Sbor. geol. věd	Užitá geofyz., 24	Pages 107–132	9 figs.	2 tabs.	— pl.	Praha 1990 ISSN 0036-5319

Earthquake activity in the north part of the Socialist Republic of Vietnam during the period from 1976 to 1984

Activité des tremblements de terre dans le Nord du Viêt-Nam pendant la période de 1976—1984

Nguyen Kim Lap[1]

Received May 4, 1987

Vietnam (northern part)
Seismic activity
Magnitude scales
Tuangiao earthquake

Nguyen Kim Lap (1990): Earthquake activity in the north part of the Socialist Republic of Vietnam during the period from 1976 to 1984. – Sbor. geol. Věd, užitá Geofyz., 24, *107–132*. Praha.

Abstract: Data related to more than 1 000 earthquakes which occurred in the north part of Vietnam from 1976 to 1984 were collected. The northwest area of the country is characterized by Tuangiao earthquake (M = 6.7) being the consequence of regional tectonic activity in the northwest-southeast direction. Earthquake activity in the north part of Vietnam was studied qualitatively by showing the space distribution of earthquakes, seismic activity A_{10}, maximum expected earthquakes and the main characteristics of the Tuangiao earthquake.

[1] *Institute of Geophysics National Centre for Scientific Research of Vietnam, Nghia do – Tu liem – Hanoi*

Introduction

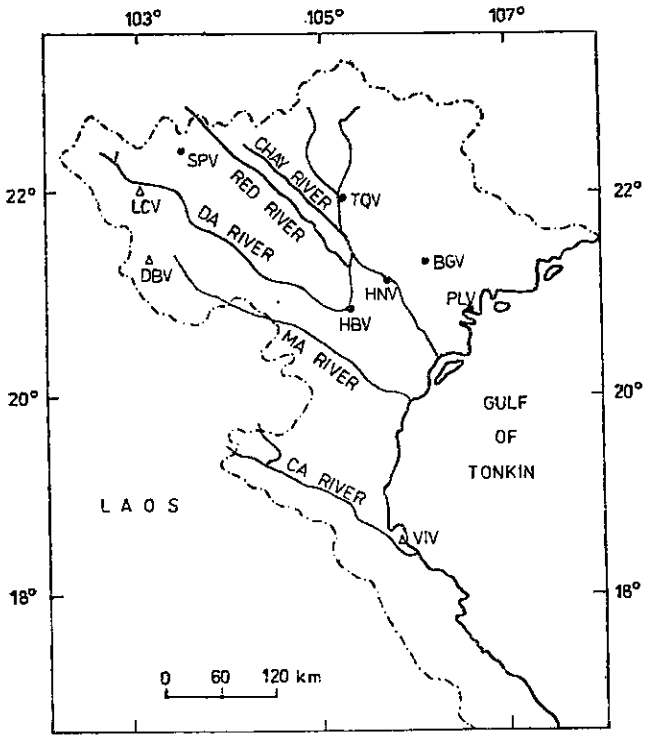
The territory of the north part of Vietnam is situated along the contact of two strongest earthquake belts of the world: the Mediterranean and West Pacific belts. These features partly determine the seismic activity of the territory of Vietnam. Seismic data show that in the north part of Vietnam large earthquakes have occurred with heavy human and material losses (Xuyen–Lap, 1985). Earthquake observations in the north part of Vietnam started as early as 1924. Since that time, Phulien seismological station is in active operation and exchanges earthquake data

with international data centres. Rapid development in seismological technology and the increased distribution of seismological stations, especially after 1975, has resulted in precise location of earthquakes of magnitude as small as 3.5. The Tuangiao earthquake of magnitude $M = 6.7$ occurred along the Sonla fault adjacent to the Red river fault system extending northwest-southeast from Yunnan province in China. The Tuangiao earthquake caused considerable damage, a number of brick building were either destroyed or damaged and a considerable amount of rice fields was damaged by falling rocks. The purpose of this paper is to investigate the main characteristics of earthquake activity in the north part of Vietnam, which are the basis of predictions at different stages.

Data

Seismological stations

Seismological stations have been established successively in the north part of Vietnam after 1975 (fig. 1). From these stations, data on the earthquake activity in this region are obtained. Generally speaking, it has been possible to monitor



1. Seismograph stations in Vietnam, solid dots are permanent seismic stations
Open triangles are stations proposed for the future

earthquakes of $M \geq 3.5$ since 1976. The list of seismological stations is given in table 1. The location of earthquakes is estimated using travel times of Central Asia.

Table 1

List of seismic stations in the north part of Vietnam

Station name and code	Coordinates		Type of instrument	Component	Siesmometer period T_s(S)	Galvanometer period T_g(S)	Maximum magnification V_{max}
	N	E					
Phulien PLV	21°42′21″	106°37′44″	SKM	NS	12	1.1	1165
				EW	12	1.25	1277
				Z	12	1.25	1920
			SM-3	NS	1.8	0.30	16130
				EW	1.8	0.30	15800
				Z	1.8	0.30	19150
Bacgiang BGV	21°17′38.9″	106°13′42.9″	Kharin	NS	1.0	0.30	42242
				EW	1.0	0.30	42020
				Z	1.0	0.30	47144
Hoabinh HBV	20°49′33.3″	105°21′06.9″	Kharin	NS	1.0	0.49	55788
				EW	1.0	0.46	43000
				Z	1.0	0.33	51124
Tuyênquang TQV	21°49′42″	105°12′30″	SU-59	NS	1.0	0.30	43957
				EW	1.0	0.30	47425
				Z	1.0	0.30	49193
Sapa SPV	20°20′08.9″	103°49′51.8″	SP-1	NS	1.2	0.14	13313
				EW	1.2	0.14	14492
				Z	1.2	0.14	14355

Magnitude scales

Earthquake magnitude is a measure of the elastic strain energy released during earthquakes in the form of elastic waves. In this work, the adopted formulas for surface wave magnitudes are as follows (Thuc, 1979).

$$M_H = \log \frac{A_H}{T} + 1.33 \log \Delta\,[\text{km}] + 1.43, \qquad (1)$$

$$M_Z = \log \frac{A_Z}{T} + 1.66 \log \Delta \text{ [km]} + 0.44, \qquad (2)$$

where A_H and A_Z are the maximum horizontal and vertical amplitudes in micrometers.

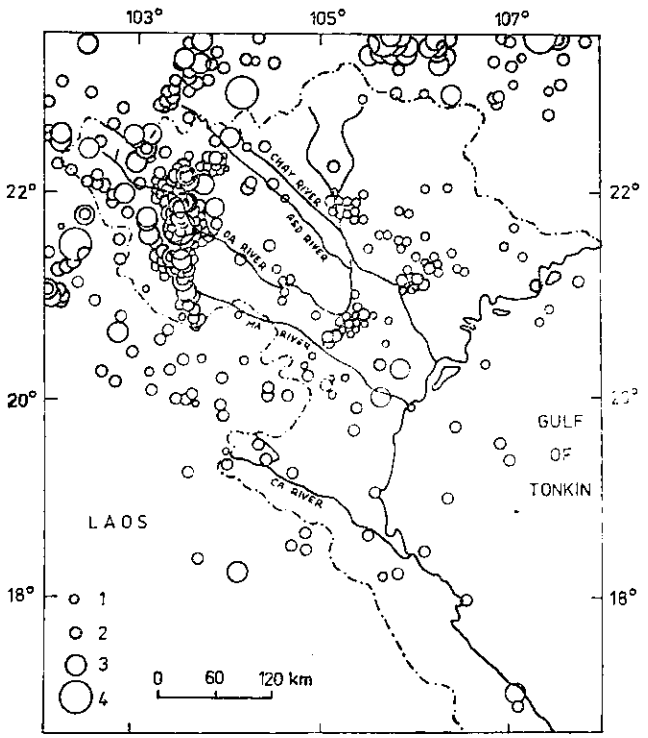
Another formula for magnitude scale, elaborated from the duration of seismic records, is also used (Xuyen, 1972):

$$M_D = 2.67 \log (F - P) - 2.49, \qquad (3)$$

where $F - P$ is the duration of seismic record in seconds, F is beginning of seismic record, P is end of seismic record. Magnitude was determined by formulas 1, 2 and 3 almost equal with magnitude of Gutenberg and Richter (Xuyen and Lap, 1985).

