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# Lineament analysis in fractured rocks, methodology and application to the Suoimuoi Karst catchment

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**Abstract:** Vast areas of the world consist of hard rocks (basement complexes), where water is restricted to secondary permeability, and thus to the fractures and the weathered zones. Most of such areas have a shortage of water. As the success ratio of drilling in hard rock terrain may be low, and the use of geophysics is often judged as too expensive, the study of lineaments from remote sensed imagery is an attractive alternative. High production areas in hard-rock aquifers are generally associated with conductive fracture zones. An effective method for defining the fracture zone is based on lineament indices, which are extracted from satellite imagery. Together with a detailed structural analysis and understanding of the tectonic evolution of a given area it provides a useful tool for hydrogeologists for studying groundwater in fractured rock and developing water resources.

The relationship of lineaments, fractures and groundwater is studied by Mabee *et al.* (1994), Kresic (1995), Sander (1997), Magowe (1999), Krishnamurthy *et al.* (2000). They agree that a high density of lineaments indicate in general the presence of groundwater. Hung *et al.* (2002) suggested that fractured rocks could be analysed by studying lineaments with the help of lineament indices. An application of the proposed methodology, on basis of Landsat ETM images, is given here for the tropical Suoimuoi karst catchment, NW-Vietnam.

## INTRODUCTION TO THE STUDY AREA

The study area, the Suoi Muoi River catchment, is situated northwest of the city of Son La, between longitude 103°33' E and 104°00' E and latitude 21°20' N and 21°29' N, covering 284 km<sup>2</sup> (Fig.1). The population of the Son La province is 650,000 inhabitants, resulting in an average density of 48 inhabitants/ km<sup>2</sup>. Natural hazards, droughts and floods are frequent threats to daily life. The Son La karst area is part of the Son La-Thuan Chau karst highland, a mountain range extending over 300 km in NW-SE direction and with an average width of 10-30 km. The karst landscapes include the absence of permanent surface flow, closed depressions, caves, the existence of large springs, and the presence of sinkholes into which entire streams, like the Suoimuoi River, disappear underground. In the Suoimuoi catchment, the karst landscape occurs mainly in the central part and stretches from northwest to southeast, averaging 10 km wide and ranging from 500-850 m high. The landscape is characterized by a peak cluster morphology (cf. Chinese Fengcong), blind valleys, deep dolines, narrow valleys, chained sharp peaks and many swallow holes exiting underground into caverns. In the middle part of the area, mainly peak forest landscape dominates with residual karst peaks and tower karst, which emerge here and there above the dissolution- erosion valleys (Tuyet 1998).

The Son La-Thuan Chau karst area consists mainly of two sub-areas. The southwestern parts are composed of karst water-bearing carbonate rocks of Paleozoic age, Banpap (D<sub>2</sub>bp) and Early Permian-Carboniferous Chienpac (C-P<sub>1</sub>cp) Formations. The northeastern part is of Middle Triassic age with the Dong Giao Formation (T<sub>2</sub>dg). In the Suoimuoi catchment, karst occurs in limestones and dolomites of Late Cambrian, Middle Devonian, Carboniferous - Early Permian and Middle Triassic age. These carbonates have a favorable composition, texture, and structure for karstification (Hung 2001).

Many different tectonic phases and neotectonic movements have intensively affected these rocks. The present Son La karst highland is dissected by NW-SE, SW-NE, sublatitudinal, and submeridional trending faults. The NW-SE fault system resulted from the collision of continental crust in the Precambrian. The

region then was affected by NW-SE oriented folding due to Indosinian closure of the Paleotethys, starting in Late Permian and culminating during Middle Triassic. All the deposits were finally uplifted during the Neogene Himalayan collision event (Tri *et al.* 1977; Tri and Tung 1979; Tien *et al.* 1991). A series of sub-parallel strike-slip faults can be recognized in the Son La fault zones. Furthermore, Son La town is located on the active Tuan Giao-Son La seismic zone where many destructive earthquakes with intensities of up to 6.5 on the Richter scale have been recorded in this zone.

The continuous tectonic activity in the Son La region accompanied by strong uplift and associated tilting towards the Da River valley to the east, has resulted in the destruction of the Miocene-Pliocene peneplane surface and the creation of deeply incised valleys. This system modifies the block structures formed by the faulting. The SW-NE fault system is younger than the NW-SE one. These SW-NE transform faults are discontinuous. The width of fractured zone ranges from 800-1200 m (Hop 1997).

