ON THE GANSU-QINGHAI-SICHUAN SEISMO-GENETIC BLOCK AND THE CHARACTERISTICS OF ITS EARTHQUAKE ACTIVITIES

YAN ZHIDE (阎志德) AND GUO LÜCAN (郭履灿)
(Institute of Geophysics, State Seismological Bureau, Beijing)

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I. INTRODUCTION

In the recent 20 years, research on plate tectonics has shown that large earthquakes are closely related with plate boundaries, revealing some regularities of earthquake occurrences, particularly in oceanic and continental boundary regions. On further researches, more miniplates have been divided by some investigators, such as for some intracontinental plates. The terms subplates[1] or brewing separation plate boundaries[2] have been given. We have discussed the features of seismic activities along the subplate boundaries, and suggested the supplementary criteria for dividing subplate boundaries[1]. Many subplates within a continent are usually seismo-genetic blocks.

The characteristics of earthquake activities in space distribution are seismic gaps, seismic belts, seismic grids, and seismic blocks which have been noticed recently. The present paper deals with the peculiarities of some earthquakes with $M \geqslant 6$ in the Gansu-Qinghai-Sichuan region, analyzes the block nature of the strong earthquakes in space distribution, and identifies the "Gansu-Qinghai-Sichuan seismo-genetic block" from geological backgrounds. As the strong earthquakes occurred generally in the marginal and corner areas of the seismo-genetic block, the paper also discusses the mobility of the earthquakes in the boundary areas of the block, and the corresponding and alternate features of earthquakes at both sides of the block in different periods. It concludes that the stability of this seismo-genetic block is adjusted by the strong shocks in the marginal areas of the block, and subsequently points out the seismic risk of the marginal areas of this seismo-genetic block.

II. THE "GANSU-QINGHAI-SICHUAN SEISMO-GENETIC BLOCK"

In 1974 Guo Zengjian divided the Chinese mainland into 9 great blocks, and based on the distributions of great earthquakes of $M \geqslant 7$ and their directions of magistoseismic areas, the extensions of large fractures and dislocations of source regions obtained from seismic waves, he further divided the complicated Qinghai-Xizang Plateau into the south and north blocks. The north block being the seismo-genetic block we are going to deal with.

The northwest edge of this block, coinciding with the northwest of the Plateau,

ranges from the epicenters of the two earthquakes of M=7$\frac{1}{4}$ which occurred in 1924 at east of Minfeng, Xinjiang in the west; to the epicenter of the earthquake of M=7$\frac{1}{2}$ (1932) at Changma, Gansu in the east, including the west section of NEE Altun fracture zone which is from Minfeng to Changma. Besides the above-mentioned 3 large earthquakes there also occurred nearby the boundary and the Altun fracture zone the earthquake of M=6$\frac{3}{4}$ in southwest Ruoqiang, Xinjiang (1933), the earthquake of M=6 in east Subei, Gansu (1951), the shock of M=6 in Aqqikkol Lake, Xinjiang (1966), and the earthquake of M=6.4 between Xinjiang and Qinghai (1977).

The northeast edge of this block extends from the epicenter of the Changma earthquake (1932) in the west; to the epicenter of the Haiyuan great earthquake (1920) in the east, its boundary crosses the two magistoseismic areas of the Haiyuan (1920) and Gulang (1927) great earthquakes of M$\geqslant$8, and the margins of the two magistoseismic areas of the Changma (1932) and Shandan (1954) shocks of M $>$ 7. The strike of the block boundary is in full agreement with the orientations of the magistoseismic areas of four large shocks of M$>$7, as well as with the direction of the fracture zone of the Qilian Mts connecting westwards with the Altun fracture zone. The Yumen earthquake of M=6 (1785), the Changma shock of M=6$\frac{1}{2}$ (1832), the Harahu earthquakes of M=6$\frac{1}{2}$ (1930) and M=6 (1941) all occurred in or near this block boundary and the fracture zone of the Qilian Mts and other nearby fracture zones.

The southeast boundary of this block begins from the magistoseismic area of the great Haiyuan earthquake, in the SSW direction, through the magistoseismic areas of three large shocks of M=7$\frac{1}{2}$ which occurred respectively in Tianshui in 1654, in Wudu in 1879 and in Maowen, Sichuan Province, in 1933, crossing the epicentral areas of the Songpan and Pingwu large shocks of M=7.2 (1976), to the epicentral area of the Kangding earthquake of M=7$\frac{1}{2}$ (1955). This boundary is consistent with the Longmenshan fracture zone, and also is the boundary of "Southeast China-Indonesia Plate"[1], situated in the Central-China seismic zone. Therefore the Longmenshan fracture zone and its nearby areas were the site of several strong earthquakes of M$\geqslant$6 in history, and so far still remains a zone of strong seismic activities.