Regional distribution of earthquakes in the north part of Vietnam

In the north part of Vietnam, the earthquakes are distributed in narrow bands along tectonic faults which are the boundaries of the geological blocks. The distribution of earthquake epicentres is shown in fig. 2, where their magnitudes are also marked.



2. Epicentral distribution of earthquakes in North Vietnam during the period 1976 to 1984
Magnitude: 1. M < 3;
2. M = 3÷4;
3. M = 4.1÷5.0;
4. M ≥ 5.1

The earthquake density is higher in northwestern Vietnam, and relatively low in southern part of the studied region. In the north part of Vietnam, the earthquakes usually lie along a recently active fault zone and seismic activity is increasing in the studied period. It should be mentioned that all earthquakes are shallow and their foci are considered to be within the crust (crustal thickness about 35 km). From earthquakes in the north part of Vietnam, for which the depth could be determined, we observe that about 90 % of earthquakes have hypocentres in the depth from 5 km to 20 km.

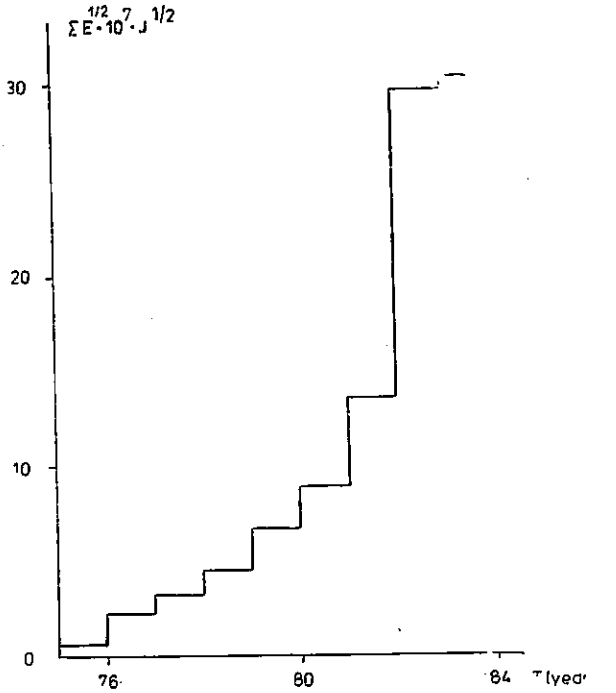
Cumulative strain release

Benioff assumed that the strain state of the medium around a hypocentre is directly proportional to the square root of earthquake energy. To study seismicity as a function of time, a strain release curve was computed. In evaluating the energy (E) of an earthquake, the formula by Gutenberg was used:

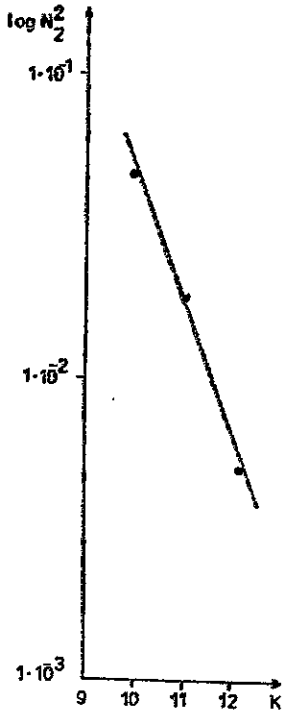
$$\log E = 4.3 + 1.8\,M, \tag{4}$$

where M is the surface wave magnitude and E is the energy of the shock in Joules.

The time variation of the strain release in the north part of Vietnam during the period 1976 to 1984 is presented in fig. 3. This curve shows that the major earthquakes ($M \geq 5$) occurred in 1983. From the strain release curve the yearly strain release can be estimated to be approximately $3.5 \cdot 10^7$ Joules$^{1/2}$.



3. Cumulative strain release for earthquakes in North Vietnam during the period 1976 to 1984



4. Earthquake reccurrence graph of North Vietnam during period from 1976 to 1984

Seismic activity in the north part of Vietnam

Earthquake frequency law

The seismicity of this region was analysed using the method proposed by Riznichenko (1960). This method is based on the earthquake frequency law expressed by the frequency-energy relation (Riznichenko, 1960):

$$\log N = \alpha - \gamma K, \tag{5}$$

where: N – cumulative number of earthquakes,
α – parameter related to the level of activity,
γ – slope of frequency graph,
K – energy class.

Seismic activity A equals α for a certain value of K, e.g. K = 10, according to Riznichenko (1960). The coefficients in equation (5) are calculated using the least squares method. The application of equation (5) to the earthquakes which occurred in the north part of Vietnam within an area of about 426 000 km^2 during the period 1976 to 1984, led to the following relation

$$\log N = 2.27 - 0.38\,K. \tag{6}$$

The graph of equation (6) is given in fig. 4.

Table 2

List of earthquakes with M ≥ 3.0 which occurred in the north part of Vietnam during period from 1976 to 1984

N°	Date			Origin time (GMT)			Epicentre		H	M
	D	M	Y	h	m	s	N	E	(km)	
1	19	01	1976	13	07	07	22.4	103.1	15	3.3
2	29	01		08	56	22	23.6	106.4	10	3.6
3	26	02		11	59	46	22.9	105.4	15	3.0
4	09	03		10	16	11	20.9	103.5	20	3,0
5	09	03		10	58	00	20.1	103.2	15	3.1
6	25	03		18	16	26	21.9	106.7	20	4.0
7	26	03		07	05	50	22.0	103.2	15	3.1
8	07	04		05	34	32	20.3	103.3	15	3.1
9	12	07		20	30	00	18.5	104.9	15	3.4
10	13	07		21	59	48	21.3	102.3	15	3.7
11	19	08		11	44	34	22.6	101.9	10	3.8
12	09	09		17	55	11	19.8	104.0	15	3.1
13	04	10		16	23	06	21.7	103.9	10	3.0
14	08	11		08	09	13	21.1	107.3	10	3.0
15	09	11		06	09	49	23.7	102.4	10	3.7
16	09	11		06	11	35	23.6	102.7	15	5.1
17	23	11		02	00	43	18.6	104.7	15	3.6
18	31	11		14	28	26	21.9	105.1	6	3.6
19	11	01	1977	14	56	05	21.2	102.9	10	3.4
20	04	02		11	12	50	22.1	102.6	13	3.6
21	05	02		04	33	00	19.9	104.0	20	3.4
22	21	02		13	32	59	22.3	105.1	15	3.3
23	24	02		20	33	00	23.3	104.5	10	3.4
24	28	02		09	41	00	19.7	106.4	20	3.1
25	19	03		18	28	32	19.4	104.0	20	3.5
26	03	04		16	38	40	21.2	106.0	10	3.1
27	07	04		04	07	31	19.3	106.7	20	3.6
28	08	04		11	48	39	20.9	102.6	10	3.3
29	09	04		14	02	43	26.6	106.9	10	4.1
30	13	04		00	08	32	18.6	104.9	10	4.0
31	13	04		02	33	41	23.3	104.1	10	3.8
32	24	04		02	16	09	23.6	106.9	20	3.4
33	26	04		08	45	23	23.3	107.6	20	4.0
34	14	05		13	37	00	20.1	105.2	20	3.0
35	02	06		16	48	31	21.0	102.0	25	3.6
36	29	06		19	15	14	22.3	102.2	15	3.3
37	06	07		12	27	00	20.8	105.3	15	3.3
38	15	07		14	16	46	22.5	102.9	10	3.4
39	12	08		06	02	35	20.2	102.8	20	3.3
40	19	09		09	51	52	21.1	103.5	25	3.5

