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Spatial variation of the active stress field in the North West of Vietnam: implication for related geohazard mitigation

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Abstract. The NW of Vietnam is currently affected by a stress field characterizing by approximately NS and EW sub-horizontal maximum and minimum principal stress axis respectively. The results obtained from field investigations and numeric modelisation reveal that the present stress field varies not only in relative magnitude but also in orientation of principal stress axes from point to point and in depth. The tectonic stress variation strongly depends on the geometry and active kinematics of faults as well as on their earthquake history. The modeling shows that the tectonic stress field tends to simplify from the subsurface downward to 40km depth. At this level depth, the stress concentrates along the Dien Bien-Lai Chau fault while other faults release stress. Horizontally, the high tectonic stress accumulates in some area such as western side of the Dien Bien-Lai Chau fault, the area from Dien Bien Dong to Lai Chau, along the Son La, Song Ma faults and in some segments of Song Ca fault. These stress anomalies link closely to historic earthquakes.

Keywords: Stress field; Geohazard; Active tectonics; Geodymanics; Earthquake.

1. Introduction

The NW of Vietnam is limited to the north east and to the east by the Red River fault system, to the south by the Song Ca fault, to the west by the Dien Bien-Lai Chau fault. The whole region is sliced by NW-SE trending faults net that inherited from the Indosinian shear zones [4]. Most of them are active as sinistral strike slip faults during Late Oligocene to Middle Miocene and subsequent dextral strike slip in Late Pliocene up to presence. Along some of those such as the Dien Bien-Lai Chau, Son La, Ninh Binh, Song Ca, Song Ma, Red River faults, the moderate earthquakes still occur recently. Actually, the region under investigation is constrained by an approximate NS compression and EW extension stress regime [10]. Under a such active geodynamics, the fault systems behave differentially and subsequent earthquakes as well as other geohazarsds are also differentiated [9].

The researches published in recent years [1-3,7,8] reveal that a relatively close tie between the seismic activities with fault geometry and tectonic stress anomalies. Therefore, the elucidation of the tectonic stress distribution

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induced by the interaction between faults systems in NW Vietnam with the regional geodynamic setting plays an important role to understand the distribution of historical earthquakes and related hazards.

2. Methods

In order to investigate the spatial variation of the active tectonic stress field in the north west of Vietnam, the integration of field researches for characterization of brittle tectonics, especially focusing on the latest tectonic event with the numeric modeling formulated and developed by Okada [5,6]. The input parameters for modeling includes the fault length and wide, dip direction and angle of dip, the rake angle of the striation, the maximum magnitude of historical earthquakes, the regional orientation of 3 principal stress axes, ratio of stress ellipsoid. The numerical results then will be converted to a suitable format with GIS software for displaying on maps at various scale.

2.1. Characteristics of the active stress field magnitude

The active stress field of the NW Vietnam is displayed on fig. 1. Based on the magnitude of stress vectors, whole area is divided into 4 sub areas and displayed by color code. The sub area from number one to number four is colored by marine blue, sky blue, yellow and red respectively. The surface of each area is given in the table 1. It is recognizable that the NW Vietnam suffers from low stress field. The surface of the sub area number one occupies the largest part with 63.13% of the total surface of the whole region and suffers from a stress magnitude of less than 0.1bar. The sub area that locates under high stress field with magnitude varying from 2-3 bar occupies only 2.03% of the total NW region. The rest of the region corresponding to the sub area number 2 and 3 on the fig. 1. These two sub areas are affected by two range of stress magnitude varying from 0.1 to 0.5 bar and from 0.5 to 2 bars corresponding to a surface of 28.66% and 6.17% respectively. Thus, the area suffering from stress magnitude lower 0.5 bar occupies approximately 92% while the high stress magnitude ranging from 0.5 to 2 bar affects only 8% of the total surface of the NW region.

