SEISMOTECTONIC FEATURES OF THE RED RIVER FAULT ZONE IN NORTH VIETNAM

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ABSTRACT

This paper presents the results of study on seismotectonics of the Red River fault zone in North Vietnam. The seismotectonic characteristics of the zone such as maximum possible earthquake, recurrence interval between major earthquakes, long term slip rate of recent seismotectonic motion ... were estimated on the basis of seismic data.

1. INTRODUCTION

The Red River fault is one of the greatest regional faults. It has long been recomized as a profound geological discontinuity marking the southwest margin of the South China platform. From near China-Vietnam border southeast toward to the Tonkin gulf northeast of the Red River fault in the distance of about 17 km a parallel deep fault-the Chay River one-is contemporally developed. They are combined into a system separating the south part of the China platform to the northeast and the Lao-Vietnam fold system to the southwest (Fig.l). Regional recent stress field is characterized by north-south compression and east-west extension with the suphorizontal stress axes σ_1, σ_3, respectively. Accordingly the faults are right lateral (Allen, 1984; Nguyen Trong Yem et al, 1995). But in the southeast part from near Viettri, participating in the cenozoic intensive rift activity creating the Hanoi Cenozoic depression the faults have an appriciable component of dip slip (Nguyen Trong Yem et al, 1995). On the contrary to the present day low seismic activity there was in this century a period in which the seismicity seemed to clearly manifest itself (Nguyen Dinh Xuyen et al, 1996).

Scientists around the world were concentrating their efforts to understand different aspects of the faults and have outlined many conclusions and suggestions on the displacement along the faults, the slip rate, the degree of seismic activity and hazard etc. However among these conclusions and suggestions many are still debatable. The purpose of our study is on the basis of seismic data to estimate some seismotectonic characteristics of the Red-Chay Rivers faults zone such as the maximum possible earthquake, recurrence interval between major earthquakes, and the recent slip rate of seismotectonic flow. The obtained results are presented in this paper as a small contribution to the present discussion.

2. SEISMICITY IN THE RED-CHAY RIVERS ZONE AND ITS CHARACTERISTICS

In the studies on seismicity and seismic hazard assessment of Vietnam carried out in the period 1964-1996 a large number of earthquakes occurred in the territory of Vietnam from ancient time through 1995 have been collected from different sources: instrumental observation, field investigation and the historical notes (Rezanov, 1968; Nguyen Dinh Xuyen et al, 1996). Those occurred in the Red-Chay River zone and vicinity are shown in the Fig. 1. The earliest events are the earthquakes occurred in Hanoi in 1276, 1278 and 1285. Their magnitude is estimated to be equal to 5.1-5.5. Many historical earthquakes (with intensities less than VI in MSK (or MM) scale) are not shown because we could not distinguish them from the shaking caused by the strong earthquakes outside the studied zone. Most the data are the events of this century. For the period 1900-1975, because of absence of a necessary seismological network only the earthquakes of magnitude $M_s \geq 4.5$ are sufficiently observed. Since 1976 the seismological network in North Vietnam was reinforced and most the events of $M_s \geq 3.0$ were recorded. The largest events are the earthquakes occurred 1954, November, in Lucyen, M_s=5.4 and Bacgiang, June 21, 1961, M_s=5.3-5.9 (Rothe, 1965). They are as large as the events occurred in Hanoi about 700 years ago.