Table 2 (continued)

N°	Date			Origin time (G M T)			Epicentre		H	M
	D	M	Y	h	m	s	N	E	(km)	
41	20	09	1977	11	09	56	20.7	103.3	20	3.1
42	21	09		03	03	00	20.6	103.3	25	3.0
43	29	09		21	18	06	23.5	102.4	25	5.0
44	09	09		05	55	23	19.3	103.6	20	4.0
45	19	10		02	44	38	23.5	107.3	20	5.2
46	19	10		03	55	00	23.5	107.5	25	4.6
47	19	10		21	39	04	23.5	107.0	20	3.5
48	25	10		05	29	58	21.2	105.8	10	3.0
49	16	12		18	20	00	21.8	102.5	20	3.5
50	19	01	1978	19	25	36	23.1	107.6	10	3.9
51	02	02		20	36	26	22.1	103.8	15	3.2
52	06	02		06	08	59	21.4	102.4	10	3.9
53	08	03		18	21	47	23.5	103.5	20	3.5
54	12	03		20	36	54	21.1	102.4	10	3.9
55	06	04		18	12	54	22.5	104.3	10	3.6
56	26	04		11	52	27	22.9	102.9	10	3.3
57	29	04		12	08	10	21.2	107.4	10	3.1
58	03	05		22	01	35	19.0	106.4	15	3.5
59	08	05		08	48	00	23.0	106.9	25	3.1
60	19	05		03	13	19	22.8	107.4	10	3.6
61	16	07		16	53	51	23.4	106.9	20	3.2
62	29	07		22	33	17	22.6	102.2	15	4.2
63	10	08		09	38	58	21.9	102.7	20	3.7
64	19	08		21	17	59	22.4	103.0	10	3.2
65	06	09		22	41	08	21.3	102.8	10	3.3
66	10	09		11	57	00	21.9	101.8	25	3.5
67	10	09		14	04	00	22.2	103.2	15	3.2
68	10	09		14	39	08	22.2	102.6	10	3.2
69	11	09		18	42	31	22.8	104.1	10	3.5
70	28	09		07	33	23	21.2	103.3	15	3.0
71	28	09		08	23	03	22.4	102.4	15	4.5
72	01	10		20	50	38	21.5	103.6	10	3.4
73	04	10		01	56	33	20.8	102.8	25	3.6
74	07	10		12	25	43	22.5	102.6	10	3.2
75	09	10		21	42	36	24.1	104,1	10	4.2
76	09	10		22	55	14	22.1	104.3	10	3.8
77	13	10		04	54	48	22.1	102.0	10	3.4
78	21	10		06	39	11	21.3	106.2	15	3.1
79	01	11		01	47	17	23.2	102.3	10	3.5
80	04	11		06	31	00	21.6	101.9	20	3.7
81	06	11		00	21	03	20.0	104.7	10	3.2
82	11	11		22	32	07	21.5	104.4	10	3.3

Table 2 (continued)

N°	Date			Origin time (G	M	T)	Epicentre		H	M
	D	M	Y	h	m	s	N	E	(km)	
83	15	11	1978	09	24	25	21.2	106.0	10	3.2
84	16	11		01	22	32	23,2	101.9	10	4.2
85	28	11		12	03	23	23.0	106.9	10	3.1
86	28	11		17	53	11	23.0	107.0	10	3.3
87	11	12		13	42	09	22.1	105.0	10	3.2
88	13	12		18	21	09	22.8	101.5	20	3.4
89	19	12		02	01	50	21.4	104.1	10	3.2
90	22	12		05	56	58	22.3	103.8	15	3.7
91	23	12		08	15	40	22.3	103.8	15	3.1
92	09	01	1979	23	29	00	21.6	102.3	10	5.1
93	09	01		23	34	00	21.0	102.8	10	4.8
94	13	01		06	41	30	20.7	102.8	10	4.5
95	24	02		10	15	57	20.2	105.1	15	3.2
96	03	03		10	28	24	23.3	103.9	20	3.3
97	24	03		19	05	12	23.0	103.5	15	3.1
98	26	03		22	24	09	21.0	102.1	15	3.8
99	04	04		17	12	32	20.2	104.0	15	3.4
100	06	04		19	18	00	23.0	106.3	13	4.6
101	14	04		08	00	25	19.4	104.4	10	3.4
102	20	04		19	22	35	22.9	102.0	20	3.8
103	01	05		10	29	04	21.3	102.1	20	3.6
104	07	05		07	59	34	22.6	103.8	15	3.5
105	20	05		20	58	06	22.9	103.2	10	3.2
106	13	06		12	43	00	22.7	102.7	10	3.5
107	28	06		18	29	41	21.3	102.2	10	3.9
108	30	06		03	01	17	23.0	105.7	15	3.6
109	17	07		18	40	47	21.3	106.2	7	3.6
110	05	08		21	29	42	18.7	105.5	15	3.6
111	14	09		12	55	52	19,7	105.3	15	3.2
112	20	10		19	03	22	21.8	102.9	15	3.7
113	22	01	1980	01	21	00	20.0	103.6	10	4.0
114	22	01		14	07	00	20.1	103.6	15	3.5
115	03	04		20	38	00	20.2	104.9	10	3,0
116	07	04		05	04	00	22.6	102.0	15	3.9
117	17	06		21	46	00	23.0	104.1	15	5.7
118	17	06		22	16	00	22.3	103.0	10	4.2
119	17	06		23	02	00	21.8	103.1	10	4.6
120	18	06		00	57	00	23.4	103.8	10	4.0
121	18	06		03	43	01	22.4	103.0	10	3.7
122	18	06		05	13	01	23.4	103.7	10	3.7
123	18	06		07	33	00	22.8	103.2	10	3.2
124	18	06		12	55	00	23.9	104.2	10	4.3

Table 2 (continued)

N°	Date			Origin time (GMT)			Epicentre		H	M
	D	M	Y	h	m	s	N	E	(km)	
125	18	06	1980	20	40	00	23.5	103.6	10	4.5
126	19	06		07	11	00	23.2	103.6	10	4.0
127	21	06		10	58	00	22.6	103.1	15	4.3
128	22	06		07	22	00	23.3	103.7	15	4.3
129	22	06		19	06	00	23.5	103.8	15	3.6
130	23	06		06	42	00	23.0	103.4	15	3.8
131	23	06		15	04	00	23,3	103.6	15	3.8
132	06	08		10	20	55	23.6	104.3	15	3.7
133	06	08		20	44	24	23.7	104.5	15	3.4
134	10	08		14	28	48	23.8	104.1	15	3.3
135	10	08		21	45	00	23.2	103.6	20	3.2
136	10	12		01	43	00	22.9	103.3	15	3.7
137	10	12		11	47	00	22.9	103.3	15	3.7
138	29	12		08	45	00	21.1	102.1	20	4.2
139	14	01	1981	04	30	03	22.1	104.3	15	3.3
140	14	01		11	40	41	23.7	104.8	20	4.0
141	16	01		22	23	28	23.2	103.4	15	3.0
142	31	01		00	13	37	21.6	102.8	10	3.4
143	04	02		06	26	10	23.0	103.3	20	3.3
144	19	02		21	21	34	20.7	101.1	15	3.7
145	23	03		18	58	32	22.3	101.1	10	3,3
146	27	03		14	39	04	20.8	104.9	15	3.0
147	21	04		19	05	50	22.7	103.0	20	4.3
148	21	04		19	11	14	21.9	102.7	15	3.1
149	27	05		21	10	38.1	20.3	102.7	10	3.3
150	28	05		15	09	42	23.3	105.1	20	3.0
151	08	06		00	37	00	22.5	103.1	25	4.3
152	16	06		14	04	03	22.5	108.4	10	3.3
153	18	06		13	32	20	23.3	105.8	15	3.3
154	11	07		03	01	38	20.6	108.4	10	3.7
155	18	07		10	55	12	21.2	103.2	15	3.8
156	23	07		05	47	23	22.8	101.8	15	3.7
157	01	08		00	44	57	24.1	102.7	20	3.5
158	18	08		15	17	03	20.0	101.2	20	4.2
159	18	08		17	13	23	20.5	102.9	15	4.0
160	19	09		06	50	56	23.1	101.3	3	5.4
161	06	07		14	59	09	23.4	103.8	10	3.2
162	18	12		10	10	44	23.3	103.4	10	3.2
163	23	12		20	47	19	22.6	103.0	15	3.2
164	26	12		08	00	26	23.5	107.9	20	3.5
165	08	04	1982	12	23	15	21.6	103.1	15	4.4
166	24	06		14	01	45	22.5	102.2	20	4.4

