pulled apart by the dominant fault movement. The linkage of adjacent fault segments is typically through the development of R-shear splay faults. At a constant volume of the deforming transtension zone, local extension will produce vertical shortening and surface depression. This pull-apart area will be site for sedimentation.

A strike-slip fault system commonly shows a braided pattern of anastomosing contemporaneous faults. Constructional and extensional bends and offsets can thus alternate along a single yet complex strike-slip zone.

Negative flower structure: If the vertical component is normal, faults tend to be listric and to form a normal or negative flower structure, which forms a depressed area. This subsiding, commonly synformal area has generally, in map-view, a wedge-or a rhomb-shape. It forms a sagpond, a rhomb graven or, on a larger scale, a pull-apart basin. Negative flower structures are also called tulip structures. Strike slip faulting and sedimentation: Sedimentary basins developed in strike-slip settings are usually rhomb-shaped, fault bounded pull-apart depressions formed in transtension settings.

3. Results and Discussion

3.1. Digital elevation model and remote sensing image of the Dien Bien area

The obtained model of DEM construction covers an area of 845 km^2 and 110 m to 2,049 m above sea level. Extracted lineament is based on a change in the angle of illumination shaded relief map in Figure 5, contour map is interval of every 40m in Figure 4 and the spatial model (3D surface) in Figure 11.

Contour maps are also commonly called topographic maps or topo maps. As the name suggests, this is interpretation of terrain. Terrain height and morphological information are represented by contour lines. Contour density in the contour map is taken into account and concentrated in contour lines when dealing with linear structures shown in Figure 5.

Performed interpretation of splot images at 1:100,000 scales covered an area of 527.53 km^2 is that it consists of two images of the Lai Chau and Lao Cai areas in Figure 6 and the obtained results are treated as a complement to photo-interpretation digital elevation model.

Criteria is adopted for determining the tectonic lineaments (Gupta, 2002), which are presented as follows:

1) Drainage - upright sections of rivers and tributaries and the specific system, such as dendrite; rectangular and angulated; parallel; and rectilinear patterns;

2) Incision and surface uplift recorded by the river-buttresses, ridges and indentations of erosion;

3) Drainage offset – since they either displace or deflect river courses;

4) Alignment of seams and basins – indicated fault trace;

5) Linear river segments or linear valleys extending for several kilometers suggest faulting;

6) Topographic relief along a fault - fault a scarp gives a direct indication of dip slip and forms triangular faces; beheaded valley, and shutter ridge;

7) Linear features marked by contrasting topography, tone, texture and vegetation;

8) Groups of various elements listed from 1 to 7.

Lineaments reflect the faults or fracture zones identified on the basis of the terrain (topolineament), DEM and remote sensing image analysis. Please note that in relation between faults, which developed in remote sensing and DEM methods can only point to one

Figure 4. Shaded relief map of the Dien Bien area, light position angles horizontal 138°, vertical 65°

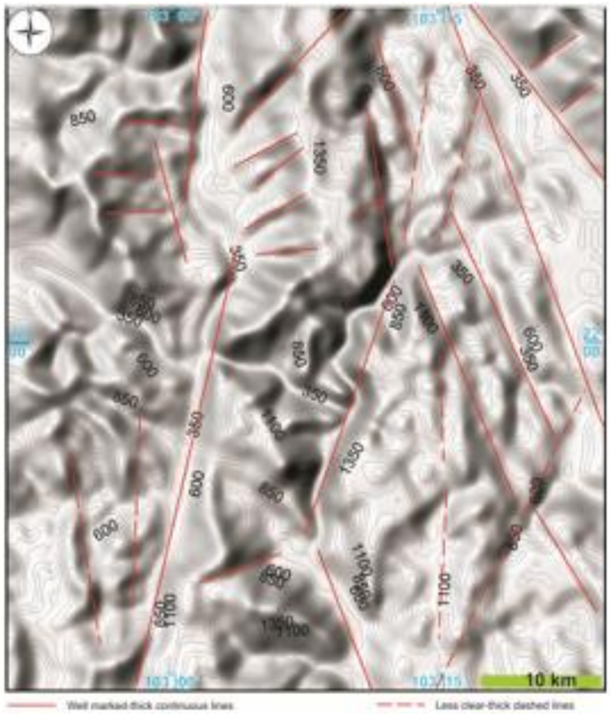

Figure 5. Shaded relief map combined with contour lines intervals of every 40m for the Lai Chau-Muong Lay area, light position angles horizontal 138°, vertical 65°.

