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REVELATION OF SEISMOGENIC ZONES AFTER GEOLOGICAL AND GEOPHYSICAL DATA

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This paper presents a complex of methods used for prediction of earthquake characteristics and revelation of great seismogenic zones, based upon geological and geophysical data on the territory of Vietnam. The data used in this paper are newly collected up to 1990. The obtained results described in the paper can be considered as newest in the field of earthquake study in Vietnam. The major objectives illustrated in this paper are the studying characteristics of seismic activity and the correlation between geological and geophysical existing data and the characteristics of earthquake serving for prognosis of zones possibly generating earthquake and its zonation.

I. INTRODUCTION

The territory of Vietnam is located within two strong seismic belts, one is the Pacific and the other is Mediterranean. The history of tectonic development on the territory is very complicated and tectonic activities occurred in deferent periods of time. A numerous earthquakes were occurred on this territory of which some were of great magnitude, possibly estimated of about 7 Richter degree.

In the past years, there are many scientific works were published by Vietnamese and overseas geophysicists, who carried out the study of different characteristics of earthquakes occurred on the territory of Vietnam [1-9]. Among them, the most remarkable is the scientific work of Co-authors of the Institute of Geophysics, published in 1985 [9].

The prediction of earthquake characteristics by using geophysical data was carried out by Cao Dinh Trieu (1987), Pham Van Thuc and Cao Dinh Trieu (1979), based mainly on the relation separated between A10 and gravity field, A10 and the relief height and Mmax after gravity data [1,2].

In this paper, based upon previous investigation and study, the author has proposed the combined methods for revelation of great seismogenic zone (Mmax 5.0) on the territory of Vietnam.

II. SOLUTION METHOD FOR LINEAR MULTI-REGRESSION EQUATION

If the function Y and variables $x_1, x_2, ..., x_p$ are given in the form

Y	X_1	...	X_p	the order of observation
Y_1	X_{11}	...	X_{p1}	1
Y_2	X_{12}	...	X_{p2}	2
...	...	...	...	.
Y_n	X_{1n}	...	X_{pn}	n

Then, the model of linear multi-regression has the form of:

$$Yi = \beta_0 + \beta_1 X_{1i} + ... + \beta_p X_{pi} + U_i \quad (1)$$
$$(i = 1, 2, ...n)$$

where: U_i is a hazard uncorrelated variable, having expected value 0 and invariable variance, so

$$E(U_i) = 0 \quad (\gamma_i) \quad (2)$$
$$E(U_i U_j) = 0 \quad (\gamma_i \neq \gamma_j) \quad (3)$$
$$D(U_i) = E(U_i^2) = \delta^2 \ (\gamma_i), \quad (4)$$

$\beta_0, \beta_1, ...\beta_p, \delta^2$ are the parameters that should be approximately evaluated.

Suppose that U_i is the function of standard distribution.

$$U_i \in N(0, \delta^2) \quad (5)$$

the approximation of i are calculated by least square method, i.e. the minimum of function

$$S(\beta_0, \beta_1, ...\beta_p) = \sum_{i=1}^{n} (Y_i - \beta_0 \beta_1 X_{1i} - ... - \beta_p X_{pi})^2 \quad (6)$$

In other words, $\hat{\beta}_i$ $(i = 1, 2...)$ are the roots of the system of equations

$$\begin{aligned} \frac{\delta S}{\delta \beta_0} &= 0 \\ \frac{\delta S}{\delta \beta_1} &= 0 \\ .... & \; ... \\ \frac{\delta S}{\delta \beta_p} &= 0 \end{aligned} \quad (7)$$

than the linear multi-regression equation has the form of

$$\hat{Y} = \hat{\beta}_0 + \hat{\beta}_1 X_1 + ... + \hat{\beta}_p X_p. \quad (8)$$