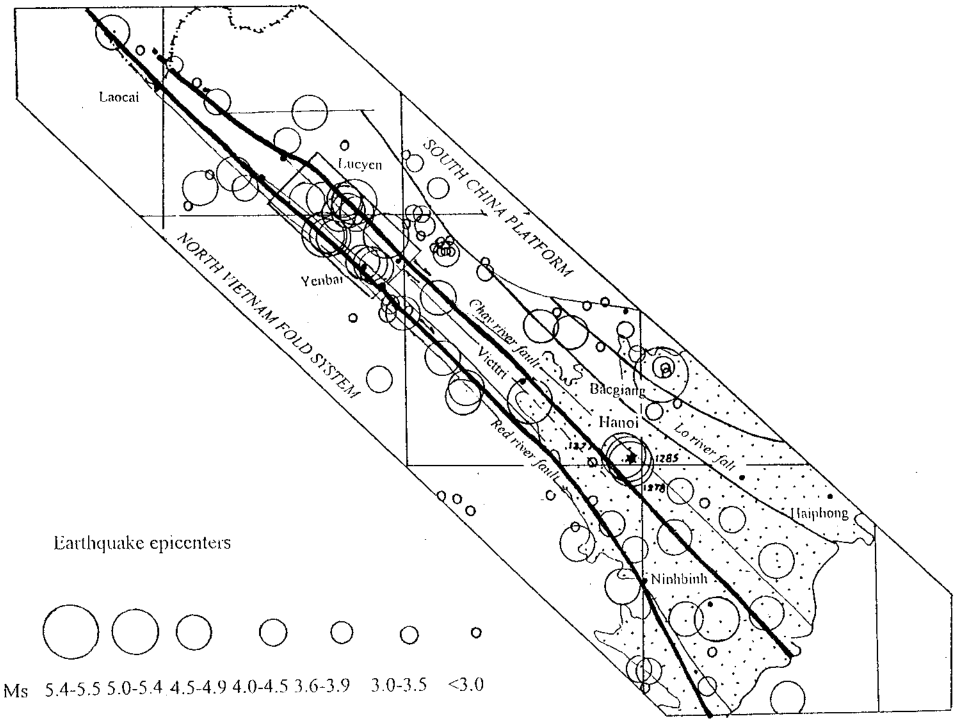

Figure 1. Seismotectonic sketch map of the Red River fault zone in North Vietnam. Box shows the focal zone of the Luc Yen Earthquake of Nov. 1954, M_s = 5.4

The maximum possible earthquake in the Red-Chay Rivers zone.

For the Red-Chay River zone and vicinity we have applied the third Gumbel's distribution of extreme values to determine maximum possible earthquake. Using data from 1900-2000 we obtained very stable results $M_s = 5.4 \pm 0.5$. The other approach is to determine the maximum possible earthquake following the fault dimensions characterized by the fault segment length and active layer thickness. In the world, there are many empirical correlation between the magnitude and faults dimension, but, as it was shown by Leon Reiter (1990), better fitting equation to use is that derived from the data restricted to studied tectonic setting than non- regional regression. We have also showed that the available correlations can give much different estimations of earthquake magnitude ((Nguyen Dinh Xuyen et al, 1997). So for estimation of maximum possible earthquake in the Red-Chay Rivers zone better to use the correlation derived from the Vietnamese data - bases as follows:

$$M_{smax} \leq 2\log L(km) + 1.77 \quad (1)$$

and

$$M_{smax} \leq 4\log H(km) + 0.50 \quad (2)$$

Where L is the fault segment length, H- is thickness of the layer in which the earthquakes may be generated (below we shall call it the active layer). These formulae have been established on the basis of the correlation between earthquake focus dimensions and the magnitude. Observation results in different regions showed that the dimension of preparation zone is 2.5-3 times greater than the dimension of respective focus (Ananin, 1973). So we can consider that the fault segment length is 2.5- 3 times greater than the focus length of maximum earthquake that may occur in it. It is needed to note that the two formulae must be satisfied simultaneously.

For the Red-Chay Rivers zone we have no any information about the fault segments. But we can assume that they are long enough, so the magnitude of maximum possible earthquake will be limited only by the active layer thickness. The latter is equal to or less than 25 km that is proved by seismic data: the focal depth of all the observed earthquakes don't exceed 25 km. If we take into account the thickness about 3 km of the sedimentary layer we shall have for active layer the thickness H = 22-25 km. With these data the second formula gives for maximum magnitude the value $M_{smax} = 5.9\text{-}6.1$

Thus we can attribute to Red-Chay Rivers zone the maximum possible earthquake of magnitude $M_{smax} = 6.0 \pm 0.1$, or $M_{smax} = 6.0 \pm 0.3$ if we take into account the error about 0.3 of magnitude estimation. It seems to be small in comparison with some other estimations for example with those given by Alien (1984), who suggested that along the Red River fault at least to Vietnam border may occur the earthquake of magnitude 8.3. But there are many uncertainties in these suggestions. Otherwise our estimation physically can be explained. Firstly, the magnetotelluric investigation results showed that in the Red River fault zone in the depth greater than 25 km there is a high conductivity layer (Pham, 1995). We can consider this layer a viscous, plastic one having no capacity to accumulate stress for earthquake generation. Because of this the active layer is thin (no greater than 25 km as above mentioned) and energy of maximum possible earthquake must be limited. The second specific feature of the Red-Chay Rivers zone and North Vietnam in general is a "weak" seismic environment manifesting itself in large dimension of earthquake foci. On the basis of macroseismic data of Vietnam we have established the correlation between the focus dimensions and magnitude as follows

$$Lgl_x = 0.5M_s - 1.06 \pm 0.3 \quad (3)$$

$$Lgl_z = 0.25M_s - 0.125 \quad (4)$$

Where l_x, l_z, the focus length and height respectively (Nguyen Dinh Xuyen et al., 1996), (Fig.2). The correlations are valid for earthquakes of $M_S \leq 6.5$. They prove that the earthquakes in this region have the larger focus than ones of same magnitude in the other regions. That is to say: in the fault segment of same length here we expect smaller earthquake than in the other regions. The earthquakes in this environment belong to the class of "soft" ones. They occur in condition of low friction in the fault plane. If our estimation is true the low seismic activity in the Red River faults zone is its attribute.