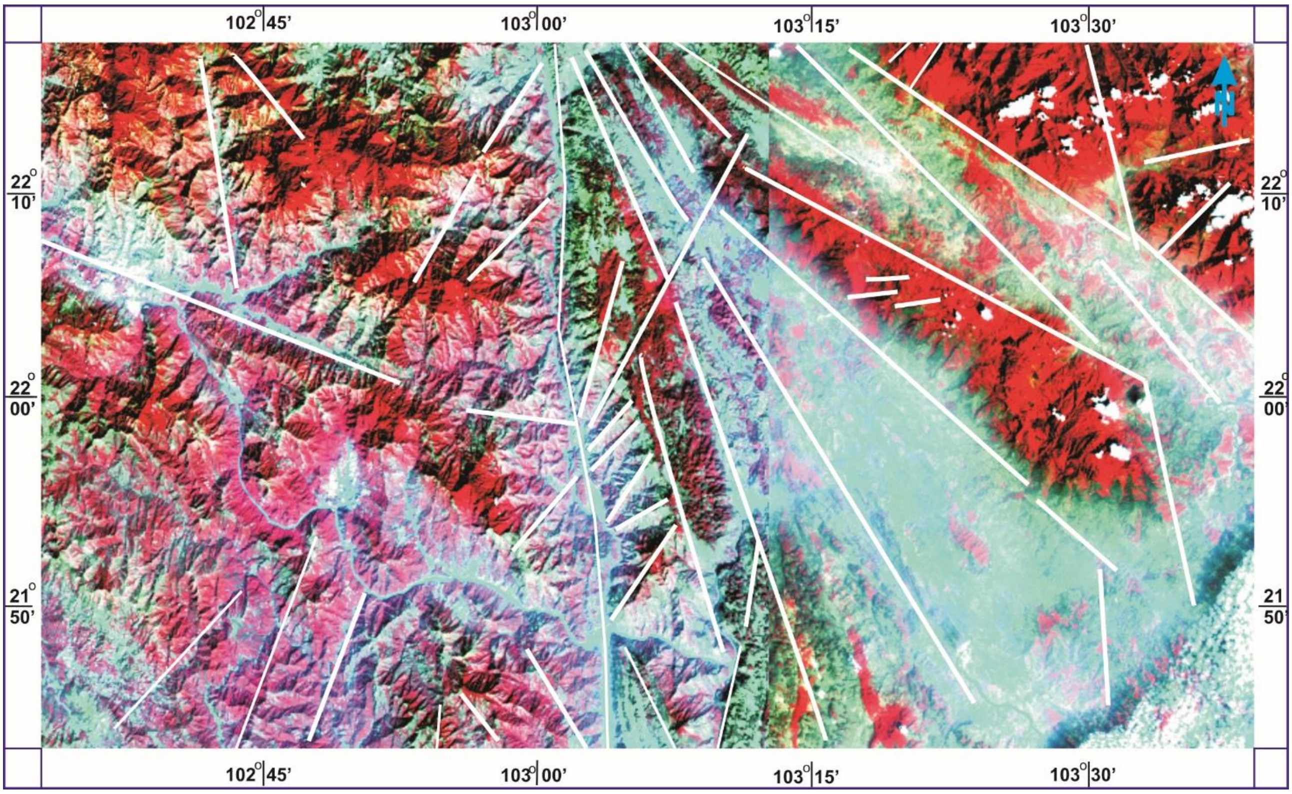

Figure 6. The splot images (XS mode) of the Lai Chau area on scale of 1:100,000. The white-lines indicate tectonic lineaments.

parameter - line fault, a fault trace on the surface area.

