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STUDY ON SEISMIC ZONING OF CHINA-MONGOLIA ARC AREAS

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Abstract

According to the agreement of Cooperation on seismic zoning between Institute of Geophysics, China Earthquake Administration and Research Center of Astronomy and Geophysics, Mongolian Academy of Science, the data of geotectonics, active faults, seismicity and geophysical field were collected and analyzed, then field investigation proceeded for Bolnay Faults, Ar Hutul Faults and Gobi Altay Faults, and a uniform earthquake catalogue of Mongolia and North China were established for the seismic hazard study in China-Mongolia arc areas. Furthermore, the active faults and epicenters were mapped and 2 arc seismic belts, Bolnay-Baikal Seismic belt and Altay Seimsic Belt, and their 54 potential seismic sources are determined. Based on the data and results above mentioned the seismicity parameters, including b-value of G-R relations and annual average rate, v, for the two seismic belts and their potential sources were studied. Finally, the seismic zoning with different probability in China-Mongolia arc areas was carried out using China probabilistic hazard analysis method.

By analyzing the data and results, we draw the following conclusions. Firstly, the origin of tectonic stress field in the study area is the collision and pressure of the India Plate to Eurasian Plate, passing from the Qinghai-Tibet Plateau. This is the reason why the seismicity is higher in the west than in the east, and all of earthquakes with magnitude 8 or greater occurred in the west. Secondly, the determination of the 2 arc seismic belts are reasonable in terms of their geotectonic location, geodynamic origin and seismicity characteristics. Finally, there are some differences between our results and the Mongolia Intensity Zoning map published in 1985 in terms of shape of seismic zoning map, especially in the areas near Ulaanbaatar. We argue that our results are reasonable if we take into account the data use of recent study of active faults and their parameters, so it can be used as a reference for seismic design.

Keywords: seismic zoing, China-Mongolia arc areas, China probabilistic hazard analysis method

1. Introduction

China-Mongolia arc area is a giant arc tectonic zone located in the northern China and Mongolia. In terms of tectonic setting, it is a part of 'Paleo Asian Orogenic Belt', which had developed in Paleozoic in the Central Asian. China-Mongolia arc area is sandwiched between the two relatively stable continental block, ancient China continental blocks and the ancient Siberia continental block. Paleo Asian Orogenic Belt had been formed in Caledonian Age and reached its peak in Variscan Age. The tectonic and fault activities had been significantly weakened in Mesozoic, since Cenozoic, boundary faults between some large block had been active again, accompanied by a series of strong earthquakes, since the 20th century, there have been recorded several earthquakes with magnitude 8 [1-2].

According to the Agreement of Cooperation between Institute of Geophysics, China Earthquake Administration (IGP-CEA) and Research Center of Astronomy and Geophysics, Mongolian Academy of Science (RCAG-MAS), our study is for the seismic hazard analysis and zoning map of the China-Mongolia arc area. The studies on the seismic hazard of Mongolia before were mainly led by scientists of Russia, the United States, France and other developed countries under the frame of deterministic method or Cornell probabilistic seismic hazard analysis method [3-7]. Mongolia is closely connected with the mainland of China and the study area is located within Eurasia Plate, just like the mainland of China, and earthquakes in these areas are characterized by intraplate earthquakes, so China method of Probabilistic Seismic Hazard Analysis is used for our research on the study area. In this method, the potential sources are determined following two steps. Firstly, based on the distribution of recorded earthquakes, characteristics of geotetonics, neo-tectonic and geophysical field, seismic belts or seismic provinces are determined for seismicity statistics, then, according to the studies of seismotectonic and locations of large earthquakes, potential sources are determined within the seismic belts or seismic provinces (National standard of the people's Republic of China, GB17741-2005)[8].

2. Earthquake Catalog Establishment

According to the Agreement of Cooperation on Establishing the Uniform Earthquake Catalogue of North China, Mongolia and adjacent Areas, the earthquake catalogue of Mongolia and North China has been established for the seismic hazard study in these areas. The events are within the region 80-130° E, 40-55° N and with magnitude 3.5 or greater. The earthquake data are from the following three catalogs: earthquake catalog used in the mapping of China seismic zoning, catalog provided by Research Center of Astronomy and Geophysics, Mongolian Academy of Science (RCAG-MAS) and the global earthquake catalogue [9].