The southwest boundary of this block starts from the Xianshuihe fracture zone, cutting the magistoseismic areas of the Kangding (1786) and Luhuo (1923 and 1973) earthquakes of M$\geqslant$7, extending northwestwards to the epicentral area of the Darlag earthquake of M=7$\frac{3}{4}$ in Qinghai Province, and finally connects with the epicentral areas of the great Alamhu earthquakes of M$\geqslant$7 (1937 and 1963) in Qinghai Province. From the earthquake data, it is seen that the strong seismic activities are mainly distributed over the southern and central sections of the Xianshuihe fracture zone. The section from

Garze to Kangding is the most intense tectonic activity region in west Sichuan Province, with high seismic recurrence rate and large earthquake potential. Strong earthquakes of $M \geqslant 6$ have generally a belt-like distribution over the Xianshuihe fracture zone, a visible boundary of the block.

The west boundary of the block extends from the epicentral areas of the 1937 Alamhu shocks of $M \geqslant 7$ (1937 and 1963) to the epicentral areas of two large Minfeng earthquakes of $M=7\frac{1}{4}$ in Xinjiang, then westwardly from the Xianshuihe fracture zone to the north edge of Kunlun Mts. Although there are no historical earthquake records for this section, four recent earthquakes of M=6 (1952, 1959, 1962 and 1966) all took place on both sides of the boundary.

The "Gansu-Qinghai-Sichuan seismo-genetic block" with a total area of 870,000 km^2 has been identified and plotted in Fig. 1, based on the comprehensive analyses of supplementary criteria for dividing subplate boundaries, proposed in line with the divisions of the global tectonic plate using the seismological data together with geological evidences[1].

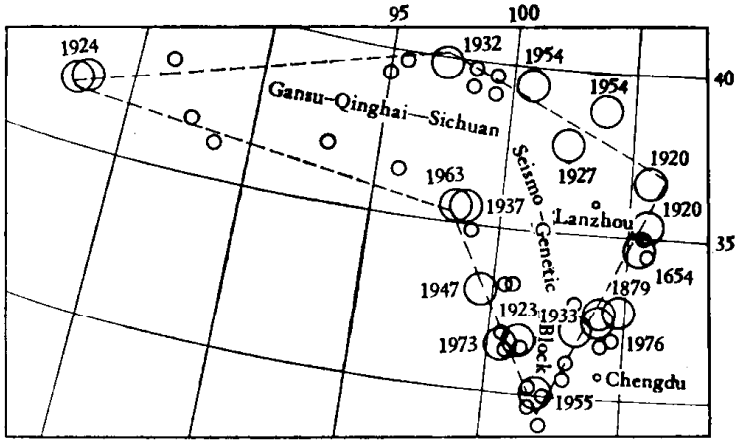


Fig. 1. The distributions of the strong earthquakes with $M \geqslant 6$ and the large ones with $M \geqslant 7$ in the "Gansu-Qinghai-Sichuan seismo-genetic block" and its surrounding areas.

III. The Characteristics of the Earthquake Activities Around the Block

Historical and recent distributions of the strong earthquakes of $M \geqslant 6$ and $M \geqslant 7$ around the block are shown in Fig. 1. About 20 great shocks of $M \geqslant 7$ all occurred in the marginal and corner areas of the block, and those of $M \geqslant 6$ were also distributed here except the three shocks taking place in 1929, 1930 and 1938 in the central area of this block.

1. *The Correspondence and Alternate Phenomena of Earthquake Occurrences*

Nine periods can be roughly divided, beginning from 1919, in accordance to the periodical studies of the strong earthquakes of $M \geqslant 6$ around the block. They are: 1919—1923, 1924—1930, 1932—1935, 1936—1937, 1938—1941, 1947—1952, 1954—1955, 1958—1966 and 1967—1976. It is apparent that the earthquakes of $M \geqslant 6$ within each of these

periods were all located on both sides of the block, and occurred correspondingly and alternately. Taking for example the two recent periods of 1958—1966 and 1967—1976, 6 earthquakes of $M \geqslant 6$ occurred correspondingly at the southeast and west boundaries in the period of 1958—1966, and 9 earthquakes of $M \geqslant 6$ also took place alternately on the southeast and southwest boundaries in the period of 1967—1976. This is also the case for several other historical periods. Tracing back from 1919 to 1654, 3 periods can be identified, and similar phenomena also existed, only with longer time span.