3.1.1. Lineament extraction by drainage network analysis

This study focuses on utilizing drainage network extracted from several topographic maps at 1:100,000 scale in order to constrain the structure of the NWVN area. Topographic base was derived from the compilation by State Department for Cartography, and Geodesy and Cartographic Department of General Staff of the Vietnam published from 1990 to 1994.

Drainage network of the NWVN area has preserved good geological record of the movement, displacement, regional uplifts and erosion of tectonic units; simple linear patterns are arranged reflecting linear subsurface structures. We are dealing here with the Da River, Nam Na River. They are mainly playing a key role controlling drainage network of the area and are considered as old rivers, which more or less reflected actual offset of the faults. Common is the linear deflection of several rivers in a certain direction, visible in the tributaries of the Da, and Nam Na Rivers. Perhaps the lineaments along main Da, and Nam Na Rivers designated dislocations within the area. In addition, there are many straight stretches of river valleys, often contracted along a line zone, such as the Nam Cay, Nam Kim, Nam Co, Nam Khai streams. Their stream courses often coincide with the occurrence of many small tectonic lineaments and indicate a similar course. This type of elements is dominated on the lines of Da, and Nam Na rivers.

Nam Ma River is oriented by Dien Bien - Lai Chau fault. The drainage network is transformed into lineament map shown in Figure 7. In this experiment, 166 lineaments are identified basing on analysis of the individual river. The minimum and maximum lengths recorded are 3.09 and 55.468 km. The mean length of the lineaments is 17.679 km, and the total sum of their lengths is 2,917.1 km. They are divided into four groups by terms of direction, namely ESE-WNW, SSE-NNW, NNE-SSW, and ENE-WSW directions shown in Figure 7. Among them, the lineament group of ESE-WNW direction is dominating and often set along the main rivers and streams in the area. Second one is lineament group of SSE-NNW direction, which cut and moves lineaments of the NNE-SSW and ENE-WSW systems.

3.1.2. Lineament extraction by terrain analysis

Limited coverage of the NWVN area indicated by a digital elevation model and remote sensing image of the site matches the description presented above. The study area comprises the Lai Chau, Son La provinces.

Lineament terrain map presents lineament accumulation derived from analysis of selected remote sensing images, and DEM (shaped relief, contour maps and spatial model). Moreover, lineament map also can be attributed to the fractures that are recognizable on other remote sensing image (*http://earth.google.com*). Most lineaments were designated by individual model, then they were compared with each, chosen according to similar direction, aligned, averaged and affixed to one foundation forming shaded relief image shown in Figure 5. *The advantage*of this method is that *interpretation* of results reveals tectonic lineaments, which are not visible on the area surface, and therefore not marked on the available geological maps at 1:200,000 scale. However, some of the designated lineaments are recognized in the field as the Dien Bien-Lai Chau fault zone. Analysis of the digital elevation model in comparison with the drainage network produces a better result in the lineament interpretation. It is possible to designate not only the lineament directions, but also their lengths. The obtained results from splot and remote sensing images interpretation have demonstrated the usefulness of digital elevation model in lineament map shown in Figure 5. A total of 122 lineaments were extracted from the terrain model with length range from 2.543 km to 53.298 km, and average values of their lengths are 14.739 km.

Interpretation of the direction and spatial distribution of lineaments in Figure 11 demonstrate that four main directions dominate. These directions also influence lineaments' density. Analyzing the drainage network, we are dealing here with lineaments trending NNE-SSW, ENE-WSW, SSE-NNW and ESE-WNW shown in Figures 8 and Figure 9.