By using the following Matrix symbol

$$Y = \begin{bmatrix} Y_1 \\ Y_2 \\ \vdots \\ Y_n \end{bmatrix}, \quad X = \begin{bmatrix} 1 & X_{11} & \dots & X_{p1} \\ 1 & X_{12} & \dots & X_{p2} \\ \vdots & \vdots & \ddots & \vdots \\ 1 & X_{1n} & \dots & X_{pn} \end{bmatrix}$$

$$\beta = \begin{bmatrix} \beta_0 \\ \beta_1 \\ \vdots \\ \beta_n \end{bmatrix}, \quad U = \begin{bmatrix} U_1 \\ U_2 \\ \vdots \\ U_n \end{bmatrix}, \tag{9}$$

then the model (1) can be described in the form of

$$Y = X\beta + U \tag{10}$$

$$E(U) = 0 \tag{11}$$

$$D(U) = \delta^2 I_n, \tag{12}$$

I_n is a matrix having degree n (n-order) then, The system of equation (8) becomes

$$X'X\hat{\beta} = X'Y. \tag{13}$$

Denote

$$\hat{\beta} = (\beta_0, \beta_1, ...\beta_p)$$

$$e = (e_1, e_2, ...e_n)$$

where $e_i = Y_i - \hat{Y}_i = Y_i - \beta_0 - \hat{\beta}_1 X_{1i} - ... - \hat{\beta}_p X_{pi}$, $V = \{U_{ij}\}$ denote the symbol of matrix $(X'X)^{-1}$ and $\hat{\beta}$ can be written in the form

$$\hat{\beta} = (X'X)^{-1}(X'Y). \tag{14}$$

With the combining (11) and (12) we can write

$$E\hat{\beta} = 0 \tag{15}$$

$$D\hat{\beta} = \delta^2 (X'X)^{-1}$$

The parameter 2 is evaluated approximately

$$S^2 = \frac{1}{n-p-1} e', e = \frac{1}{n-p-1} \sum_{i=1}^{n} e_i^2. \tag{16}$$

The estimation for $D(\hat{\beta}_i)$ is descried as

$$S_i = S\sqrt{V_{ij}}, \; i = 1, 2, ..., p. \tag{17}$$

Square coefficient of definite function (R^2) of linear multi-regression equation is

$$R^2 = \frac{\sum(\hat{Y}_i - \overline{Y})^2}{\sum(Y_i - \overline{Y})^2}, \tag{18}$$

where

$$\overline{Y} = \frac{\sum_{i=1}^{n}}{n};\ 0 \leq R^2 \leq 1.$$

In order to resolve the earthquake prediction problem, the author has established the regression equation step by step. In this case, the first variable chosen to introduce in the equation following the maximum standard of the correlation coefficient of the Y with the variables Xi.

$$r(Y, Z_1) = \max_{1 \leq i \leq p} (Y, X_i) \tag{19}$$

By using the least square method as above presented, we can evaluate approximately the equation

$$Y = b_0 + b_1 Z_1 \ (R^2) \tag{20}$$

In the variables $X_i, ..., X_p$ different than Z_1 we will choose a variable Z_2 to introduce in the regression equation. The Z_2 will be chosen as variable in order that the regression equation has must signification, i.e. has a maximum determined coefficient R^2.

The variables were continued to introduce in the same principle until when R2 reaches a value nearly 1 and the continuation of variable introduction does not make R2 greater. So, we have the regression equation

$$Y = b_0 + b_1 \dot{Z}_1 + b_2 \dot{Z}_2 + ... + b_r \dot{Z}_r \ (R^2) \tag{21}$$

where $r \leq p$.

III. PREDICTION OF EARTHQUAKE MAXIMUM MAGNITUDE (MMAX) IN VIETNAM

In order to establish the linear multi-regression equation between the magnitude Mmax with the other geological and geophysical characteristics we determined mean value in each square space. The spaces having for side a = 20km must be divided in order that the area of the ith will coincide with the 1/2 area of the neighbor area.

The values Mmax used to establish the equation were the value Mmax of earthquake observed in the past time.