2. *The Direction and Migration of Earthquake Activities*

(1) At the northwest boundary of the block and nearby the Altunshan fracture zone, two great shocks of $M>7$ in Minfeng, Xinjiang in 1924 were followed by a shock of $M=7\frac{1}{2}$ in 1932 in Changma, Gansu, the intersection of the other end of the Altunshan fracture zone and the Qilianshan fracture zone. It showed that the earthquakes were moving in NEE direction along the Altunshan fracture zone. Another group of earthquakes also exhibited a remarkable linear mobility; the earthquake of $M=6\frac{3}{4}$ (1933) in southwest Ruoqiang, Xinjiang, was followed by the earthquake of $M=5\frac{1}{2}$ (1935) in Suganhu, Qinghai and three other earthquakes of $M=5\frac{1}{2}-6$(1951—1952) nearby Subei, Gansu. Because of the relatively low frequency of seismic activities in the northwest boundary of this block and nearby the Altunshan fracture zone of west China, as the seismic swarms with small magnitudes in 1966—1979 were taken into consideration, the earthquakes started from Aqqikkolhu, Xinjiang (M=6, 1966) to migrate along the fracture zone, the boundary and their vicinities.

(2) Along the northeast boundary of the block and the Qilianshan fracture zone, the shocks seemed to migrate from the Haiyuan shock of $M=8\frac{1}{2}$ (1920), the Gulang earthquake of M=8 (1927), the Harhu earthquake of $M=6\frac{1}{2}$ (1930), to the Changma earthquake of $M=7\frac{1}{2}$ (1932).

(3) Along the southeast boundary and the Longmenshan fracture zone, the seismic mobility markedly appeared, as the great Haiyuan earthquake was succeeded by the Jingyuan shock of M=7 and the Jingning shock of $M=6\frac{1}{4}$. Meanwhile, according to the historical seismic records, a linear migration was very distinct along the boundary and the fracture zone, as the Guyuan earthquake of M=7 (1622) in Ningxia followed by the Tianshui shock of $M=7\frac{1}{2}$ (1654), the Wenchuan shock of M=6 (1657) in Sichuan, and the Diexi shock of $M=6\frac{1}{2}$ (1713) in Sichuan Province. Based on recent earthquake activities, the earthquake frequency is very high in this region, the migration feature is even more significant, when the earthquakes with smaller magnitudes were taken into

account.

(4) Along the southwest boundary and the Xianshuihe fracture zone, earthquake activities appeared to migrate orderly, from the Alamhu shock of M=7 (1963) in Qinghai, to the Xianshuihu fracture zone, and from the Luhuo shock of M=6.8 (1967), the Dulan shock of M=6.8 (1971), and the Luhuo earthquake of M=7.9 (1973) to the Kangding earthquake of M=6.2 (1975).

(5) In the west boundary of the block and marginal areas of Kunlun Mts, small earthquakes were not fully observed due to few seismic recording stations, mobility cannot be examined within smaller magnitude earthquakes. However, from the several strong earthquakes recorded recently, the migration appeared in the seismic activities as controlled by tectonic backgrounds. The Haramlunshankou earthquake of M=6 (1959) in Xizang was followed by the north Hubuxunhu earthquake of M=6.8 (1962), then the Alamhu shock of M=7 (1963) in Qinghai, the west Aqqikkolhu shock of M=6 (1966) in Xinjiang and the Dulan shock of M=6.8 (1971) in Qinghai, all along the margin of Kunlunshan and the west boundary of this block.

IV. Discussion on the Seismic Risk Probability of the Gansu-Qinghai-Sichuan Seismic-Genetic Block

From analysis of the characteristics of the seismic activities in this block, it may be preliminarily suggested that the seismic activities in the Gansu-Qinghai-Sichuan region seem to be controlled by the seismogenetic-block. The correspondence and alternate phenomena of earthquake occurrences in the marginal sides of the block have presented that stability of the block is adjusted by strong earthquakes which occur correspondingly and alternately. Mobility of the earthquakes along the block boundaries has elucidated that the spatial distributions of earthquakes along the block boundaries are closely related with the tectonic faults on the block boundaries. Around the block boundaries and in the side and corner areas of the block, strong earthquakes will perhaps be seen in the future due to differences between the geological faults in the different boundaries of the block.