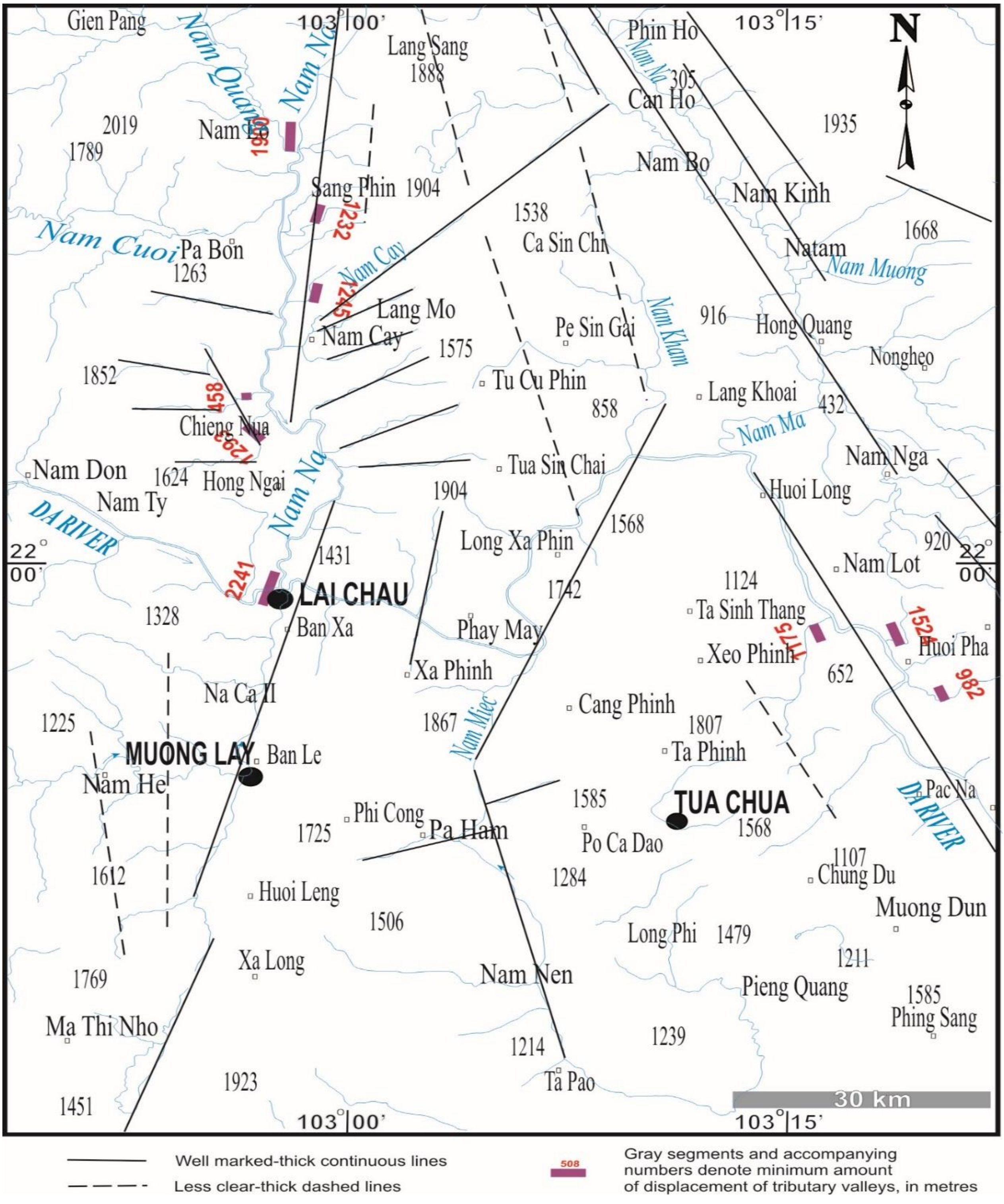

Figure 7. Lineaments extracted from the drainage network analysis

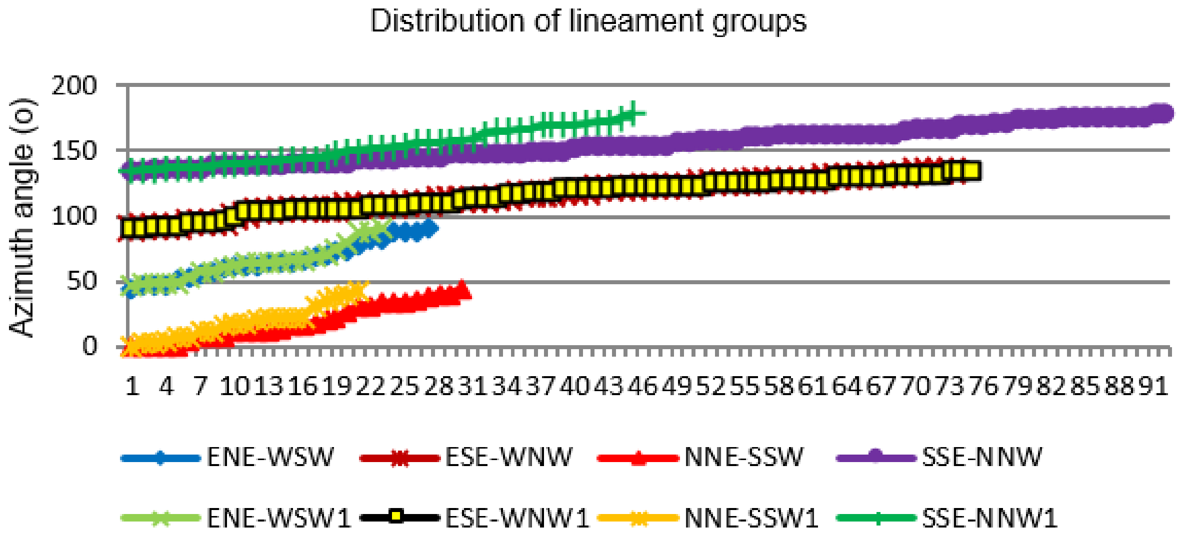

Figure 8. Distribution of lineament groups from the river network and terrain.

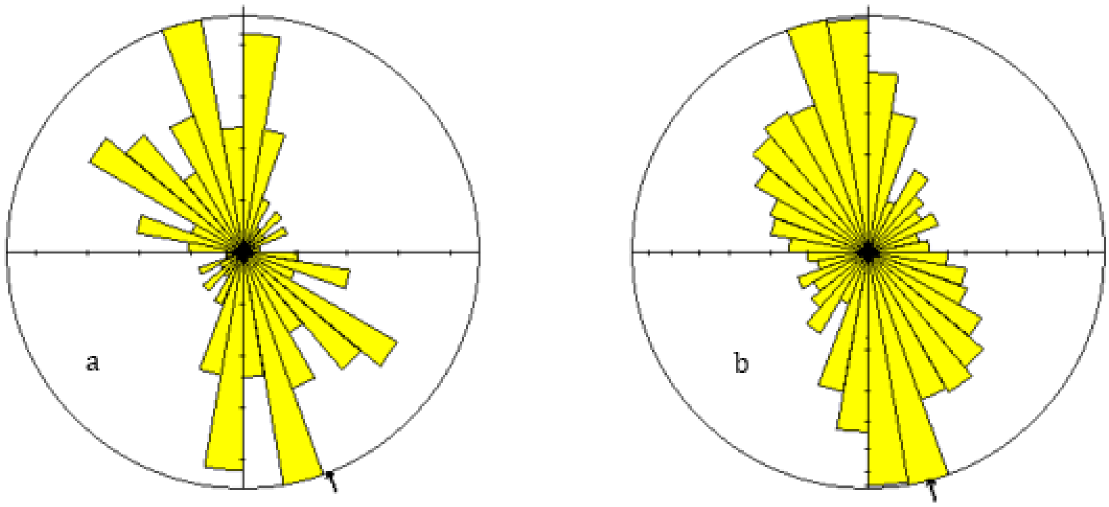

Figure 9. The length and azimuth rose diagrams of lineament directions of: a - drainage pattern; b - terrain aspect.

Figure 10. Example of tectonic landform (triangular facets) pointing to differential uplift along Dien Bien – Lai Chau fault zone near Lai Chau province, the white lines indicate tectonic lineaments.