The geology-geophysical characteristics used are 1. The value of isostatic anomaly, G. (at 1:1,000,000 scale)

2. The gradient of isostatic anomaly, Gx (at 1:1,000,000 scale)]
3. The gradient of gravimetric anomaly Boughue, gx (at 1:1,000,000 scale)
4. The gradient of geomagnetic anomaly, Tax (at 1:1,000,000 scale)
5. Geomagnetic remanent anomaly with radius R=10, Taa (at 1:1,000,000 scale)
6. Knot concentration of deep faults, n1 (at 1:1,000,000 scale)
7. Knot concentration of lineaments on the surface, n2 (at 1:1,000,000 scale)

The experimental formula (22) established based on above-mentioned data in combination with catalogue of 835 Earthquakes in Vietnam occured since ancient time up to 1990 with magnitude from 3.0 to 7.0

$$\begin{aligned} M_{max} &= 2.4050 - 0.4423G_x + 0.2126G_x + 0.0522T_{ax} + 0.1977n_1 \\ &+ 0.1562n_2 - 0.0064T_{aa} + 0.0045G \quad R^2 = 0.4466 \end{aligned} \tag{22}$$

IV. SEISMOGENIC ZONES ($M_{MAX} \geq 0.5$)

4.1. The principles for revelation of seismogenic zones

Firstly, the seismogenic zones are revealed on the basis of the principle seismotectonic method used usually in the world.

The zones where earthquake can occur are the active tectonic faults or system active tectonic faults. In these zones the tectonic movement are the most dislocated. The capacity of earthquake occurrence in the fault depends on the dimensions, character and active level of the fault. The more active capability (greater earthquake, greater frequency) belongs to deep fault, in the limits of neotectonic structure zones, earthquake can be occured inside the fault zones, but in small size.

The width of earthquake genesis zones and its location in comparison with projection of faults on the earth surface depend on active layer.

The principle of geological extrapolation shows that the fault, having the equivalence on tectonic characteristics, will have the same capability of earthquake occurrence.

4.2. Method for the evaluation of earthquake characteristic in the seismogenic zones

- The utilization of extrapolation principle on the basis of occurred great earthquakes. The strongest earthquake occurred in a part of the fault can occur in the other parts of this fault and in the other equivalent fault. The parameters of this earthquake can be used as characteristics of the zone of the same class.

- The upper limit of maximum magnitude Mmax of the strongest earthquake can be evaluated after the dimensions of the fault section crossed by the other fault with same level or higher level by the following formula (Nguyen Dinh Xuyen, 1987)

$$M_{max} \leq 2lgL(km) + 1.17 \tag{23}$$

$$M_{max} \leq 4lgH(km) + 0.48 \tag{24}$$

where

L - the length of fault direction; H - the tickness of active layer determined by the epicentral distribution of the observed earthquakes.

- The minimum of focus depth of maximum magnitude earthquake (Mmax) determined by formula

$$h_{min(M_{max})} = 10^{0.25M_{max}-0,3}. \tag{25}$$

- The limit of seismic in the maximum earthquake epicenter, determined by the MSK-64 scale, will be

$$I_{omax} = 1.45M_{max} - 3.2lgh_{min}(M_{max}) + 2.8 \tag{26}$$

In this formula S is the area of seismogenic zones, where earthquake generated maximum seismic at the studied zone.

4.3. Method for the determination propagated seismic

The intensity of propagated seismic from the source (earthquake focus) having magnitude M and focus depth h to any zone having a focus distance Δ is determined by the seismic field equation (6)

$$I = bM - Slg\sqrt{\Delta^2 + h^2} + C. \tag{27}$$

In the territory of Vietnam, the coefficients b, S, C are determined on the basis of isoseismic map of strong or feeling earthquake (I by MSK - 64 scale) (3,6,9).

In the direction perpendicular to the seismogenic zone:

$b = 1.5; S = 2.5; C = 3.0$

In the direction to the seismogenic zone:

$b = 1.45; S = 3.0; C = 2.6$

In the middle direction:

$b = 1.45; S = 3.2; C = 2.8$

V. STRONG SEISMOGENIC ZONES ($M_{MAX} \geq 5.0$) IN VIETNAM

On the basis of the results of study by the above described method we can determine the capable strong seismogenic zones of the territory of Vietnam (Fig.2).