Table 1

The Frequency of the Time Intervals for Two Successive Earthquakes of M≥6

Number of Shocks \ Time	Month		Year			
	3	5—8	1—2	3—4	5—6	≥10
n	5	8	17	7	4	9

Table 1 shows the statistics of time intervals for the two successive shocks of M≥6 around the Gansu-Qinghai-Sichuan seismo-genetic block. Due to absence of historical earthquake records and seismic network before 1919, there might possibly be some omissions of strong earthquakes of M≤6 in the west boundary of the block. The time interval for the two successive shocks of M≥6 can be seen from Table 1, and there were 17 shocks within the 1—2-year period which was the predominant interval for earth-

Table 2

Catalogue of Recent Earthquakes of M≥6 in the Marginal Areas of the Gansu-Qinghai-Sichuan Seismo-genetic Block

Period	Occurrence Time	φ°,N	λ°,E	M	Region
1	1919.5.29	31.5	100.5	$6\frac{1}{4}$	Luhuo, Sichuan
	1919.8.26	32.0	100.0	$6\frac{1}{4}$	Garze, Sichuan
	1920.12.16	36.5	105.7	$8\frac{1}{2}$	Haiyuan, Ningxia
	1920.12.25	35.6	106.3	7	Jingyuan, Ningxia
	1923.3.24	31.3	100.8	$7\frac{1}{4}$	Luhuo, Sichuan
	1923.6.14	31.0	101.0	$6\frac{1}{2}$	Dawu, Sichuan
2	1924.7.3	36.8	83.8	$7\frac{1}{4}$	Eastern Minfeng, Xinjiang
	1924.7.12	37.1	83.6	$7\frac{1}{4}$	Eastern Minfeng, Xinjiang
	1927.5.23	37.6	102.6	8	Gulang, Gansu
	1930.7.14	38.1	98.2	$6\frac{1}{2}$	Harahu, Qinghai
3	1932.3.6	30.1	101.8	6	Kangding, Sichuan
	1932.12.25	39.7	97.0	$7\frac{1}{2}$	Changma, Gansu
	1933.8.25	32.0	103.7	$7\frac{1}{2}$	Maowen, Sichuan
	1933.9.26	38.3	86.9	$6\frac{3}{4}$	Ruoqiang, Xinjiang
	1935.4.28	29.4	102.3	6	Luding-Shimian, Sichuan
4	1936.8.1	34.4	105.8	6	Southern Tianshui, Gansu
	1937.1.7	35.5	97.6	$7\frac{1}{2}$	Dulan, Qinghai
5	1938.3.14	32.3	103.6	6	Songpan, Sichuan
	1941.4.19	39.1	97.0	6	Harahu, Qinghai
	1941.6.12	30.1	102.5	6	Luding, Sichuan
	1941.10.8	32.1	103.3	6	Heishui-Songpan, Sichuan
6	1947.3.17	33.3	96.5	$7\frac{3}{4}$	Darlag, Qinghai
	1952.9.30	28.4	102.2	$6\frac{3}{4}$	Mianning, Sichuan
	1952.10.6	37.1	93.2	6	Wutumeiren, Qinghai
7	1954.2.11	39.0	101.3	$7\frac{1}{4}$	Shandan, Gansu
	1954.7.31	38.8	104.2	7	Minqin, Gansu
	1955.4.14	30.0	101.8	$7\frac{1}{2}$	Kangding, Sichuan
8	1958.2.8	31.5	104.0	6.2	Maowen, Sichuan
	1959.11.11	36.2	88.7	6	Haramlunshankou, Xizang
	1960.11.9	32°47′	103°40′	$6\frac{3}{4}$	Songpan, Sichuan
	1962.5.21	37.1	96.0	6.8	Huobuxunhu, Qinghai
	1963.4.19	35.5	97.6	7	Alamhu, Qinghai
	1966.10.14	36.8	87.5	6	Aqqikkolhu, Xinjiang
9	1967.8.30	31°37′	100°20′	6.8	Luhuo, Sichuan
	1970.2.24	30°26′	103°12′	6.2	Qionglai, Sichuan
	1971.3.24	35°27′	98°00′	6.8	Dulan, Qinghai
	1973.2.6	31.4	100.6	7.9	Luhuo, Sichuan
	1973.8.11	32°53′	104°00′	6.5	Lanping, Sichuan
	1975.1.15	29°27′	101°50′	6.2	Southern Kangding, Sichuan
	1976.8.16	32.7	104.2	7.2	Songpan, Sichuan
	1976.8.22	32.7	104.2	6.7	Songpan, Sichuan
	1976.8.23	32.5	104.2	7.2	Songpan, Sichuan

quakes. Taking into consideration the seismic patterns in different historical periods, the areas nearby the southeast boundary of the block, nearby the northwest boundary of the block and the Altunshan fracture zone, and nearby the southwest boundary of the block will be the most possible localities for the strong earthquakes of $M \geqslant 6$ in the future.

In Table 2, the catalogue of recent earthquakes of $M \geqslant 6$ in the marginal areas of the Gansu-Qinghai-Sichuan seismo-genetic block have been listed in time sequence of periods. It is apparent that earthquakes in each period occurred correspondingly and alternately on both sides of this block.

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