Table 2 (continued)

N°	Date			Origin time (GMT)			Epicentre		H	M
	D	M	Y	h	m	s	N	E	(km)	
167	07	06	1982	02	12	26	21.6	101.9	20	4.3
168	23	10		10	40	11	20.9	102.2	20	3.9
169	25	01	1983	12	16	54	23.7	105.3	15	3.9
170	17	02		04	24	55	25.6	105.1	15	4.6
171	07	03		06	55	00	20.6	105.2	10	3.1
172	08	03		10	03	04	22.2	102.3	15	3.5
173	30	04		09	16	19	20.3	105.7	10	3.0
174	04	05		11	59	48	19.4	107.0	15	3.6
175	24	06		06	54	24	21.5	103.4	10	3,5
176	24	06		07	18	22	21.7	103.4	23	6.7
177	24	06		08	15	12	21.6	103.5	15	5.0
178	24	06		09	05	08	21.7	103.5	10	3.0
179	24	06		09	44	24	21.8	103.4	5	3.0
180	24	06		09	52	28	22.2	103.4	5	3.4
181	24	06		10	46	31	21.4	103.3	10	4.0
182	24	06		11	23	21	20.5	103.6	15	4.0
183	24	06		11	33	56	21.8	103.4	10	3.3
184	24	06		11	38	52	21.7	103.3	15	3.6
185	24	06		13	02	12	21.7	103.4	5	3.6
186	24	06		13	44	41	22.0	103.5	10	3.5
187	24	06		13	52	56	21.6	103.5	5	3.5
188	24	06		14	03	44	21.8	103.7	10	4.0
189	24	06		14	49	08	22.1	103.7	15	4.1
190	24	06		15	39	01	21.8	103.4	10	3.6
191	24	06		16	46	27	21.7	103.4	5	3.5
192	24	06		16	48	46	21.7	103.4	5	3.5
193	24	06		17	37	44	22.2	103.5	10	3.6
194	24	06		20	12	32	21.6	103.4	5	3.2
195	24	06		21	02	13	22.0	103.4	7	3.7
196	24	06		22	02	02	22.0	103.4	5	4.0
197	25	06		01	47	37	22.0	103.4	5	3.8
198	25	06		03	42	20	22.2	103.4	2	3.3
199	25	06		03	51	59	21.3	103.4	5	4.6
200	25	06		05	02	44	21.6	103.4	5	4.1
201	25	06		05	18	45	21.4	103.4	2	3.5
202	25	06		08	07	53	21.5	103.5	1	3.7
203	25	06		08	18	24.3	21.8	103.4	5	4.1
204	25	06		08	31	12.2	21.3	103.5	5	4.5
205	25	06		09	23	00	21.6	103.4	5	3.6
206	25	06		09	47	09	21.8	103.5	7	3.6
207	25	06		10	04	17	21.6	103.4	5	3.1
208	25	06		10	53	08	22.2	103.5	7	3.4

Table 2 (continued)

N°	Date			Origin time (G M T)			Epicentre		H	M
	D	M	Y	h	m	s	N	E	(km)	
209	25	06	1983	12	55	24	21.7	103.4	6	4.2
210	25	06		13	16	21	21.8	103.4	5	4.2
211	25	06		14	48	21	21.6	103.4	10	3.9
212	25	06		16	09	40	21.5	103.4	15	3.5
213	25	06		16	13	04	21.6	103.4	15	3.4
214	25	06		16	52	02	21.6	103.5	20	3.5
215	25	06		18	39	00	21.8	103.5	20	3.2
216	25	06		19	20	22	22.0	103.5	20	3.3
217	25	06		20	27	33	21.7	103.4	15	3.7
218	25	06		20	28	54	21.8	103.4	15	4.2
219	25	06		22	34	59	21.6	103.4	5	3.5
220	26	06		00	21	44	21.6	103.4	10	4.2
221	26	06		02	05	04	21.7	103.3	5	3.3
222	26	06		03	36	14	21.8	103.4	7	3.8
223	26	06		04	40	15	21.8	103.4	8	3.2
224	26	06		04	47	57	21.5	103.8	5	3.3
225	26	06		05	30	00	21.7	103.4	4	3.8
226	26	06		16	12	04	22.0	103.5	5	3.2
227	26	06		17	36	50	21.9	103.5	15	3.6
228	26	06		17	55	46	21.8	103.5	15	4.1
229	26	06		19	37	46	21.6	103.4	15	3.4
230	26	06		19	40	38	21.2	103.4	15	3.3
231	26	06		20	03	16	21.9	103.4	15	3 3
232	26	06		20	15	24	21.6	103.4	10	3·2
233	27	06		01	51	42	22.0	103.5	15	3·3
234	27	06		02	15	12	21.8	103.4	15	3·9
235	27	06		02	43	31	21.9	103.6	15	3·6
236	27	06		11	18	16	21.9	103.8	10	4·1
237	27	06		13	38	27	21.6	103.4	5	4·2
238	27	06		14	54	32	21.3	103.5	5	3·3
239	27	06		15	44	25	21.4	103.4	5	4.7
240	27	06		20	11	07	21.8	103.5	2	3.4
241	27	06		20	54	36	21.7	103.4	1	3.7
242	28	06		02	38	32	21.7	103.5	2	4.0
243	28	06		07	12	19.3	21.4	103.4	2	3.2
244	28	06		11	19	09	28.4	103.5	10	3.3
245	28	06		20	35	04	21.6	103.4	15	3.7
246	28	06		22	23	07	21.5	103.5	10	3.4
247	29	06		13	13	21	21.2	103.3	5	3.6
248	30	06		01	31	01	21.5	103.5	2	3.0
249	30	06		16	44	06	21.2	103.5	5	3.9

Table 2 (continued)