2.1 Data Source

The catalogue of China mainly comes from: Catalogue of China Historical Strong Earthquakes (23rd century B.C. to 1911 A.D.) [10], Catalogue of Chinese Modern Times Earthquakes (1912 A.D. to 1990 A.D. Ms≥4.7) [11] and Catalogue of China Earthquake Networks Center (1970 A.D. to 2012 A.D.).

The catalogue of Mongolia comes from the catalog (1902 A.D. to 2012 A.D.) provided by RCAG-MAS.

Earthquakes of adjacent areas of Mongolia with magnitude 4.5 or greater come from the global earthquake catalogue compiled by Song et al. [9].

2.2 Data Information

The information of catalogs from the three sources is shown in Table 1.

Table 1 - the Data Information

Data source	**Beginning and ending time (year)**	**M**	**Earthquake number**
catalog of China	19－2010	≥3.5	4916
catalog of Mongolia	1902-2010	≥3.5	3238

global catalog	19-2010	≥4.5	868

2.3 Catalog Compiling Method

If all of the above-mentioned three catalogs use the same world standard time and are compiled in chronological order, the following cases will appear. 1) Earthquakes, which just exist in one catalogue, need to be verified further. If the earthquakes occurred in the country where the catalog comes from, then they will be adopted. If not, it should be checked with other more data. For example, small events (maybe blasts), recorded by Mongolia catalogue, which occurred in Xinjiang Province of China but do not appear in China catalogue, should not be adopted. 2) Some events may exist in several catalogues, and their seismic parameters, such as location and magnitude, may be exactly the same, or partly the same, or completely different. Under this circumstance, they should be treated separately. The events whose parameters from different catalogues are exactly the same will be adopted with the parameters. The events whose parameters from different catalogs are different need further verification to ensure the selected parameters reasonable. 3) The events that come from the global catalogue [9] not only include the earthquakes that occurred in China or Mongolia, but also include the events that happened in the adjacent areas of the two countries.

The events that come from the three data sources have be checked and verified adopting the following principles to establish the uniform catalogue of the study area. (1) The parameters of earthquakes that occurred in China will be taken from China catalog. (2) The parameters of earthquakes that occurred in Mongolia will be taken from Mongolia catalog. (3) The parameters of earthquakes that occurred in the adjacent areas will be taken from the global catalog by Song et al.

According to the cataloging principles, the uniform catalogue of North China, Mongolia and adjacent areas has been established. From the year when the first event occurred to August, 2010, there were 7509 events with magnitude 3.5 or greater in the study area and the distribution of their magnitude is shown in table 2.

Table 2 - the distribution of magnitude

Magnitude	**3.5-3.9**	**4.0-4.4**	**4.5-4.9**	**5.0-5.4**	**5.5-5.9**	**6.0-6.4**	**6.5-6.9**	**7.0-7.4**	**7.5-7.9**	**≥8.0**
Number	4035	1847	857	398	198	87	55	18	8	6

3. Seismicity

3.1 The Spatial Characteristics of Earthquake Activities

Figure 1 is the epicenter distribution map of earthquakes in the study area. It shows that the epicenter map can be roughly divided into two parts, bounded by the longitude line 105°E , in accordance with the 'North-South Seismic Belt' in the mainland of China. The seismicity is in a high level with many strong earthquakes in the west and is in a low level with little strong events in the east. The strong earthquakes with Magnitude 7 or greater mainly occurred in the area of Lake Baikal, Sayan, Altai and Tianshan Mountains. There are rarely strong earthquakes in the east, except in the area around the latitude line 40°N, i.e. Yanshan seismic belts of China. Table 3 is the catalog of earthquakes with magnitude 7 or greater in the study area