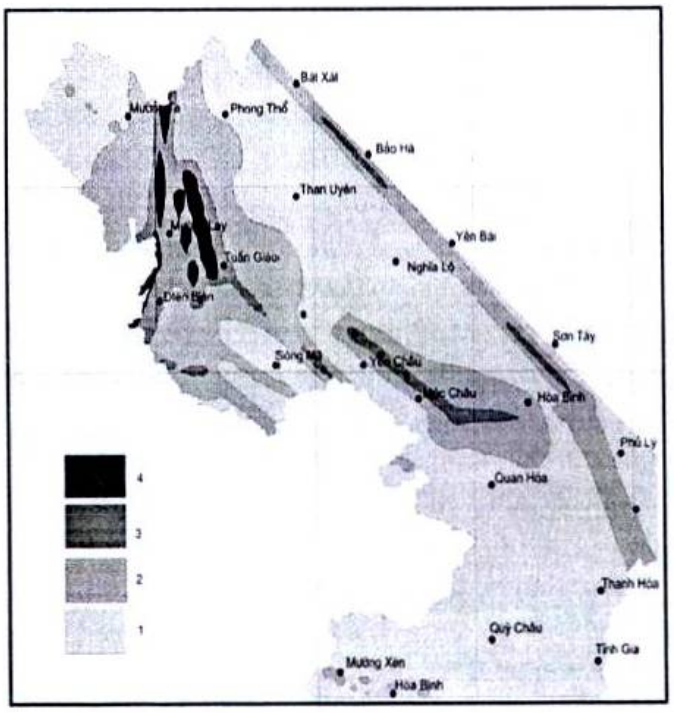

Fig. 1. Tectonic stress distribution in the NW of Vietnam.

1. Sub-area with magnitude 0.01-0.1 bars,
2. Sub-area with magnitude 0.1-0.5 bars,
3. Sub-area with magnitude 0.5-2 bars, 4- Sub-area with magnitude 2-4.

Table 1. Surface of sub-areas with different stress magnitudes

	Sub-area 1	Sub-area 2	Sub-area 3	Sub-area 4	Total surface (km^2)
Stress magnitude (bars)	0.01-0.1	0.1-0.5	0.5-2	2-4	
Surface km^2	44759.5	20319.08	4376.77	1404.719	70896
Percentage	63.13%	28.66%	6.17%	2.03%	100%

It is easy to recognize from fig. 1 that the area with high stress field magnitude corresponding to the sub-area number 4 distributes in two bands and some spots. They are characterized by the following features:

The first band locates to the west of Dien Bien-Lai Chau fault. This band composes of three small bandeaux with strike parallel to NS Dien Bien-Lai Chau fault. The northernmost bandeau, which stretches up to 45 km and its width varying from 5 to 9 km, starts from Vietnam-China boundary and then decreases in magnitude toward Chan Nua town. The second bandeau initiates from Lai Chau town and ends at Muong Lay with the length of 45km and the width varying from 3 to 8km. The third one with more than 60km long locates to the west of Dien Bien Phu basin and expands toward Laos. The distribution of high tectonic stress along this fault zone corresponds well with high frequent seismic activities on the western side of the fault while the eastern side records less seismics.

The second band with NW-SE orientation and 68 km long, 9km wide distributes westward of Tuan Giao-Tua Chua fault. Some stress spots with magnitude higher than 4 bars exists within this band. In this area, historical earthquakes over 6.8 Richter magnitude have been recorded. In between two mentioned above bands, locates some high stress spots with magnitude over 4 bars.

Along the Song Da fault system it exists some peaks with high stress values. The first spot locates far from the east of Hat Lot town 16km. The second one situates northeastward of Yen Chau town 13km. The third one concentrates about 7km far from Moc Chau to the NE. The magnitude of those stress spots are relatively low.

In order to visualize the distribution of stress magnitude for different areas, a 3D block is displayed (fig. 2). It enables us to get a general view on the magnitude as well as the distribution of stress values in the NW Vietnam. The regions located westward of Dien Bien-Lai Chau fault, in Tuan Giao-Tua Chua area and the region in between them suffer from the high stress and attain the highest values with respect to the whole NW region of Vietnam. The regions located westward of from Hat Lot to Moc Chau towns and the right bank of Da River are the loci in which exist some places with relative high stress values. However, in comparison with the stress values along Dien Bien-Lai Chau as well as the Tuan Giao-Tua Chua fault systems, these values are much lower.

The regions coded yellow color corresponding with the stress value ranging from 0.5 to 2 bars concentrate only in some certain areas and closely related to the areas with high stress values. The largest area form a triangle shape with the base corresponding to the length from Tay Trang to the Vietnam-China boundary and the vertex locating at Tuan Giao. Along the Son La fault, it exists two bands, the first and the second one expands in the NW-SE direction from Tuan Giao to Thuan Chau town and continuing to Muong Lat with 30 km long and 5 km wide, 26km long and 4 km wide respectively.