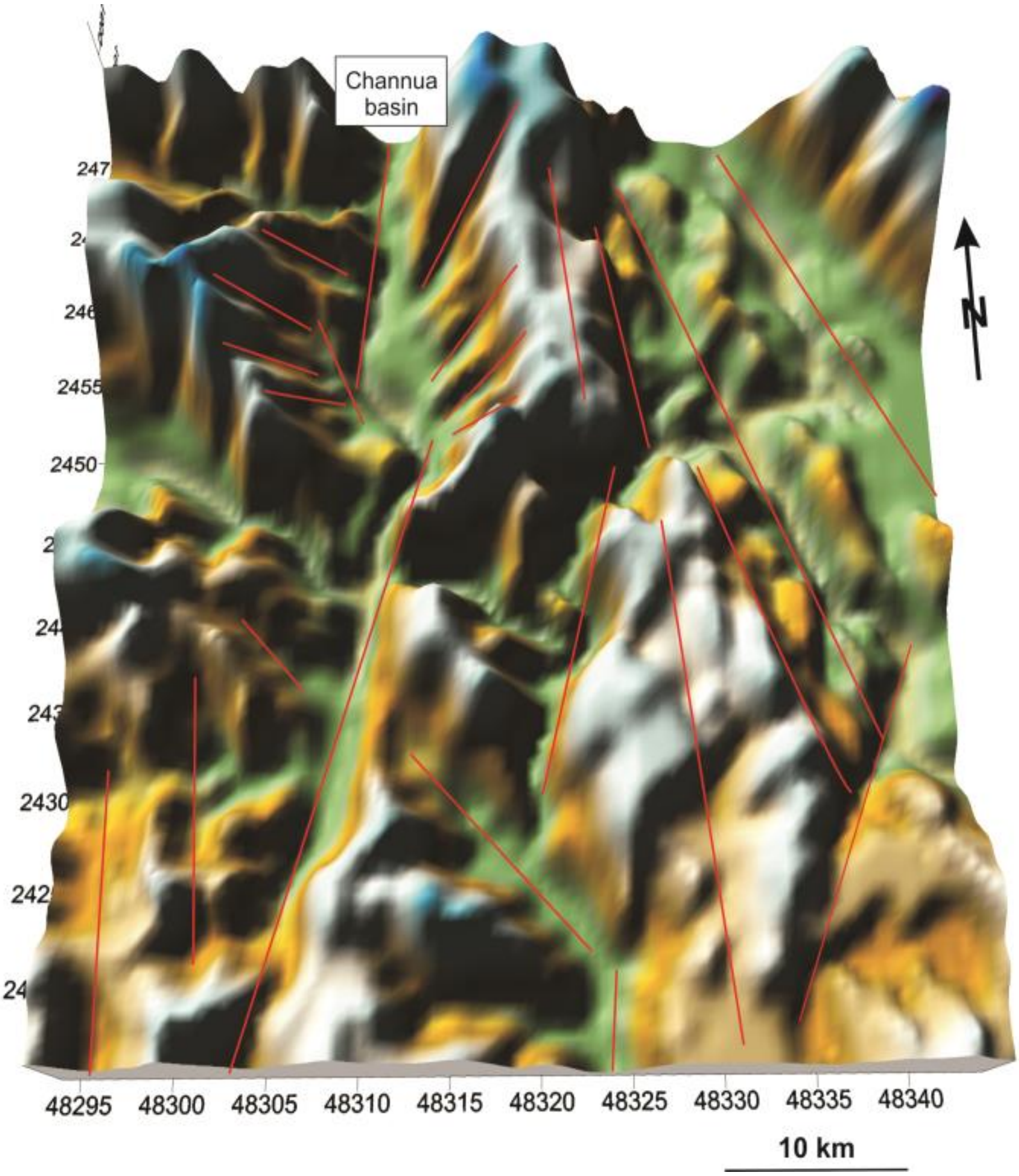

Figure 11. Digital elevation model of the Chan Nua pull-apart basin, located along the DBFZ, the red-lines indicate tectonic lineaments.