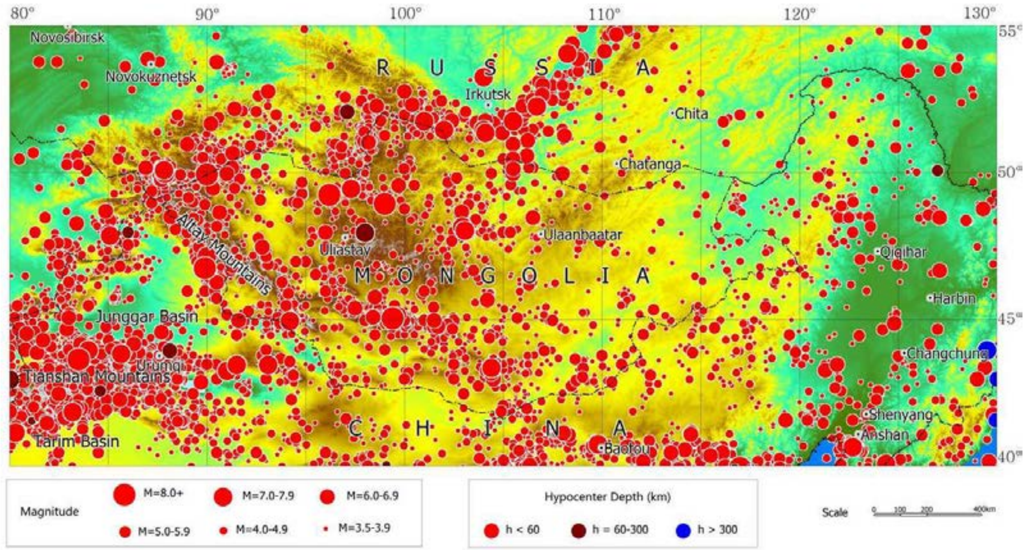

Fig. 1 - Earthquake Epicenter Distribution Map

Table 3 - Catalog of earthquakes with M≥7 in the study area

Date	**Time**	**Lat.**	**Log.**	**Depth**	**M_S**	**I_0**	**Epicenter**
8491024	00-00-00.0	40.8	109.8	0	7		Northwest of Baotou, Inner Mongolia
15000000	00-00-00.0	54.10	108.25	15	7	9	Lake Baikal region
16790902	00-00-00.0	40	117	0	8		Sanhe-Pinggu, Hebei, China
17160000	00-00-00.0	41.20	80.30	30	7.5	9	Aksu, Xinjiang, China
17420527	00-00-00.0	51.50	104.00	15	7.1		Russia : Irkutsk State
17420627	05-30-00.0	53.30	104.00	40	7.7	10	Russia: Buryatia State
17611209	17-20-00.0	50.00	90.00	30	8.3	10.5	Russia: Tangnutuwa State
17691024	13-00-00.0	51.80	105.50	40	7.3	10	Lake Baikal region
18120308	00-00-00.0	43.7	83.5	0	8	11	East of Nileke, Xinjiang, China
18290307	22-00-00.0	51.40	104.10	40	7.5	10	Russia : Irkutsk State
18390818	01-00-00.0	51.50	102.00	15	7.1		Russia: Buryatia State
18420611	00-00-00.0	43.5	93.1	0	7	9	Near Balikun, Xinjiang, China
18620112	07-19-00.0	52.30	106.70	40	7.5	10	Lake Baikal region
19030201	09-34-30	43.4	104.4	16	7.5	10	Mongolia
19030206	07-38-00	43.4	104.4	16	7		Mongolia
19050709	09-40-56	49.5	97.3	16	7.6	10	border area between Mongolia and Russia
19050711	08-38-00	49.5	97.3	16	7	9	border area between Mongolia and Russia