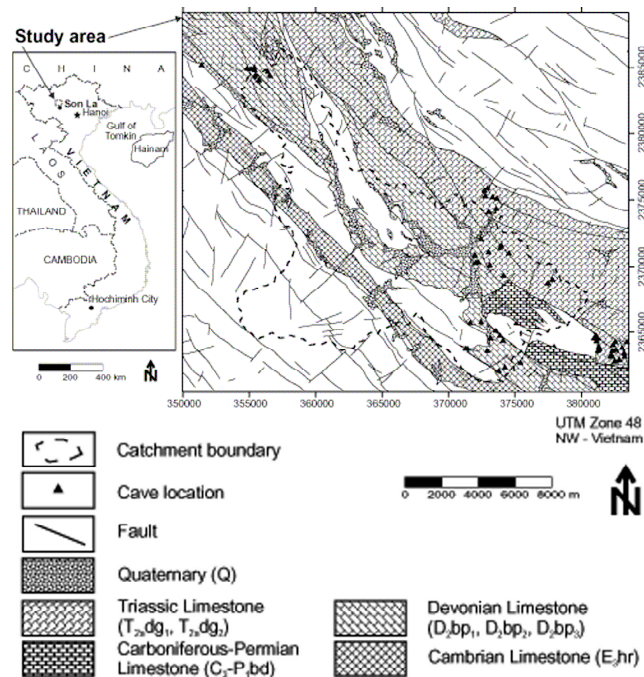
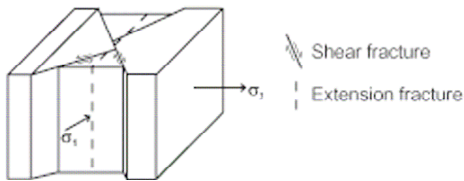


Figure 1. The Suoimuoi catchment

## STRUCTURAL DEFORMATION

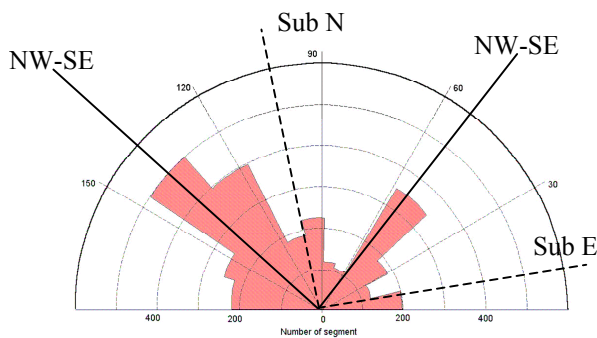
Through brittle deformation, two mechanisms or modes of propagation, shear and extension, generate fractures. Frequently, the shear fractures occur as a conjugate pair and the extension fractures bisect the acute angle in pair. The extension features are oriented parallel to the direction of the maximum compressive stress ( $\sigma_1$ ), and perpendicular to the minimum stress ( $\sigma_3$ ) (Fig.2). As a result of propagation mode, the apertures of the extension fractures tend to be larger than those of shear fractures. Groundwater flow may be more significant along the extension fractures. Fernandes and Rudolph (2001) concluded that tectonic activities, which result in brittle deformation, generate: 1) shear fractures that remain under compression and are not very transmissive; and 2) more permeable extension structures tend to be associated with wideaperture fractures. The recognition of these extension fractures would be valuable for groundwater resources development. Lineament analysis may be the most effective method to map these types of features.



**Figure 2. Stress orientation and corresponding types of fractures**

By understanding the orientation of the stress field that generated the structures in the study area, it is possible to evaluate which lineaments can be associated with mostly shear fractures or conjugated faults and which with extension fractures. Fig.2 depicts the stress field and the general position in space of the shear and extension fractures that are generated by a strike-slip tectonic regime.

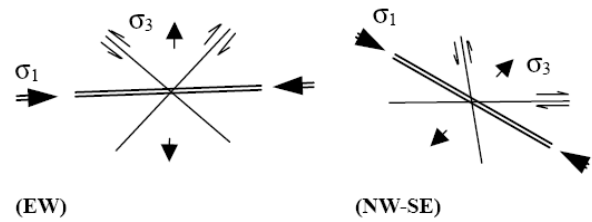
Two main types of conjugate fracture patterns are recognized for the Suoimuoi catchment, depicted by the diagrams in Fig.3 and 4. Hop (1997) supposed that both fracture types (E-W and NW-SE) generated faults (shear fractures) and extensional fractures which affected the rocks from Precambrian up to Middle Triassic. The E-W fracture type is accompanied by shear fractures with a NW-SE and NE-SW direction and extension fractures with a sub-E-W direction. The NW-SE fracture type is accompanied by shear fractures of sub-N-S and sub-EW direction and extension fractures with a NW-SE direction. The correspondence of the NW-SE shear and extension directions and the E-W correspondence of shear and extension directions, make these two directions most favorable for groundwater development. Fig.5 shows the rose diagram for the digitally extracted lineaments after correcting. The very high density of NW-SE and NE-SW lineaments in this figure is due to additional lineaments caused by times of tectonic revolution. The densities of the sub-N-S and sub-E-W lineaments are, therefore, relatively reduced.