3.1.3. Domain analysis of aligned morphological features and geological field data

Main tectonic lineament structure in the Dien Bien area is the Dien Bien-Lai Chau fault zone (DB-LCFZ). At a particular scale, some of the tectonic features may appear sharp, well defined although very extensive. On the other hand, other tectonic features may appear as a wide zone, characterized by numerous parallel en-echelons to overlapping lineaments, with a similar sense of displacement, spread over a wide zone, *e.g.* the DB-LCFZ.

The DB-LCFZ is one of the most important structures in the study area. It is clearly indicated by NNE-SSW lineaments, showing good correlation of lineament between the drainage network and terrain analysis. The DB-LCFZ is a strip of valleys lower than 1,000m and belongs to side and bottom of the river-valleys: Nam Ma, Nam Lay, Nam Muc and Nam Rom between Vietnamese-Chinese border in the North to the Vietnamese-Laos border in the South.

According to the geomorphologic studies, the DB-LCFZ can be divided into three strips. The central strip is situated along lowest part of streams, it includes hills, lower mountains, and valley flat stands isolated within the valleys (Pa Tan, Chan Nua, Lai Chau, Muong Pon, and Dien Bien). The eastern strip contains slopes with terraces and abrupt walls tens of meters high and few kilometers long. This strip is separated from the surface of the Ta Phinh plateau and flat peaks of the Huoi Long range by a big wall extending from Pa Tan to Muong Pon. The western strip contains slopes inclining gently towards south with slightly marked terraces.

Subsidiary faults within the DB-LCFZ created the type of feather structures, especially in southern part of this zone, they formed pull-apart basins filled by Quaternary fluvial sediments (Hoang & Phan, 2001), (Zuchiewicz et al., 2004). Sizes of these basins increase southwards. The basin's sediments are cut by faults, clasts composing alluvial fans are fractured parallel to the fault traces. These observations contribute to prove strike-slip motion of the DB-LCFZ.

Morphotectonic indicators of sinistral and sinistral-normal faults bounding pull-apart basins in the southern portion of the DB-LCFZ include well-developed triangular facets and shutter ridges (Zuchiewicz et al., 2004). Triangular and shutter ridges are of relatively small height at least in the Dien Bien Phu basin, and NW of Dien Bien city shown in Figure 10.

Furthermore, the evidence of offset movement is also found on the DB-LCFZ by the river features. The measured left lateral offsets of tributaries, river and drainage channels range between 270 and 790 m (Phan, 2004). In the regional scale, between Lang Sang and Phung Dat, left-lateral offsets are between 458m and 2,244m, where cumulative effect of several deformational episodes resulted in nearly 8.369 km-long left offset of the Nam Ma river (Khuong, 2011).

Studied geomorphic features indicated amplitude of sinistral strike-slip around 500-2,200m in many locations (Khuong, 2011). The age of deformation may be Quaternary (1 million year) with rates of sinistral strike-slip ranging from 0.5 to 2.2 mm/yr. The results are similar with obtained by (Zuchiewicz, 2004), who investigated amplitudes and rates of faults distributed in some valleys along the DB-LCFZ. The displaced Quaternary alluvial sediments in Dien Bien Phu basin indicate that sinistral strike-slip faults reveal minimum rates ranging from 0.6 to 2 mm/yr in Holocene and 2 to 4 mm/yr in middle-late Pleistocene times (Zuchiewicz et al., 2004).

The zigzag line of Da River when it flows through the DB-LCFZ is caused by sinistral strike-slip motion of the fault zone. The fault's amplitude reaches around 2,240m (within Quaternary basin along zigzag line of Da river), and led to the rate of sinistral strike-slip DB-LCFZ reach 2.2 mm/yr. Moreover, the rate of sinistral strike-slip DB-LCFZ in middle Pleistocene (consider as time of 1 Ma, Zuchiewicz, 2004) also reach 2.0 mm/yr. Therefore, rates of sinistral strike-slip of the fault zone range from 2.0 to 2.2 mm/yr. Similar values were appropriated for the fault zone in the Chan Nua, Dien Bien Phu basins along Nam Na River.