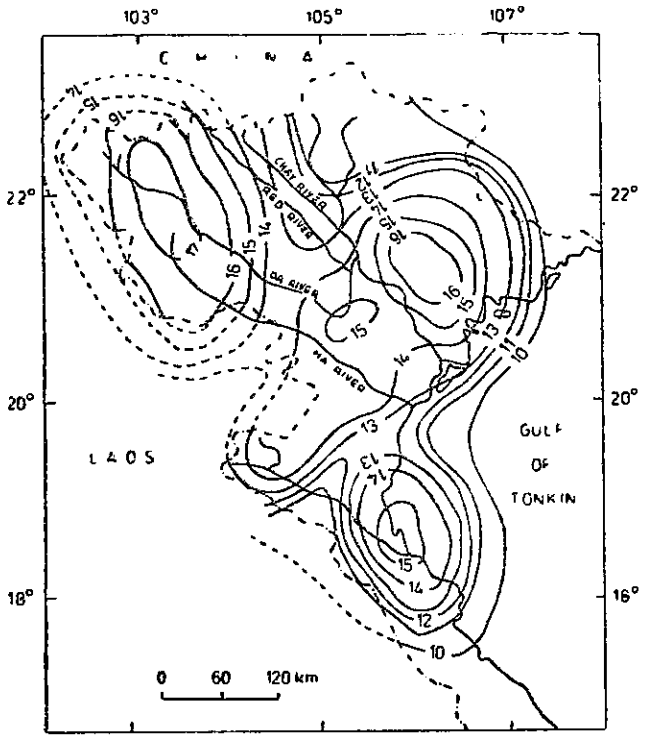
N°	Date			Origin time (GMT)			Epicentre		H	M
	D	M	Y	h	m	s	N	E	(km)	
250	02	07	1983	03	58	03	21.2	103.4	5	3.9
251	02	07		15	30	55	20.9	103.6	2	3.7
252	03	07		05	17	19	21.6	103.5	5	3.6
253	03	07		09	26	22	21.0	103.5	3	4.5
254	03	07		09	33	54	21.5	103.5	7	3.5
255	03	07		12	26	04	21.7	103.5	5	3.5
256	03	07		15	14	50	21.5	103.5	7	4.3
257	05	07		00	52	34	22.1	103.4	5	3.7
258	05	07		05	09	12	21.8	103.5	5	3.2
259	05	07		15	26	53	21.4	103.5	7	3.5
260	05	07		17	58	49	22.2	103.5	5	3.0
261	06	07		21	52	13	21.7	103.4	5	3.3
262	07	07		09	31	12	21.3	103.4	2	3.6
263	07	07		11	16	37	22.2	103.5	5	4.3
264	07	07		14	04	24	21.7	103.5	5	3.3
265	08	07		12	15	00	21.2	103.5	7	3.6
266	08	07		15	21	51	21.6	103.5	5	3.1
267	08	07		21	29	20	21.5	103.5	5	3.5
268	09	07		14	09	52	21.8	103.4	10	3.1
269	11	07		10	32	02	22.2	103.5	5	4.3
270	12	07		02	10	49	21.6	103.4	5	3.9
271	15	07		02	02	23	21.2	103.4	7	4.1
272	15	07		04	48	53	21.2	103.4	7	5.4
273	15	07		05	44	20	21.2	103.5	10	3.4
274	24	07		05	49	26	21.9	103.6	5	3.2
275	01	09		09	50	38	23.4	103.4	5	4.9
276	01	09		15	37	49	21.4	103.4	2	3.4
277	04	09		16	39	47	21.7	103.6	5	4.4
278	05	09		20	48	40	21.7	103.4	5	3.2
279	09	09		18	17	02	21.9	103.4	7	3.5
280	13	09		00	39	45	21.8	103.4	7	3.2
281	16	09		09	54	55	21.8	103.4	5	3.5
282	16	09		22	58	12	21.9	103.5	5	3.6
283	26	09		04	28	59	21.8	103.5	5	3.8
284	26	09		22	11	29	21.9	103.5	10	3.4
285	29	10		13	29	49	23.2	103.5	5	3.5
286	19	12		00	30	20	22.0	103.4	10	3.5
287	24	12		19	45	45	21.2	103.5	5	3.2
288	03	01	1984	13	17	05	21.3	103.4	7	3.4
289	04	01		22	00	34	22.9	103.4	7	3.3
290	10	01		16	57	57	18.4	103.9	7	3.5
291	14	01		09	39	43	19.6	104.3	5	3.5

Maximum expected earthquake

Knowledge of the maximum expected energy is of importance for the seismic zoning of the territory of Vietnam. To determine the maximum expected energy of earthquakes, the correlation between the possible earthquake with maximum energy class K_{max} and average seismic activity $\bar{A}$ was also used (Riznichenko 1964):

$$\log \bar{A} = \bar{2}.84 + 0.21(K_{max} - 15). \tag{9}$$

The map of expected origin zones was covered by a mesh $0.2° \times 0.2°$, and values of K_{max} were determined from each knot. A map K_{max} was computed using the programme by Zacharova (1972), Nuoi and Lap (1985). The maximum value of K_{max} is found in the northwest of Vietnam. The largest expected earthquake with $K_{max} = 17$ will take place only at the contact between the Dienbien-Laichau fault and the fault system of Sonla, River Da and of the River Ma. At the northeast of the Hanoi depression, earthquakes with $K_{max} = 16$ are considered as the possible maximum earthquakes. A zone of the River Ca has $K_{max} = 15$. The map of maximum expected earthquake in the north part of Vietnam is shown in fig. 6.



6. Map of maximum expected earthquake K_{max} in North Vietnam during the period from 1976 to 1984

The main characteristics of the Tuangiao earthquake

On June 24, 1983 at 07h 18m 22.3s an earthquake of magnitude M = 6.7 occurred near Tuangiao town in the mountainous Laichau province in northwest Vietnam. Its epicentre located by Vietnamese determination is $\varphi = 21.71$ °N, $\lambda = 103.43$ °E, H = 23 km (Xuyen–Lap 1985). It is the largest known earthquake that has taken place in the area. The Tuangiao earthquake caused considerable damage.

Aftershocks

. The main earthquake was followed by a number of aftershocks and field micro-earthquake survey conducted in May 1984 revealed quite a high level of micro-aftershock activity still in progress, eleven months after the occurrence of the Tuangiao earthquake. During the first 12 months after occurrence of earthquake in Tuangiao, 350 aftershocks of magnitude $M = 3 \div 5.4$ were recorded by Vietnamese stations: Tuyenquang, Bacgiang and Hoabinh. The largest aftershock with M = 5.4 occurred later in sequence, on July 15, 1983 at 04h 48m 52.6s, three weeks after the main shock. The length of aftershock zone is 100 km, and the width is 20 km. The hypocenters were located at a depth of 3 to 20 km. A preliminary investigation indicated that the earlier aftershocks were attached to the north-western end of the surface rupture, and later they moved to the central and south-eastern part of the fault. The aftershocks might be subdivided into two groups. The first group was located near the main shock hypocenter, in the central part of the fault zone. The second group was located near the margin of the fault zone with depth $H = 3 \div 10$ km (Lap 1985; Xuyen–Lap 1985).

The magnitude-frequency relation of aftershocks of the Tuangiao earthquake is given by the expression:

$$\log N_\Sigma = 4.1 - 0.71\, M. \tag{10}$$

The value of the coefficient b = 0.71 ($\gamma = 0.39$) shows that the aftershocks occurred in a relatively homogeneous and tectonically symmetric medium (Gibowicz 1985). The maximum expected magnitude $M_{max,a}$ of aftershocks sequence, expressed by the relation:

$$M_{max,a} = \frac{a}{b} = 5.7 \tag{11}$$

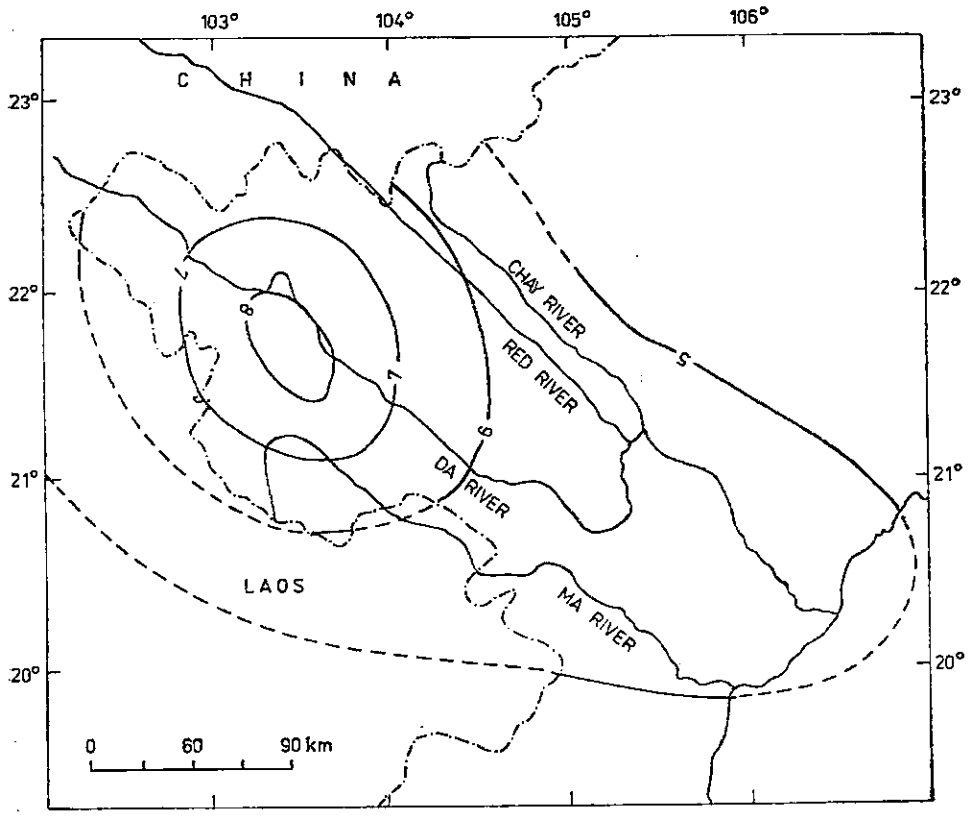
is close to the maximum observed magnitude $M_{max,a} = 5.4$.

The aftershocks activity is indicated by the ratio of energies released by aftershocks (E_a) and the main shock (E_0) (Bracinac 1976). The total energy of the aftershocks is $E_a = 2.854 \cdot 10^{14}$ Joules and the energy of the main shock is $E_0 = 1 \cdot 10^{16}$ Joules. So, the total energy of aftershocks represents 3 % of the energy of the main shock.

Microaftershocks

In May 1984 a Joint Polish-Vietnamese field expedition was organized to the mountainous epicentral area to study the microaftershocks of the Tuangiao earthquake (Gibowicz 1985). Three portable seismic stations were operated at Bancang, Tuangiao and Phadin. The stations were equipped with Portacorder RV-320 ink-recording systems manufactured by Teledyne Geotech, and with Soviet SM-3 seismometers. Altogether over 250 small aftershocks were recorded, but only 22 events were located. They occurred either at the southeast end of the surface rupture or further away in the southeast direction. Their depth could roughly be estimated as very shallow, between 1 and 7 km. The largest magnitude of microaftershock is 2.9. The frequency-magnitude relation was calculated by the maximum likelihood method and is given by the expression (Gibowicz 1985):

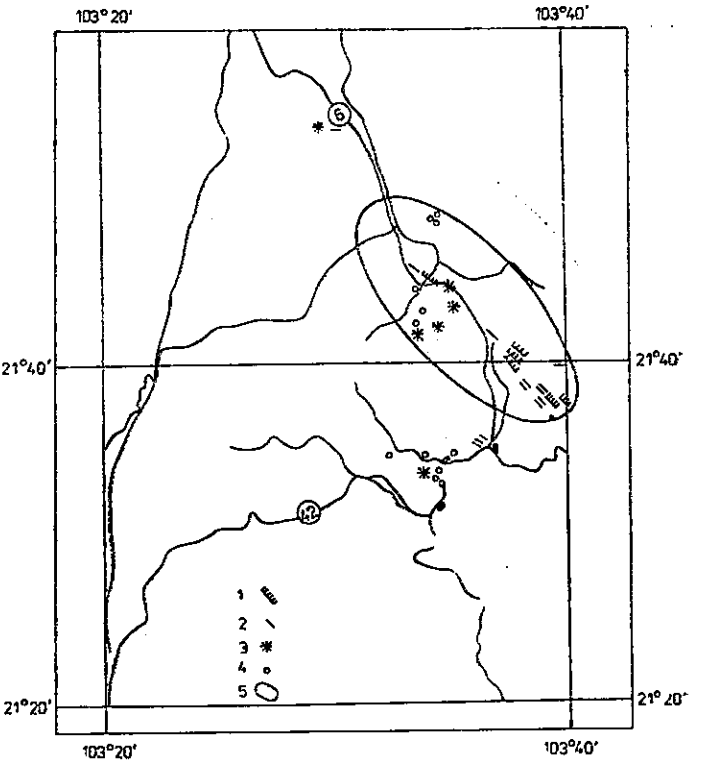
$$\log N = 2.42 - 0.83\,M. \tag{12}$$



7. Isoseismal map – MSK scale (1964 – version) of the Tuangiao earthquake

Effects of the Tuangiao earthquake

Using the MSK-64 scale, effects of the Tuangiao earthquake on the considered region were drawn in the form of isoseismal contour lines around their epicentre (fig. 7). A map of isoseismals of an intensity from V to VIII on the MSK-64 macroseismic scale was elaborated (Xuyen and Lap 1985). The maximum intensity VIII was felt up to a distance of 25 km from the centre of the elongated isoseismal and intensity was felt up to a distance of 350 km. The earthquake was associated with a surface rupture, a fresh surface rupture was found and mapped along the 23 km long segment of the Sonla fault, striking N 130 °E, with a horizontal displacement of about 16 cm, corresponding to right-lateral motion (fig. 8).



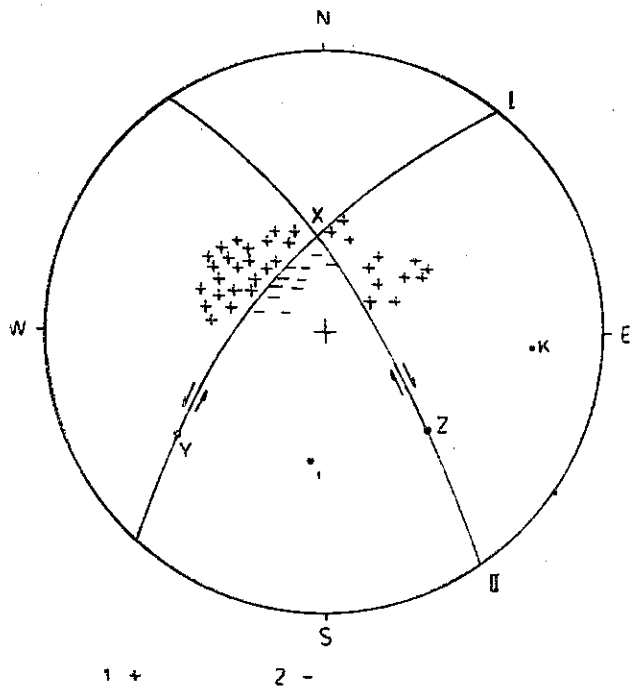
8. Scheme of surface deformations in Tuangiao
1 — Observed fault traces of Tuangiao earthquake with length larger than 100 m, *2* — Observed fault traces of Tuangiao earthquake with length over 10 m, *3* — Thunder — like booming noises, *4* — The wells observed immediately after the Tuangiao earthquake, *5* — Boundary of the area of the surface deformation; 6 and 42 are the road numbers

The variations in groundwater level for wells located in the Laichau district were observed, well-water level had a tendency to lower to 0.5 m until the occurrence of the Tuangiao earthquake, after which it recovered. The unusual behaviour of fish, dogs, rats, snakes, cats, boa reached its climax in the two days immediately before the Tuangiao earthquake. This is very interesting and may be of use in forecasting the time of earthquakes.