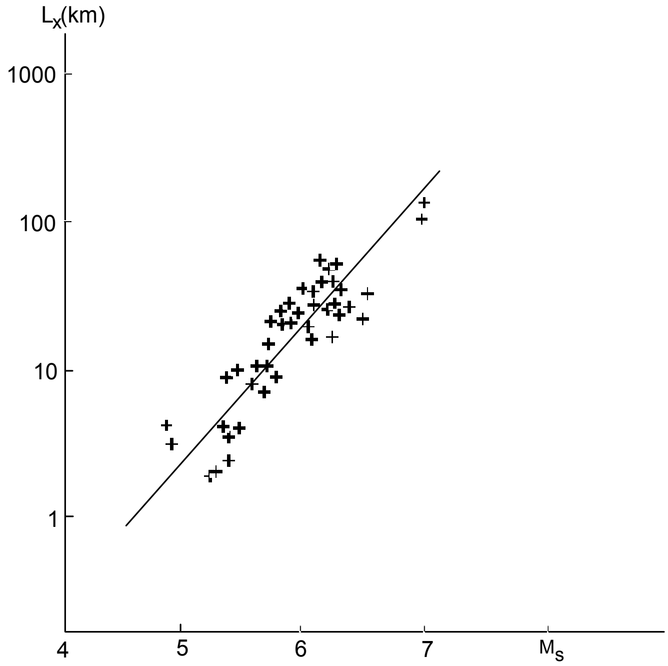

Figure 2. Correclation bettween earthquake focus length and magnitude.

Recurrence interval between major earthquakes

In order to estimate the characteristics we propose here a simple method basing on the concept of seismic cycle. The process of accumulation and release of tectonic stress in a given place are well known in geotectonics (Kasahara, 1961). This process is reflected in seismic activity by the seismic cycle that was shown clearly by Fedotov (1968) on the basis of seismic data in Kamchatka. Seismic cycle is the process of accumulation and release of seismic energy between major earthquakes in any place. It consists of 3 stages: aftershock activity, stable regime and foreshock activity. Stage of aftershock activity begins just after the main shock. Remain stress is released and seismic activity is gradually decreased to a stable regime. The new stage of accumulation of energy is beginning. It occupies most the time of the cycle; seismic activity is low and stable. Stage of foreshock activity begins the process of release of accumulated stress when the latter reached the critical state. Seismic activity is gradually increased up to the main shock time. Sometimes a short quiescence takes place before the main shock. In general for the moderate seismicity regions, seismic cycle is thousands years long and we have no data for a whole cycle. But in the areas where the major earthquake occurred we can observe some parts of the cycle such as the foreshock and aftershock stages and may be a part of stable stage before the foreshock stage or after the aftershock one. The recurrence interval between major events in those areas can be estimated following the characteristics of these observed stages. The formula for estimation of the seismic cycle duration or recurrence interval between major earthquakes

$$T = [10^{\gamma(Kmax-K1)} - t_1 (A_1 - A_2) - t_3 (A_3 - A_2)]/A_2 \quad (5)$$

where A_1, A_2, A_3- average seismic activity in the aftershock, stable, foreshock stages respectively. t_1, t_3 -duration of the aftershock and foreshock stages respectively.

In the Red-Chay Rivers zone in 1954 an earthquake of magnitude M_s = 5.4 occurred in Lucyen, Yenbai province. This is one of the largest observed earthquakes in this zone. Using the mentioned seismic data in period 1900-1995 and taking into account that Kmin = 12 with respect to threshold magnitude Ms = 4.5, slope of the frequency graph for northeast part of Vietnam including the Red River zone is equal to b = 0.877, γ= 0.877/1.8 (Nguyen Dinh Xuyen et al, 1996). We have calculated value A in the focal zone of this earthquake (box in Fig.l) for each 5 years interval from the main shock time back and forth and studied the seismic activity variation in the zone. We can see here the character of a seismic cycle and also define its foreshock and aftershock stages and a part of the stage .of stable regime. It is no doubt that the concentration of earthquakes epicenters in the Lucyen area is connected with the process of occurrence of the mentioned earthquake. Determining the average characteristics A_1, A_2, A_3, t_1, t_3 and calculating T we have for the recurrence period of major earthquake the value T = 1000-1100 years. If, as it's shown in previous item, the earthquake of magnitude Ms==6.0±0.3 is possible in the Red-Chay Rivers zone its recurrence period will be at least 2100-2200 years.