1. The Lai Chau - Dien Bien seismogenic zone.

The Lai Chau - Dien Bien zone, in the northeast-southwest direction, is a trong seismogenic zone. This zone coincides with the destroyed zone having the same name. This is a destroyed zone of the tectonic dividing zone. In this zone, earthquake occurred frequently, especially in the Lai Chau and Dien Bien points. Although the earthquake focus is shallow and the magnitude is not greater than 6. The result of our calculation shows that the Lai Chau - Dien Bien zone is a zone having high level of earthquake risks. Maximum magnitude of earthquake can reach $M_{max} = 6.1 - 6.5; h(M_{max}) = 25km, I_{omax} \approx 8$.

2. The Viet Bac seismogenic zone. The Viet Bac zone is limited in the active zone of the fault system Bao Lac and the fault system Ca Bang - Lang Son in the northwest-southeast direction. The earthquake maximum magnitude in this zone can reach $M_{max} = 5.1 - 5.5$, focus depth $h_{max} = 15$ km with $I_{omax} = 7$.

3. The Dong Bac seismogenic zone.

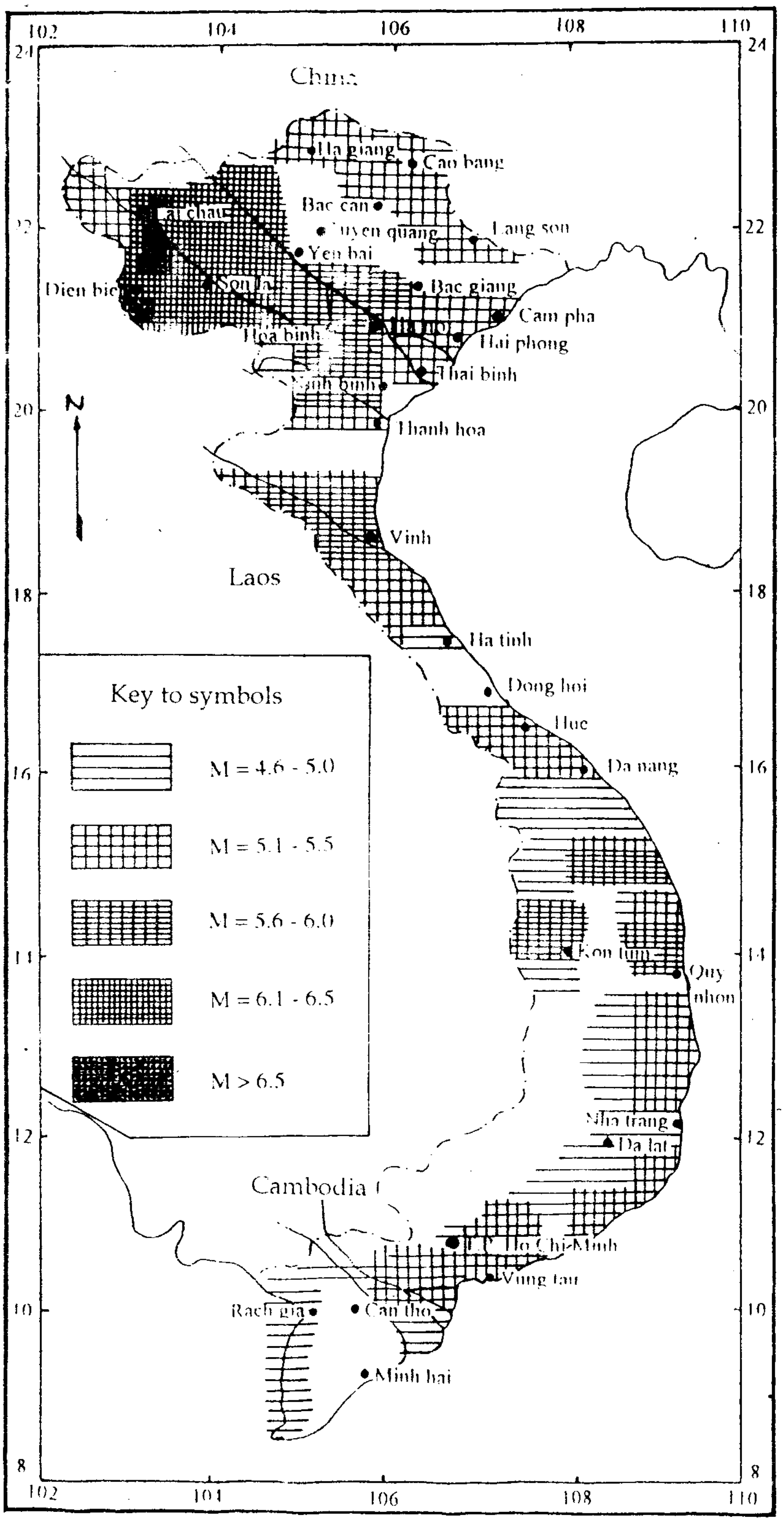
The Dong Bac zone coincides with the destruction zone Dong Trieu - Cam Pha. In this zone, the seismic activity is continuous. The maximum magnitude $M_{max} = 5.6 - 6.0$ with $h_{max} = 15 - 20km, I_{omax} = 7 - 8$.