Subsidiary faults combined with main fault of the DB-LCFZ were observed in the northwestern study area. Most of them belong to the feather structure type and form pull-apart basins as the Chan Nua basin shown in Figure 11.

4. Conclusions

The linear trending can be observed and extracted throughout the Dien Bien area from the DEM data. The DEM data can be used to map out geological structure in a satification level, particularly when some other data area not available. The results of this study demonstrate that mapping structural features through DEM can provide good-enough geological information dependent on scale of interest and data quality. The DEM technique has advantage over remote sensing data by more available with time and less expense. This data is also demonstrated by the correlation between lineaments exacted by drainage networks and terrain analysis.

Application of the DEM data can be useful for a detailed presentation of the structural characteristic features of the study area. Based on DEMs analysis of the Dien Bien area, four tectonic lineament groups are dominated, they are the ENE-WSW, ESE-WNW, NNE-SSW, and NNW-SSE groups. The result show that the fault pattern of the Dien Bien area is marked by faulting event of the ground, most often oriented NNE-SSW up to NNW-SSE. On the basis of surface fracture analysis form this DEM data, the NNE-SSW fault is possibly related to the Dien Bien-Lai Chau strike-slip fault. Results of the drainage network analysis indicate that the rate of sinistral strike-slip of the fault zone range from 2.0 to 2.2 mm/yr. Large pull-apart basins formed along main tectonic lines of strike-slip character, such as the Chan Nua basin at DB-LCFZ.

References

Burbank, D.W. and Anderson, R.S., 2001. *Tectonic Geomorphology*. Blackwell Sciences, Inc., Malden.

Gupta, R.P., 2002. *Remote sensing in geology*. Second Edition, Springer.

Keckler, D., 1994. *Surfer for Windows User's Guide*. Golden Software, Inc. USA.

Keller, E.A. and Pinter, N., 1996. *Active Tectonics: Earthquakes, Uplift and Landforms*. Prentice Hall, New Jersey.

Khuong, T.H., 2011. *The complex tectonic events and their influence on formation of mineral deposits in northwest Vietnam*. Unpublished PhD thesis, AGH University of Science and Technology, Cracow, Poland.

Jordan, G., Meijninger, B. M. L., Hinsbergen, D. J. J.V., Meulenkamp, J.E. and Dijk, P.M.V., 2005. Extraction of morphotectonic features from DEMs: Development and applications for study areas in Hungary and NW Greece. *International Journal of Applied Earth Observation and Geoinformation* 7,163-182.

Nguyen, V.H. and Hoang, Q.V., 2001. Moving characteristics of the Lai Chau - Dien Bien fault zone during Cenozoic. *Journal of Geology* (Ha Noi), 17-18, 1-16.

Panizza, M., Castaldini, D., Bollettinari, G., Carton, A. and Mantovani, F., 1987. Neotectonic research in applied geomorphological studies. *Zeitschrift für Geomorphologie* 63, 173-211.

Phan, T.T. and Hoang, Q.V., 2004. Remote sensing in the study of active tectonics and seismic hazards in Son La hydropower dam. *International Symposium on Geoinformatics for Spatial Infrastructure Development in Earth and Allied Sciences*, Public Knowledge Project 2002.

Ollier, C.D., 1981. *Tectonics and landforms. Geomorphology texts*, 6. Longman Group Limited, New York.

Ramsay, J. and Huber, M., 1987. *The techniques of modern structural geology: folds and fractures*. 2, Academic Press Limited, London.

Tran, D. T., 2005. *Geological map of Vietnam at 1:200,000 scale*. Phongsaly-Dien Bien sheet, with the explanatory note Geology of the Phongsaly - Dien Bien. General Department of Geology and Minerals of Vietnam, Hanoi.

Zuchiewicz, W., Cuong, N.Q., Bluszcz, A., Michalik, M., 2004. Quaternary sediments in the Dien Bien Phu fault zone, NW Vietnam: a record of young tectonic processes in the light of OSL-SAR dating results. *Geomorphology* 60, 269-302.