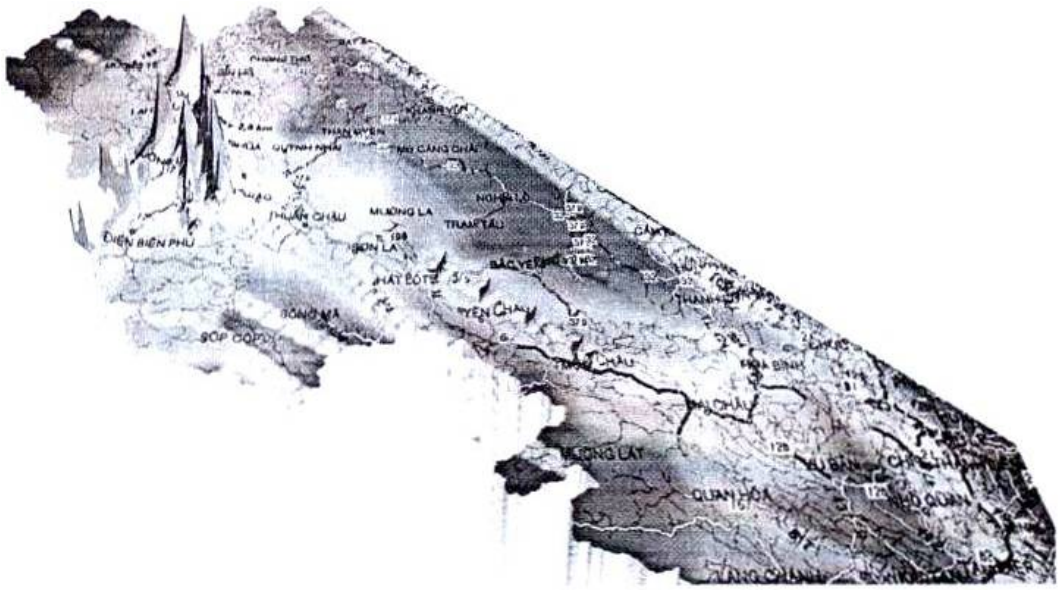

Fig. 2. Visualization of active stress magnitude on 3D schema.

In the Sop Cop area, the region with those stress values develops into a sub latitudinal band with 28km long and the width varying from 2 to 6km. Along the Song Ma fault, from Dien Bien Dong to Muong Lat occur some unconnected flocks characterized by stress values of 0.5-2bars. In the lower course of Da River corresponding to the segment between Ban Pa No and Ban Co Lon, the stress band orients NW-SE then deviates to EW direction and develop to Xom Giang near Hoa Binh town (fig. 2).

Along the Red River fault, the same stress level occurs in two narrow bands. The first one with 60km long and 2-3 km wide distributes from the Bat Xat to Bao Ha. The second one with the same dimension develops from the Hung Hoa to Xuan Mai.

The rest of the NW region of Vietnam with the surface of 65078 km2 equivalent to 92% of the whole studied area suffers from the low to very low stress level.

2.2. Distribution of the maximum horizontal stress axis

Due to the stress is a vector quantity so that its direction and orientation displays on the map by double arrow. On the fig. 3 the maximum principle axis is mapped by a centripetal double arrow. The heads of arrow locates right at calculated points. The length of arrows represent proportionally to the value of maximum principle stress axis.

In general, the predominant orientation of principle stress axis is longitudinal direction. Nevertheless, in some places where stress values vary relative large, the principle stress axis's orientation and direction as well as their magnitudes are strongly various. For example, to the west of Dien Bien-Lai Chau fault, between the longitude of $102^0$58'3"E and the road No.12, exists a band characterized by strong variation of stress axis orientation in EW direction and in the plunge varying from 0 to 30 degrees. In the vicinity of Tuan Giao-Tua Chua fault, the same scenario also presents. In the region of Song Ma-Sop Cop and Tuan Giao, Dien Bien, the principle stress axis forms the concentric bands with the convexness located in the south of Tuan Giao town. With such figure, it is possible to connect with the high accumulation of stress in vicinity of Tuan Giao. The region limited northeastward by the Red River fault, southwestward by the Son La fault

and by the Hoa Binh arc to the south, contain the stress axis that form the lines similar to the force lines of magnetic field. Those lines swing and form a large Z shape. In the NW part of this Z shape, the stress axis orientation is still longitudinal and then it change to the NE orientation at vicinity of Quynh Nhai and Than Uyen before its direction turns to the NS direction when it approaches to the Son La fault. In general view, the orientation as well as the magnitude of stress axis in the NW region of Vietnam is inhomogeneous. Their variation depends closely to the region where the stress magnitude changes abruptly. Such variation in maximum stress axis direction suggests that the possible displacement and offset might be quite different from the place to place within a same fault.