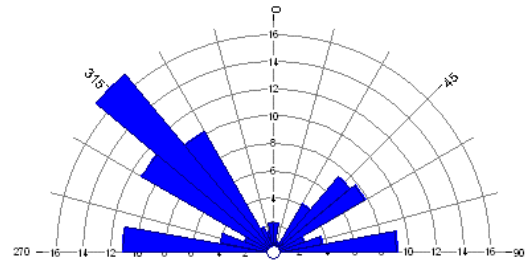
**Figure 3. Rose diagram depicts the distribution of faults on geological map (Hop 1997)**

## LINEAMENT ANALYSIS

Lineaments are extracted from satellite images by edge enhancement functions available in most remote sensing software packages.

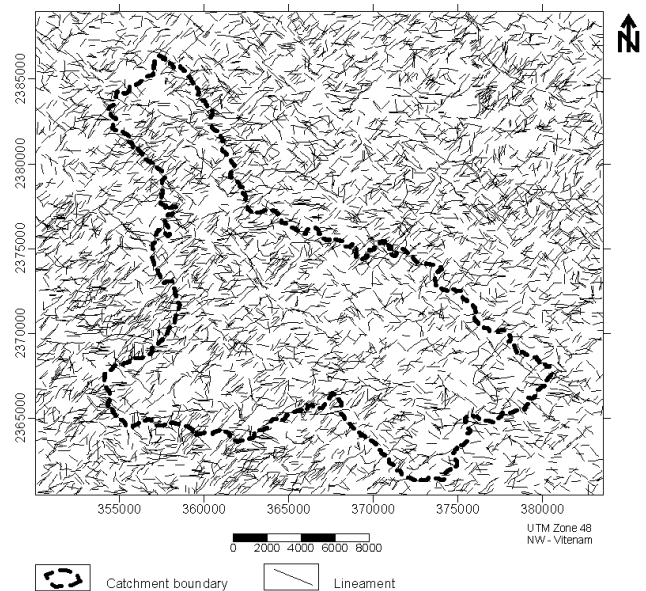


**Figure 4. the orientations of shear and extension fractures**



**Figure 5. Rose diagram depicts the distribution of lineaments in fig.7**

The module GeoAnalyst, with the Line function of PCI Geomatica software is regarded to be one of the best functions for lineament extraction. However, its result is often still confusing and contains many errors from a geological point of view (Fig.6). Therefore, a correct image pre-extraction step is critical. Important aspects to consider in the preprocessing are the choice of bands, their spectral characteristics, image transformation or ratio methods and identification of zones with hydrological features.



**Figure 6. Lineament map of the Suoimuoi karst catchment resulting from PCI Geomatica extraction, no lineament analysis software was used**

Taking the preprocessing into account will enhance lineament features and make them more appropriate for use in groundwater resources evaluation.

A necessary post-extraction step is the correction and analysis of the lineaments (Fig.7). In this article this step is performed by Lineament Analysis Software, which was developed by the

Department of Remote Sensing and Geomatics of the Research Institute of Geology and Mineral Resources of Vietnam. In this software lineaments are corrected one or more times (removing, connecting...) based on the statistical and geological characteristics and the spatial scale of the lineaments.

Three main kinds of lineament indices for characterising a fracture zone are distinguished 1) Total length of lineaments - X, 2) Total number of lineaments - Y, and 3) Total number of lineament intersections - Z. At small-scale analysis the average length index can replace the above indices. The Lineament Analysis Software further takes into account the spatial distribution of the lineaments and provides tools for mapping and classifying lineaments.

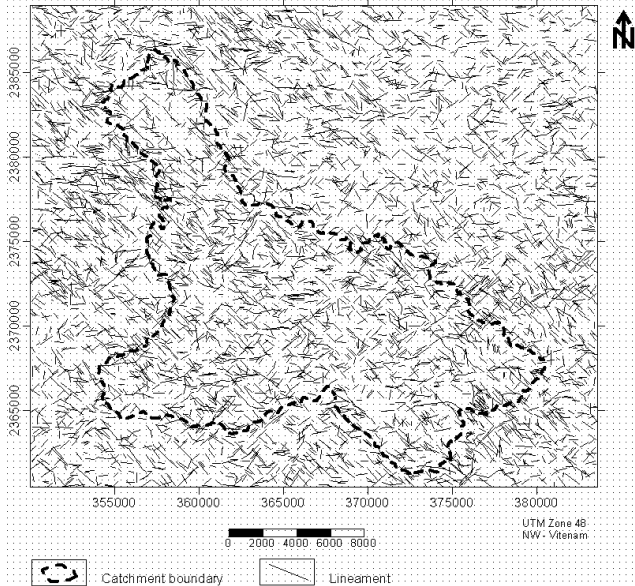


Figure 7. Map of lineaments, as given in Fig.1, postprocessed by lineament analysis correction software