3. RECENT SEISMOTECTONIC SLIP RATE IN THE RED -CHAY RIVERS ZONE

In general the tectonic displacement that can be observed in the field by the methods of geodesy, geology, geomorphology is caused by the continuous viscous, plastic flow of rock masses and the intermittent-continuous seismic flow. The latter includes elastic deformations preceding individual earthquakes and the earthquakes themselves, from a multitude of weak ones to very rare catastrophic ones. Seismic data allow us to assess the proportion of total deformation of rock masses due to earthquakes. In this item we shall make an attempt to assess the recent seismotectonic slip rate in the Red-Chay Rivers zone using the above-described seismic data.

The unique case for study is the Lucyen earthquake focal zone (box in the Fig.l) where the seismic cycle has been observed. It is also the most simple model for calculation because the fault plane is supvertical and fault direction is at angle 45° with the north, consequently in the mentioned regional stress field (north-south compression,.east-west extension with the suphorizontal stress axes σ_1, σ_3) the displacement occurs along the fault plane. As it is noticed, the displacement in this zone is caused not only by the Lucyen earthquake of 1954 but also by all earthquakes occurred in it. And because of variation of seismic activity the seismic slip rate is also varies. Therefore in order to estimate a long term of slip rate we must estimate the average one in at least one whole seismic cycle.
The formula for estimation of the average seismotectonic slip rate is

$$V = \frac{N_{\Sigma 1} b Mo(M_1) 10^{(C2-b)(M\max - M1)}}{2\mu(C_2 - b)(1 - 10^{-b(M\max - M1)}) St} \tag{6}$$

In the focal zone of Lucyen earthquake of 1954, Ms=5.4 in period 1900-1995 we have observed 23 earthquakes of magnitude Ms ≥ 4.5, among them 3 events have the magnitude Ms = 5.0-5.4. So we can take for this period the value M_1 = 4.5, $N_{\Sigma 1}$=23. For the foreshock and aftershock stages (192.0-1961) such values are M_1 = 4.5, $N_{\Sigma 1}$ = 15. Concerning the whole cycle we can take M_1 = 4.5 and calculate $N_{\Sigma 1}$ by the relation

$$N_{\Sigma 1} = \Sigma N_1(M_1) = \Sigma N\ (Mmax)\ 10^{-b(Mi - Mmax)} \quad (7)$$

grouping earthquakes with respect to the magnitude intervals 4.5-4.9, 5.0-5.4, 5.5- 5.9, Mmax=6.0 and taking N(Mmax)=1.

Assuming that $\mu= 3.\ 10^{11}$ dyn / cm^2, the focal zone cross section area S=H*L where H is active layer thickness, H = 25 km, L is focal zone width, L=27km, slope of the magnitude frequency graph b=0.877 and for the crustal earthquakes logMo(M)=16+1.6Ms (Riznichenko, 1974) we obtain the following values of average recent seismotectonic slip rate :

In the period 1900-1995 v = 1.5 mm/year
In the period 1920-1961 v = 3.4 mm/year
(Foreshock and aftershock stages)
In the whole seismic cycle
T-2100-2200 year v = 0.5-0.6 *mm/years*

As it was mentioned above, slip rate varied in time. Only the average value in the whole seismic cycle can be considered as the long-term one. If we take into account that the displacement in earthquake of MS =5.5 and 6.0 is about 15 cm and 25 cm respectively we can see also that displacement resulted due to the major earthquake is only a part of total one. In comparison with the estimations of about 5 mm/year obtained by Allen (1984) and others on the basis of field investigation (Ananin, 1973; Nguyen T. Y., 1995) the obtained in our study seismotectonic slip rate is only tenth. The fact that the seismic slip rate is much smaller than one of the general tectonic flow has been expected and explained previously. It is also proved by estimations for many regions (Rezanov, 1968). For this reason it is difficult to assess the size of earthquake and its recurrence interval following any offset and long-term slip rate along the fault observed by the method of geomorphology.

4. CONCLUSION

Summarizing the study results we can make the following suggestions:

1-The low seismic activity can be regarded as an attribute of the Red-Chay faults zone. It manifests itself in low magnitude of maximum earthquakes both observed and expected and long recurrence interval between major earthquakes. The largest events occurred in this zone are the earthquakes of magnitude Ms=5.5, the maximum possible events of MS = 6.0±0.3 are expected may arise. The recurrence interval between these events in a given place is 1000-1100 and at least 2100-2200 years respectively.

2-The average long-term recent slip rate of seismotectonic motion is approximately 0.5-0.6 mm/year. Only a part of this value belongs to the major earthquake. The seismic motion contributed only a modest part to the total tectonic motion. In the Red River fault zone it may be tenth of total-

5. ACKNOWLEDGMENTS

This work was supported by Grant No. NSC 89-2811-M-008-0001 of the National Science Council of Taiwan and the Fundamental Research Program of Vietnam. The author is very grateful to Prof. Yi-Ben Tsai and Mr.Hsin-Hung Wu for their help, attention and valuable discussions in completing this work.

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