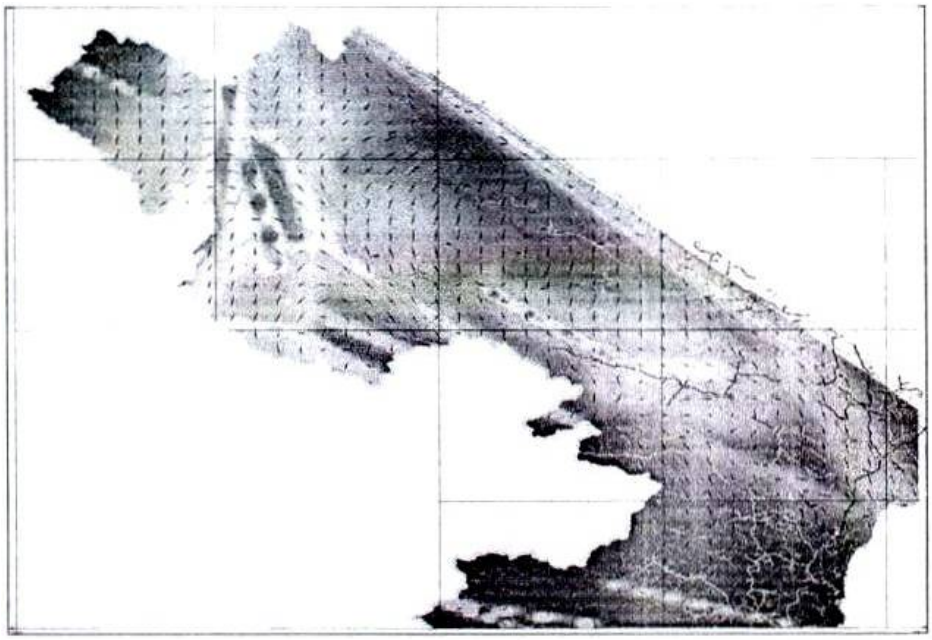

Fig. 3. Orientation of the maximum principle stress axis.

2.3. Distribution of stress anomalies

The almost studied region falls into the low stress anomalies with the exception of some areas characterized by high positive and negative stress anomalies and displayed in fig 4. Those anomalies are described consecutively afterward. The first positive anomaly band concentrates to the west of Dien Bien-Lai Chau fault and expands continuously from Vietnam-China boundary to Tay Trang frontier port and further develops toward Laos. This band is one of two highest stress anomalies in the region and is divided into two parts. The first part is featured by very high positive one expanding from the Vietnam-China boundary to Muong Pon. The second part developing from Muong Pon to Tay Trang, is characterized by the parallel existence of the highest positive next to the highest negative anomalies. The second anomaly band corresponding to the highest positive anomaly in the studied region, develops from Lai Chau through Tuan Giao to East Dien Bien in NW-SE direction and juxtaposes eastwardly to a relatively high negative anomaly. It is important to note that the juxtaposition of those two contrast anomalies coincides with a area where a historical strongest earthquake is recorded at Pu Nhung in 1983. The high contrast of stress anomalies presented in this area is eventually to produce the earthquakes occurring with high frequency. The third relatively high level stress anomaly runs parallel to Son La fault. It