Date	Time	Lat.	Log.	Depth	M_S	I_0	Epicenter
19050723	02-47-00	49.3	96.2	17	8.2	11	border area between Mongolia and Russia
19061222	18-21-00.0	43.88	85.65	0	7.7	10	Southwest of Shawan, Xinjiang, China
19140804	22-41-36.0	43.50	91.50		7.5	>8	Balikun, Xinjiang, China
19310810	21-18-43.0	46.8	89.9	0	8	11	Near Fuyun, Xinjiang, China
19310818	14-21-04.0	47.2	90	0	7.3		Near Fuyun, Xinjiang, China
19440309	22-12-58.0	44	84	0	7.2	>8	Northeast of Xinyuan, Xinjiang, China
19460111	01-33-29.0	44	129.5	580	7.2		South of Ning'an, Heilongjiang, China
19490223	16-08-11.0	41.9	83.2	0	7.3	9	Northeast of Kuche, Xinjiang, China
19500404	18-44-14	51.8	101	16	7	9	border area between Mongolia and Russia
19571204	03-39-48	45.1	99.4	17	8.1	11	South of Lake Benchagan, Mongolia
19740704	19-30-39.0	45	94.2	33	7.1		Northeast of Balikun, Xinjiang, China
19750204	11-36-04.3	40.7	122.7	16	7.3	>9	Haicheng , Liaoning , China
19900614	12-47-27.9	47.9	85.09	57	7.2	8	Northwest of Jeminay, Xinjiang, China
20030927	11-33-24.7	50.02	87.87	16	7.7		border area among Russia, Mongolia and China
20031001	01-03-24.9	50.13	87.82	9	7.3		border area among Russia, Mongolia and China

Remarks: I_0 refers to epicenter intensity.

Table 3 shows that the biggest earthquake in the study area occurred in Tangnutuwa State of Russia with magnitude 8.3 and the deepest earthquake occurred in south of Ning' an, Heilongjiang, China with magnitude 7.2 and depth 580km.

3.2 Temporal Characteristics of Earthquake Activities

Figure 2 is the temporal distribution map (M-T map) of earthquakes in the study area. It shows that there are rare earthquakes recorded before 1400 A.D. This may be due to incomplete historical records. Since 1450 A.D., earthquakes with magnitude more than 5 are basically complete. Figure 2 also shows that the seismicity of the study area is in a high level since 1700 A. D. Figure 3 shows the magnitude -frequency curve (a) and the cumulative magnitude -frequency curve (b) of the study area.