### FRACTURE ZONE CHARACTERIZATION

The fracture zone is defined on basis of the density of a lineament index. The critical value of the lineament index for defining a fracture zone boundary can be estimated by field observations of the intensity of rock deformations. The hypothesis is that a higher lineament density index corresponds to a higher rock deformation. Fracture zone (F) can be described as a function of the three lineament indices

$$F = f(X, Y, Z)$$

Two simple functions can be used for defining the fracture boundary by trial and error calibration based on the observations

$$F = aX + bY + cZ$$

$$F = X * Y * Z$$

where  $a, b, c$  are calibration constants. Fig.8 gives the resulting map of the lineament density function F.

In this study the Z value is equal to Z + 1, because in several places the Z value equal to 0 (there are no intersection of lineament).

The relationship between the identified fracture zone and the occurrence of groundwater is further improved by the results from pumping tests (Tab.1). The resulting lineament index density map can be correlated with the measured transmissivities in order to generate a groundwater transmissivity map.

The lineament software describes the fracture zones by their boundary, relative intensity, direction of lineaments and the conjugate pair of lineaments, which form the fracture zone. Fig.9 shows the distribution of shear, extensional fractures on the boundary of fracture zone. We can predict the groundwater behaviour through that map with the additional information from the topographical characteristics.

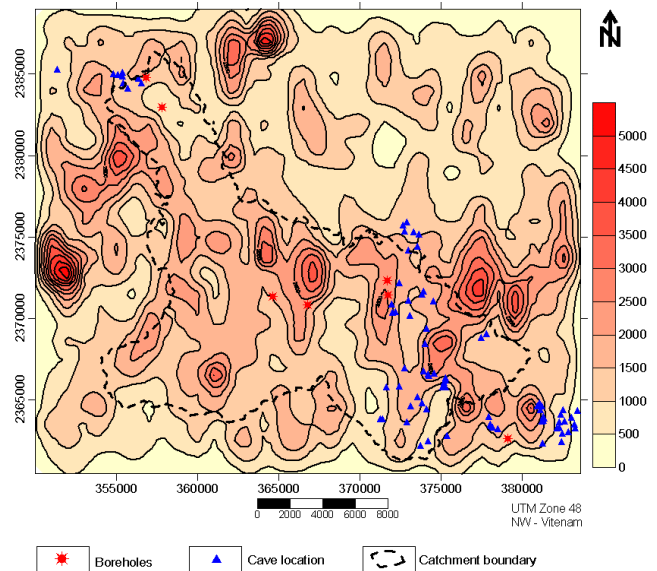


Figure 8. Map of lineament density function F

Bore-holes	Drilling depth	Thickness of overlying soil layer	Depth to static GW table	Pumping discharge
	DD (m)	ST (m)	SWT (m)	Q (L/s)
LK20	100	7.5	20.0	0.017
LK19	100	6.9	20.0	0.021
LK21	100	10.0	6.2	1.013
LK22	100	8.0	8.3	1.642
LK23	70	12.8	8.0	3.546
LK24	99	18.0	16.0	0.510
LK25	107	12.0	64.8	0.109

Table 1. Boreholes in the study area

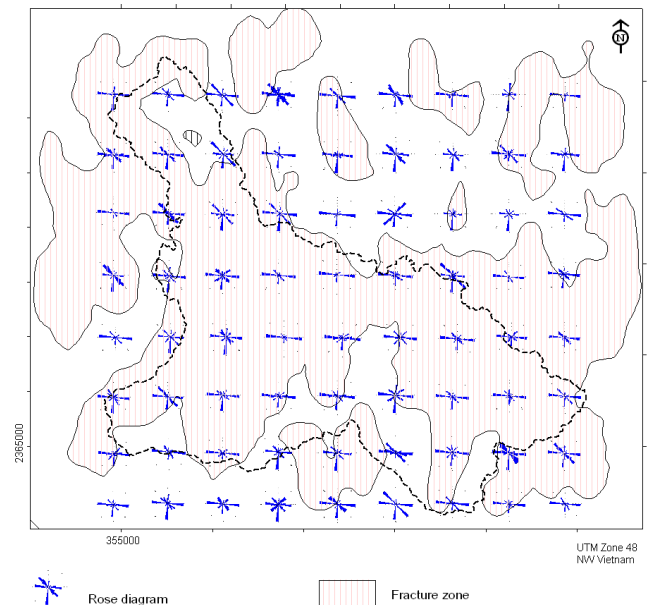


Figure 9. Map of delineated fracture zones

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