Source parameters

In order to determine the focal mechanism, we used the method of A. V. Vvedenskaia (1969). The first motion data were obtained from the seismograph station network of the USSR, Vietnam and contributing stations of neighbouring countries. The focal mechanisms of the Tuangiao earthquakes are shown in fig. 9. The distribution of compression and dilatation of the main shock and aftershock shows focal mechanism:

Focal mechanism of the main shock (fig. 9a): A strike-slip mechanism with a NE–SW striking nodal plane (1) dipping 60° towards NNW (azimuth 313°) with oblique sinistral lateral slip (slip vector az/dip: 224°/18°) and NW–SE striking plane (2) dipping 72° towards NE (az: 54°) with oblique dextral lateral slip (slip vector: 133°/30°). The compression axis (i) dips 35° towards S (az: 187°). The dilatation axis (K) dips 16° towards E (az: 93°) (Lap 1985).

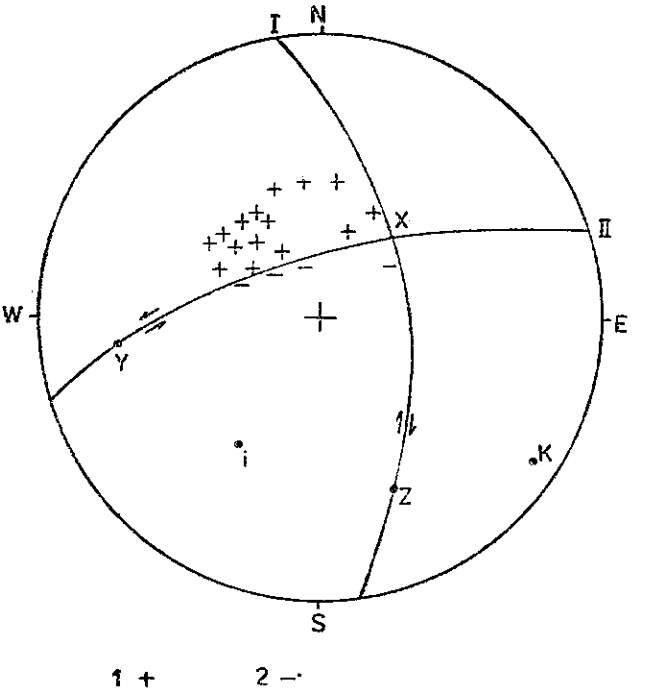


9a. Focal mechanism from P-wave first motion data shown on an equal-area lower hemisphere projection of the Tuangiao earthquake (June 24, 1983)
1 – compression,
2 – dilatation

Focal mechanism of aftershock (July 15, 1983) (fig. 9b): One of the planes (1) dips to the E (az/dip: 82°/72°), the other (2) to the NW (342°/64°). i – axis (i): 213°/21°, K – axis (K): 123°/6° (Lap 1985).

Focal mechanism of microaftershocks: A tentative composite fault – plane solution from the first-motion data of 21 microaftershocks was determined. It

indicates right – lateral strike – slip motion with a distinct normal faulting component on a fault dipping at 50° and striking at 314°, with the pressure axis plunging at about 40°. Such a mechanism could be explained by the locking of the northwestern end of the fault, where no microaftershocks were located (Gibowicz 1985).



9b. Focal mechanism from P-wave first motion data shown on equal-area lower hemisphere projection of the aftershocks of Tuangiao earthquake (July 15, 1983)
1 – compression,
2 – dilatation

The Tuangiao earthquake source is characterized by the following overall parameters: the static seismic moment $M_0 = 3.5 \cdot 10^{25}$ dyne . cm, fault length $L = 23$ km, fault width $W = 25$ km, process time $\tau_0 = 12$ s, rupture velocity $V_r = 2$ km/s; average displacement $D_0 = 28$ cm, stress drop $\Delta\sigma = 11$ bars, dynamic stress drop $\Delta\sigma_d = 7$ bars and apparent stress $\sigma_{ap} = 2$ bars. A multiple unilateral rupture, composed of two subevents, moving horizontally in the southeast direction from the epicenter along a vertical square section of the right – lateral Sonla fault seems to be a reasonable model of the source processes, deduced from the available field and seismological evidence (Gibowicz 1985).

Conclusions

From the investigation of earthquake activity in the north part of Vietnam, the following conclusions can be derived:

– The territory of the north part of Vietnam is seismically active. During the last

9 years, about 1 000 earthquakes have occurred in this region, including the large Tuangiao earthquake.

- The earthquake density is higher in northwestern Vietnam, almost all hypocenters in this region were in the Earth's crust.
- The earthquakes in the north part of Vietnam are related to the tectonic faults and geological structures in the northwest–southeast directions.
- The maximum expected values of $A_{10} = 0.2 \div 0.5$ and $K_{max} = 17$ are found in the northwest Vietnam.
- The Tuangiao earthquake of magnitude $M = 6.7$ occurred along the Sonla fault and caused considerable damage. The shock was associated with a surface rupture and aftershocks.

Acknowledgements

The author wishes to thank Dr. K. Cidlinsky for reading the manuscript critically and for providing useful suggestions.

K tisku doporučil V. Schenk

Přeložila D. Maliková

References

Bracinac, Z. et al. (1976): Seismological characteristics of the Rudnik area according to the analysis of aftershocks of the earthquake of 15 May 1927. – Proceedings of the seminar on seismic zoning maps, 27 October–4 November 1975. Skopje.

Gorbunova, I. V. (1964): Mapping of seismic activity with a constant accuracy. (In Russian.) – Trudy Inst. Fiziki Zemli, Akad. Nauk USSR, 32, *40–47*. Moscow.

Gibowicz, S. J.–Thuc, P. V. (1985): Source study of the Tuangiao Vietnam earthquake of June 24, 1983. – Acta geophys. pol. 33, *85–100*. Warszawa.

Lap N. K. (1983): Seismic regime and strain field in South-East of Asia. (In Vietnamese.) – Contu. Centre Geophys. Res. Vietnam, *60–75*. Hanoi.

– (1985): Seismicity of the territory of Vietnam and the neighbourhood (1981–1984). (In Vietnamese.) – Contr. Centre Geophys. Res. Vietnam, 4, *15–25*. Hanoi.

– (1985): Focal mechanism of Tuangiao earthquake. (In Vietnamese.) – Scientific report of NCSR of SRV, 1. *15–22*. Hanoi.

– (1985): Aftershocks of Tuangiao earthquake. (In Vietnamese.) – Scientific report of NCSR of SRV, 2. *90–97*. Hanoi.

– (1986): Seismicity of the territory of Laos. (In Vietnamese.) – Contr. Centre Geophys. Res. Vietnam, 5, (1985–1986), 80–97. Hanoi.

Nuoi, N. D.–Lap, N. K. (1985): Computation of parameters A_{10} and K_{max}. (In Vietnamese.) – Seminar on Geophysics. 20–21 December 1985. *15–22*. Hanoi.

Riznichenko, Yu. V. (1960): Methods of detailed study of seismicity. (In Russian.) Moscow.

– (1964): On relation between the energy of maximum earthquakes and seismic activity. (In Russian.) – Izv. Akad. Nauk USSR, Fiz. Zemli, 7, *869–877*. Moscow.

– (1974): Crustal seismic activity and maximum expected earthquakes in the Carpathian – Balkan region. (In Russian.) Regionalnye issledovanie seismicheskogo rezhima. Stinta, Kishinev.

Thuc, P. V.–Lap, N. K. (1979): Some properties of the seismicity in the North part of Vietnam from instrumental data. (In Vietnamese.) – Contr. Inst. Earth Sci., Geophysics, *32–45*. Hanoi.

– (1981): Seismicity of South-East Asia. – Acta geophys. pol., XIX, *63–73*. Warszawa.

Thuc, P. V.–Luong, N. V.–Yem, N. L. (1979): Seismological magnitude scale in Vietnam. (In Vietnamese.) – Contr. Centre Geophys. Res. Vietnam. *64–78*. Hanoi.