4.The Red river seismogenic zone.

Earthquake are frequently observed in this zone, but one does not still reveal earthquake with Io more than 7. After the studied and calculated results, earthquake maximum magnitude $M_{max} = 5.6 - 6.0$ with $I_{omax} = 7 - 8, h(M_{max}) = 15 - 20$km.

5. The Da river seismogenic zone.

The Da river zone covers the active peace of the destruction zone Son La - Da River in the northwest-southeast direction. In this zone, earthquake occurred frequently and had great intensity. Perhaps, the activity can increase in the northwest part of


China
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Hai phong
Hoa binh
Thai binh
Thanh hoa
Vinh
Ha tinh
Dong hoi
Hue
Da nang
Kon tum
Quy nhon
Nha trang
Da lat
Ho Chi Minh
Vung tau
Rach gia
Can tho
Minh hai
N
Key to symbols
M = 4.6 - 5.0
M = 5.1 - 5.5
M = 5.6 - 6.0
M = 6.1 - 6.5
M > 6.5

the zone. The maximum earthquake can be occurred in this zone at $M_{max} > 6$ with $h(M_{max}) = 25km, I_{omax} = 8 - 9$.

bf 6. The Ma river seismogenic zone.

The Ma river zone is developed in the activity domain of deep fault interzone Ma River and Nam Ma. This is one of the two greatest earthquake genesis zones in the territory of Vietnam. The occurred earthquakes can have $M_{max} > 6.5$ with $h(M_{max}) = 25km, I_{omax} = 8 - 9$.

7. The Ca river seismogenic zone.

The maximum earthquake inside this zone can reach $M_{max} = 5.6 - 6.0 I_{omax} = 7 - 8$ with $h(M_{max}) = 15 - 20km$.

8. The Hue - Da Nang seismogenic zone.

The Hue - Da Nang zone is limited by 2 destruction zones of Phong Dien and Hoi An. The maximum earthquake occurred in this zone have $M_{max} = 5.1 - 5.5, I_{omax} = 7.0$ and $h(M_{max}) = 10 - 15km$.

9. The Ba To - Cong Son seismogenic zone.

The Ba To - Cong Son zone in the sublatitutional direction has the activity limited in the destruction zone having the same direction as Ba To- Cong Son fault system. The maximum earthquake magnitude in this zone can reach $M_{max} = 5.6 - 6.0$ with $I_{omax} = 7 - 8, h(M_{max}) = 15 - 20km$.

10. The Thuan Hai - Minh Hai seismogenic zone.

The maximum earthquake observed in this zone have $M_{max} = 5.6 - 6.0, h(M_{max}) = 15 - 20$ km with $I_{omax} = 7.0 - 8.0$.

VI. CONCLUSION

The data used in this thesis are the geological, geophysical data having until 1990. They are published by General Department of mines and geology, and observed seismological data of the Institute of Geophysics. The tasks, methodology and results of the research all are carried out in the Institute of Geophysics. Based upon the basic of the obtained results it is shown that:

1. The strong seismogenic zones in Vietnam are the marginal faulting zones, the zonated faulting zones, having long and strong process of activity, including the neotectonic. These destructive zones have great penetrating depth.