anomaly runs parallel to Son La fault. It juxtaposes eastwardly to a vast region characterized by negative anomalies covering Yên Châu, Sơn La, Thuận Châu passing Quỳnh Nhai, Than Uyên, Mù Căng Chải, Nghĩa Lộ, Phù Yên, Bắc Yên. The fourth medium stress anomaly composing of three segments links to the Red River fault. The first segment with high anomaly value initiates from Van Ban town and develops toward China. The second segment from Yen Lap to Xuan Mai is characterized by relatively low anomaly. The middle segment suffers from a lowest stress anomaly level. The fifth positive anomaly band running in NW-SE direction from Ta Khoa to Moc Chau composes of three flocks of anomaly tentatively connected to a positive anomaly of Hoa Binh -Moc Chau running in EW direction. The sixth weak positive anomaly develops along the Song Ma fault from Quan Hoa to Hau Loc. The seventh positive anomaly of Sop Cop - Muong Lat consists of some discrete small flocks of stress anomalies in which only the one of vicinity of Tin Toc village is highest. The eighth positive anomaly distributes along Song Ma and consists of some discrete stress anomaly spots with low magnitude of stress. Approaching to the Dien Bien basin, this high positive anomaly decreases to null value and vanishes in the negative stress anomalies. The ninth positive stress anomaly band develops along the Song Ca active fault. However, this anomaly composes of discrete spots characterized by relatively low values. Apart from that, further to the north of Song Ca fault zone, along the normal fault coinciding with the road No.48 exist also some very low values of discrete stress anomaly. The tenth anomaly distributes equilaterally around the Pusamcap mountain and unrelated to any fault but eventually to intrusions during Cenozoics.

It is recognizable that apart from two negative stress anomalies distributed along the Dien Bien-Lai Chau and Tuan Giao-Tua Chua faults, most of the NW region of Vietnam suffers from largely distributed negative stress anomalies. They include the following areas: East of Tuan Giao, Tua Chua, Quynh Nhai, East of Thuan Chau, Son La city, east of Mai Son, Yen Chau, Muong La, south of Than Uyen, southwest of MU Cang Chai, east of Bac yen, west of Phu Yen, Da Bac, south of Mai Chau, east of Muong Lat, northwest of Sin Ho and Phong Tho, Muong Nhe, west of Muong Lay, Dien Bien Dong. In the northeast of the Red River fault, a weak negative stress anomaly is also existent. The weakest stress anomaly band with NW-SE strike extends from My Duc through Lac Thuy, Gia Vien to Nga Son.

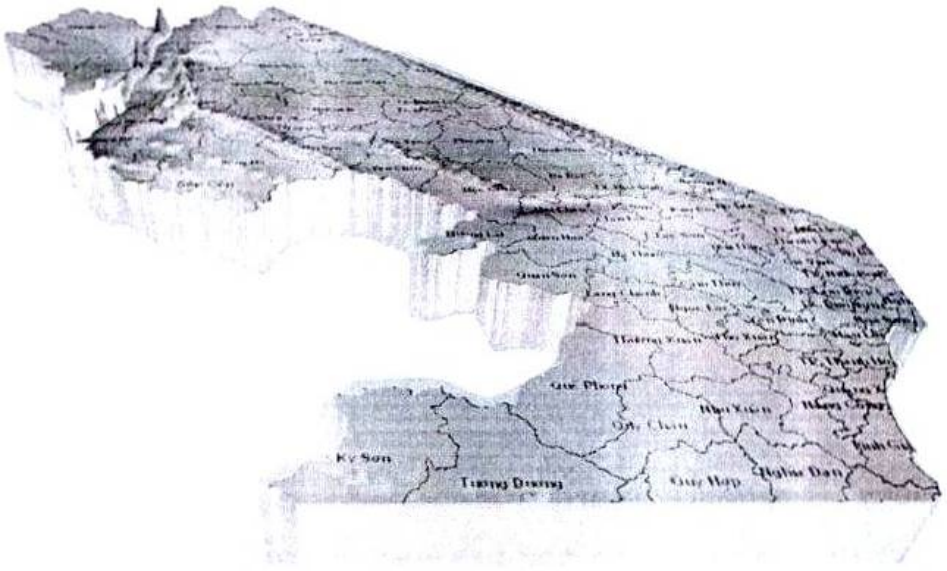

Fig. 4. Distribution of the active tectonic stress anomalies in the NW of Vietnam.