Xuyen, N. D. (1972): Seismological magnitude scale for local earthquakes in Vietnam. (In Vietnamese.) – Biology and Earth Sci., X. *10–16*. Hanoi.

Xuyen, N. D.–Lap, N. K. (1985): The Tuangiao earthquake, June 24, 1983. (In Vietnamese.) – Contr. Centre Geophys. Res., IV, *61–72*. Hanoi.

Zacharova, A. J. (1974): Computation of parameters of seismic regime. (In Russian.) – FAN. Tashkent.

Activité des tremblements de terre dans le Nord du Viêt-Nam pendant la période de 1976—1984

(*Résumé du texte anglais*)

Nguyen Kim Lap

Présenté le 4 mai 1987

Le territoire de la partie Nord du Viêt-Nam est situé à la proximité des deux zones de tremblements de terre les plus fortes du monde: celle de la Méditerranée et celle de l'Océan pacifique occidental. Les dates séismiques montrent de lourdes pertes en vies humaines et en biens causées par de grands tremblements de terre dans la partie Nord du Viêt-Nam. Pendant la période 1976—1984 on a observé dans cette région 800 tremblements de terre à peu près, y compris un immense tremblement de terre à Tuangiao ($M = 6,7$ et $I_0 = 8 \div 9$). Les tremblements de terre sont situés le long de grandes failles comme suit: rivière Rouge, rivière Chay, Dien Bien-Lai Chau, Son La, rivière Ma, rivière Da, rivière Ca et le Nord-Est de la plaine de Hanoi. La densité des tremblements de terre est la plus importante au Nord-Ouest du Viêt-Nam, leur fréquence est relativement basse dans la partie du Sud de la région récherchée. On considère que tous les focus du tremblement de terre se trouvent dans la croûte terrestre à une profondeur de moins de 40 km. La loi de la fréquence de tremblements de terre est exprimée par la rélation: $\log N = 2,27 - 0,38\,K$. L'activité séismique A_{10} (le nombre moyen de tremblements de terre de l'échelle d'énergie $K = 10$ se déroulant dans l'unité spatiale de temps) dans la partie Nord du Viêt-Nam était de 0,01 à 0,5. Les valeurs maximales A_{10} étant égales à $0.1 \div 0,5$ furent observées au Nord-Ouest du Viêt-Nam où se croisent de différentes failles de profondeur, telles que Dien Bien-Lai Chau, Son La, rivières Da et Ma. Dans cette zone mentionnée s'est produit le plus grand tremblement de terre avec $I_0 = 8 \div 9$ (MSK-64). Dans le delta de la rivière Rouge on a déterminé la zone de l'activité séismique de $A_{10} = 0,02 \div 0,2$. Les zones plus basses $A_{10} = 0,05$ sont observées dans la faille de la rivière Ca. Le plus grand tremblement de terre attendu ($K_{max} = 17$) se déroulera justement au contact entre la faille de Dien Bien-Lai Chau et le système de la faille de Son La, des rivières Da et Ma. Comme les tremblements de terre maximaux sont prévus ceux au Nord-Est de la plaine de Hanoi ($K_{max} = 16$). Dans la zone de rivière Ca on attend un tremblement de terre maximal avec $K_{max} = 15$. Le 24 juin 1983 s'est produit le plus grand tremblement de terre à la proximité de la région Tuangiao

($\varphi = 21{,}71°$ N, $\lambda = 103{,}43°$ E, H = 23 km). Le tremblement de terre à Tuangiao est arrivé le long de faille de Son La. La solution de la faille plane montre un mouvement du côté droit sur la faille presque verticale passant sous l'angle de 140° ± 10°. L'intensité maximale (8 ÷ 9) s'est abaissée à la distance de 25 km du centre de l'isoséisme prolongé et l'intensité s'est abaissée à la distance de 350 km. Le tremblement de terre à Tuangiao a eu lieu près de la surface, on a constaté et dressé la carte de certaines ruptures fraîches le long du segment de faille Son La à la longueur de 23 km passant sous l'angle de 130°, au déplacement horizontal de 16 cm à peu près. On a observé la variation du niveau de la nappe aquifère dans un puits de la région de Lai Chau; le niveau d'eau dans le puits avait la tendance d'être plus bas avant le tremblement de terre à Tuangiao, après lequel il est remonté. On constate de même certains symptômes caractéristiques en ce qui concerne le comportement des animaux avant le tremblement de terre. La plupart des animaux se trouvant dans la zone séismique deviennent très inquiets, plusieurs d'entre eux sentant une grande angoisse. L'endommagement total causé par le tremblement de terre à Tuangiao présente 30 millions de dongs viêtnamiens. La détérioration de si grande importance avait des influences néfastes sur l'économie dans plusieurs régions de la partie Nord du Viêt-Nam.

Přeložila P. Kellnerová

Légendes des tableaux

Tableau 1. Liste des stations séismiques dans la partie de Nord du Viêt-Nam.
Tableau 2. Liste des tremblements de terre avec M ≥ 3.0 qui se sont produits dans la partie du Nord du Viêt-Nam pendant la période des années 1976–1984.

Légendes des figures

1. Stations séismographiques au Viêt-Nam; les points plains représentent les stations séismiques permanentes. Le triangle ouvert montre les stations proposées pour l'avenir.
2. Distribution des épicentres des tremblements de terre au Viêt-Nam du Nord pendant le période des années 1976–1984.
   Magnitude: 1. M < 3; 2. M = 3÷4; 3. M = 4,1÷5,0; 4. M ≥ 5,1.
3. Relaxation cumulative de la tension pour les tremblements de terre du Viêt-Nam du Nord pendant la période des années 1976–1984.
4. Graphe des tremblements de terre répétés au Viêt-Nam du Nord au cours de la période 1976–1984.
5. Carte de l'activité séismique A_{10} au Viêt-Nam du Nord dans les années 1976–1984.
6. Carte du tremblement de terre maximal K_{max} attendu au Viêt-Nam du Nord pour les années 1976–1984.
7. Carte isoséismique – l'échelle MSK (1964 – version) du tremblement de terre à Tuangiao.
8. Schème des déformations de surface à Tuangiao.
   1-les traces observées des failles du tremblement de terre de Tuangiao étant plus longues que 100 m, *2* – les traces observées des failles du tremblement de terre de Tuangiao étant

plus longues que 10 m, *3* – l'orage – comme le bruit croissant, *4* – les trous observées immédiatement après le tremblement de terre à Tuangiao, *5* – les bornes de surface des déformations superficielles; *6* et 42 – le numéro de la route.

9a. Mécanisme de focus des données du premier mouvement de la vague P montré sur la projection de l'hémisphère inférieure à la conservation de surface du tremblement de terre à Tuangiao (le 24 juin 1983).
1 – compression, *2* – dilatation.

9b. Mécanisme de focus des données du premier mouvement de la vague P montré sur la projection de l'hémisphère inférieure à la conservation de surface au cours des chocs suivants aprés le tremblement de terre à Tuangiao (le 15 juillet 1983).
1 – compression, *2* – dilatation.

Активность землетрясений в северной части Социалистической Республики Вьетнам за 1976—1984 гг.

В представленной работе составлен каталог землетрясений в северном Вьетнаме за 1976 до 1984 гг., магнитуда которых превышала $M \geq 3{,}0$. Для северо-западной части страны характерно землетрясение Туанзао ($M = 6{,}7$), происшедшее на глубине 30 км в глубинном разломе Шонла, простирающемся в с.-з. направлении. Качественное изучение активности землетрясений занималось пространственным распределением землетрясений, сейсмической активностью A_{10}, максимумом возможных землетрясений K_{max} и основными характеристиками землетрясения Туанзао.

Přeložil A. Kříž