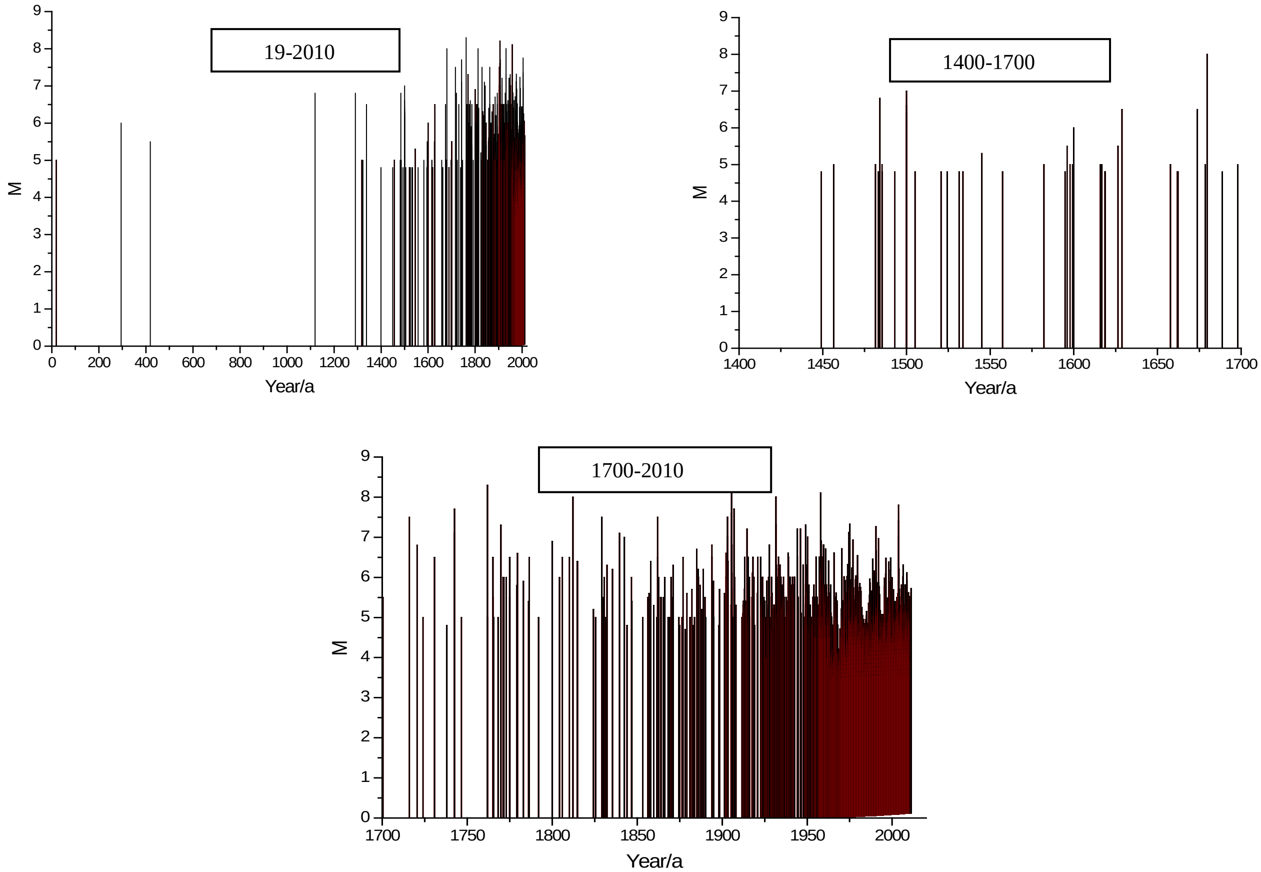

Fig. 2 - Earthquake Time Series Distribution map (M-T)

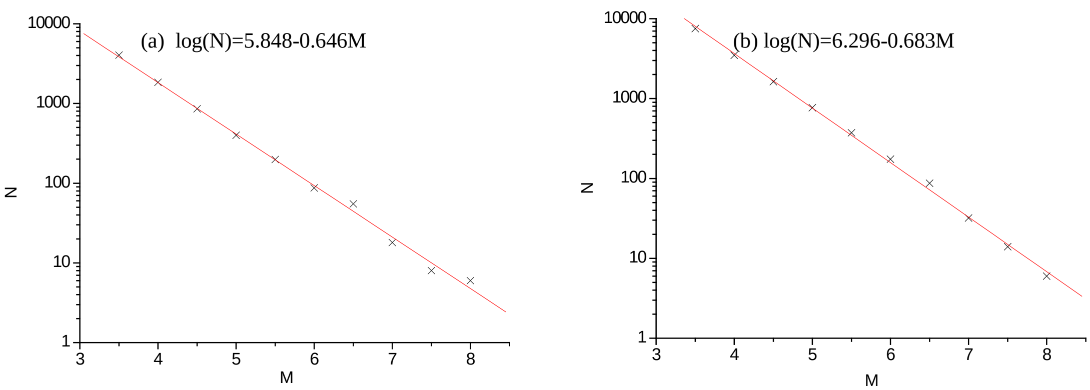

Fig. 3 - Log(N)-M Curve

(a) Magnitude - Frequency Curve; (b) Cumulative Magnitude - Frequency Curve

4. Geological Setting and Seismotectonics

In terms of geotectonic units, The study area is located among paraplatforms that had been formed in the Precambrian, namely Siberia Craton in the north, Sino-Korean paraplatform and Tarim paraplatform in the south. The middle of the study area is arc orogenic belts, had been formed in the Phanerozoic, namely Siberia orogenic belt and ancient China orogenic belt [12].

China-Mongolia arc areas had suffered many periods of tectonic movements. Many specific structures had been formed corresponding to their specific tectonic movement, these structures should have been reformed by the late tectonic movements, as results, distribution, nature, mode of motion, period and time of faulting in this areas are very complex. In Cenozoic, especially since Quaternary, the Tethys tectonic stress field had resulted in these existing faults being active again, and controlling the seismic activity in the areas

There are three groups of active faults in the study area[13-19] shown as figure 4, according to the geological data, field investigation proceeded for the three main structures, E-W striking Bolnay Faults, NW striking Ar Hutul Faults and E-W striking Gobi Altay Faults show that they are mainly strike-slip faults, the E-W striking ones behave as left lateral slip and NW striking ones performance as right lateral slip, which also can be proved by the focal mechanism solutions.