2.4. The variation of tectonic stress in depth

The variation of tectonic stress in depth is also assessed according to Okada's algorithm. The computed results reveal that the downward simplicity of the tectonic stress distribution pattern. From the surface to the depth of 40km where the maximum thickness of regional crust can be attained, the pattern of distribution became more and more simplified (fig. 5). The such distribution suggests that the tectonic stress anomalies in the NW Vietnam does not eventually develop deeper than 40km from the surface. The most complicated pattern of the tectonic stress concentrates in the depth range in between 10 to 20km from the topographic surface. From the third to the tenth band of tectonic stress anomalies mentioned in the early section do not exist over 15km deep. However, the stress anomalies distributed along the Dien Bien-Lai Chau and vicinity of Tuan Giao-Tua Chua fault systems develop deeper and they tend to unify at the depth of 35 to 40km to form a larger tectonic stress anomaly but smaller magnitude. The existence of such tectonic stress anomalies pattern at the lower crust implies that this area is potential for high seismicity in the NW region of Vietnam. The earthquake sources also concentrate at the depth corresponding with the stress anomalies.

Fig. 5. 3D Schema illustrate tectonic stress anomalies at 40km depth.

Apart from the positive stress anomalies, in the NW Vietnam, the negative stress anomalies also vary from the surface downward to the depth 40km. The vicinity of Dien Bien-Lai Chau fault systems, the area of Than Uyen, Quynh Nhai, Thuan Chau, Tram Tau suffer from a negative tectonic stress. The rest of the studied area is in neural stress anomalies or other word in the region without deviatory stress caused by tectonics.

2.5. Conclusion remarks

By integration of the field investigations with the modelisation of the interaction between fault systems and the active regional geodynamics for the NW Vietnam, some conclusion remarks can be delineated as followings:

Almost of the NW Vietnam is affected by a low tectonic stress with the exception of ten

positive stress anomalies among which the one of Dien Bien-Lai Chau and Tuan Giao-Tua Chua are highest.

Apart from the positive anomalies, the existence side by side of the negative to the positive anomalies along the vicinity of Dien Bien-Lai Chau and Tuan Giao-Tua Chua fault systems reveals that the close relationship between high stress level with the frequent earthquakes in this areas.

From the surface downward up to 40km, the rule of tectonic stress anomalies distribution tends to simplify and disappear with the exception of a large anomaly covering the area of Dien Bien-Lai Chau to Tuan Giao-Tua Chua.

The clearest and most complicated patterns of stress anomalies distribute at the depth between 10 and 20km.

The areas suffering from high tectonic stress anomalies are places where seismicity are relatively high. Therefore, the exact identification of stress anomalies provide the basic sciences for the earthquake zonation, sources pattern and the sources distribution as well as the possible occurrence of earthquake.

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References

[1] L. Haihua, H. Jianjun, L. Shuwen, Z. Zufeng, Tectonic stress field and large earthquake recurrence period in China, *Episodes* 21, 3 (2003) 167.

[2] R.A. Harris, R.W. Simpson, Suppression of large earthquakes by stress shadows: A comparison of Coulomb and rate-and-state failure, *J. Geophys. Res* 103 (1998) 24.

[3] G.C.P. King, R.S. Stein, J. Lin, Static stress changes and the triggering of earthquakes, *Bull. Seismol. Soc. Am* 64 (1994) 935.

[4] C. Lepvrier et al., Indosinian NW trending shear zones within the Truongson belt (Vietnam) 49Ar/39Ar Triassic age and Cretaceous to Cenozoic oveprints, *Tectonophysics* 283 (1997) 105.

[5] Y. Okada, Surface deformation due to shear and tensile faults in a half-space, *Bull. Seismol. Soc. Am* 75 (1985) 1135.

[6] Y. Okada, Internal deformation due to shear and tensile faults in a half-space, *Bull. Seismol. Soc. Am.* 82 (1992) 1018.

[7] B. Smith, D. Sandwell, Coulomb stress accumulation along the San Andreas Fault system, *Journal of Geophysical Research* 108 (2003) 2296: doi:10.1029/2002JB002136, 2003.

[8] S. Toda, R.S. Stein, P.A. Reasenberg, J.H. Dieterich, Stress transferred by the Mw=6.9 Kobe, Japan, shock: Effect on aftershocks and future earthquake probabilities, *Journal of Geophysical Research* 103 (1998) 24.

[9] N.V. Vuong, V.V. Tich, N.N. Thuy, B.V. Duan, Attempt at zoning and characterizing the active displacements of crustal material in NW Vietnam based on the interaction between regional stress field and fault activities, *Journal of Geology* Serie A, 285 (11-12) (2004) 49.

[10] M.L. Zoback, First and second-order pattern of stress in the lithosphere: the world stress map project, *Journal of Geophysics Research* 97 (1992) 11703.