2. The new multilinear interrelation investigating method depends on the characteristics of seismic activity and the other geology-geophysical characters successfully applied

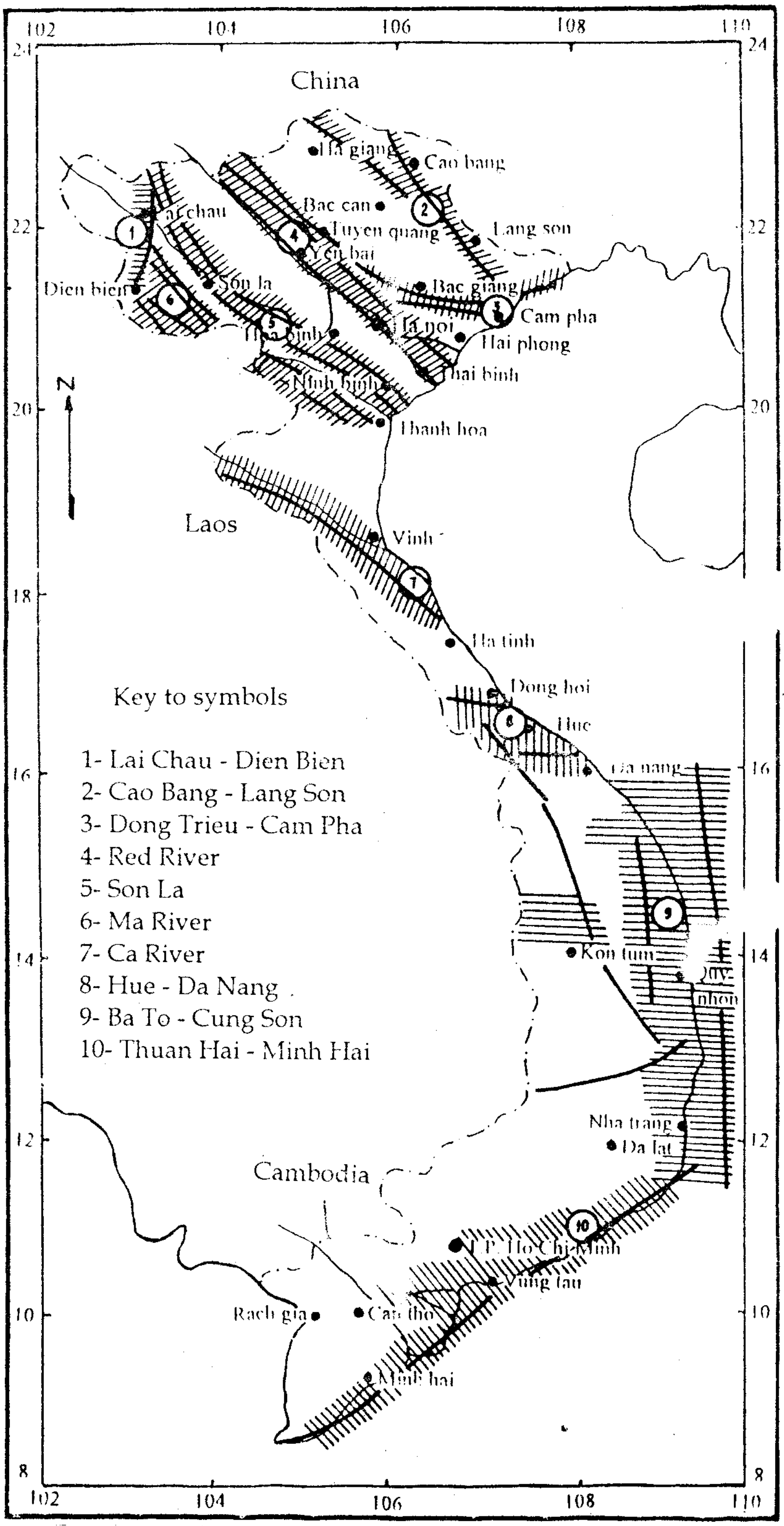

Figure 2. The strong earthquake genesis zones

on the studied territory. The strict relation between the submentioned characteristics allows to forecast the seismogenic zones and their characteristics of activity.

3. The Da river and Ma river seismogenic zones are the two zones which have the greatest degree of seismic danger in Vietnam.

It is hoped that our investigated results concerned with this work can be considered as the primary and successful results. They can be used as the basis for more future detailed research.

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