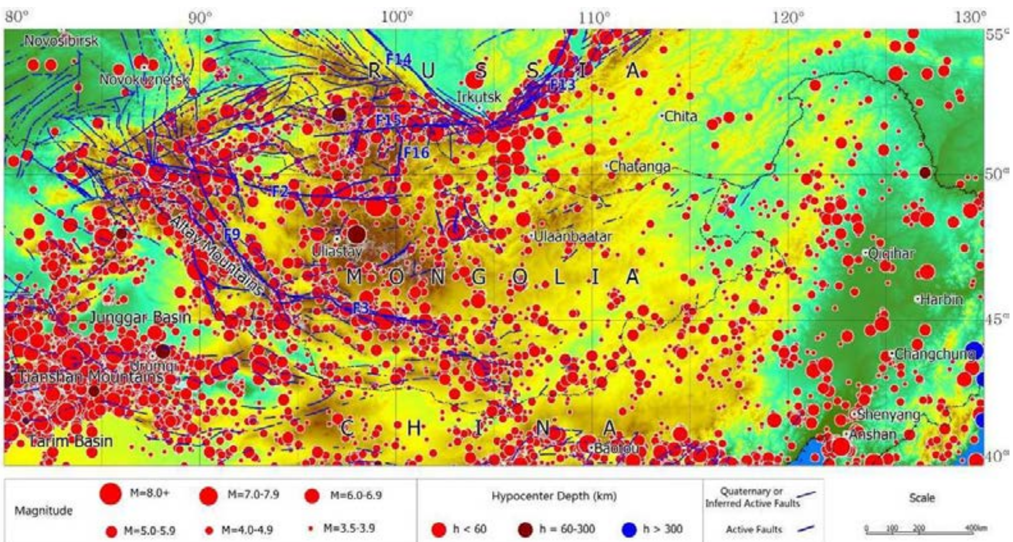

Fig. 4 - Seismotectonics of China-Mongolia arc areas

5. Determination of Seismic Belts and Potential Sources

Based on the distribution of recorded earthquakes, characteristics of geotetonics, neo-tectonic and geophysical field, two seismic belts, Altay seismic belt and Bolnay-Baikal seismic belt, for the study area are determined for seismicity statistics. According to field investigation, the studies of seismotectonic and locations of large earthquakes, 54 potential sources are determined within the two seismic belts.

Figure 5 are the two seismic belts, Altay seismic belt and Bolnay-Baikal seismic belt. Figure 6 are the 54 seismic potential sources determined in the study area.

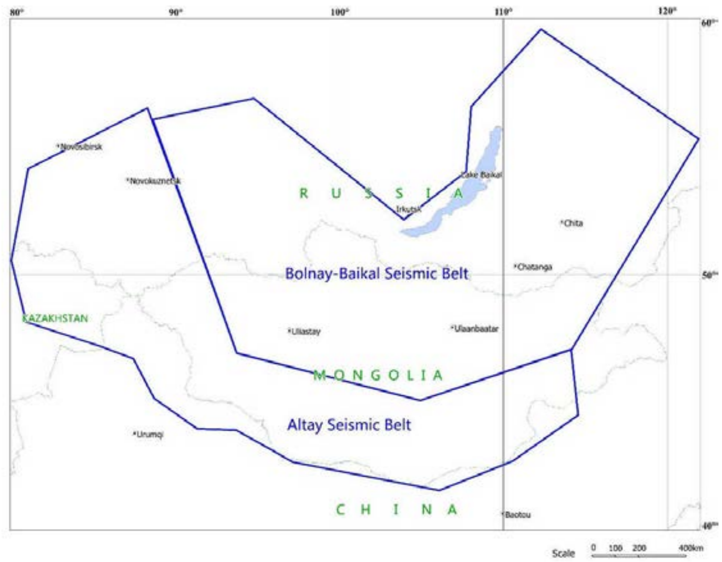

Fig. 5 - Seismic Belts Determined

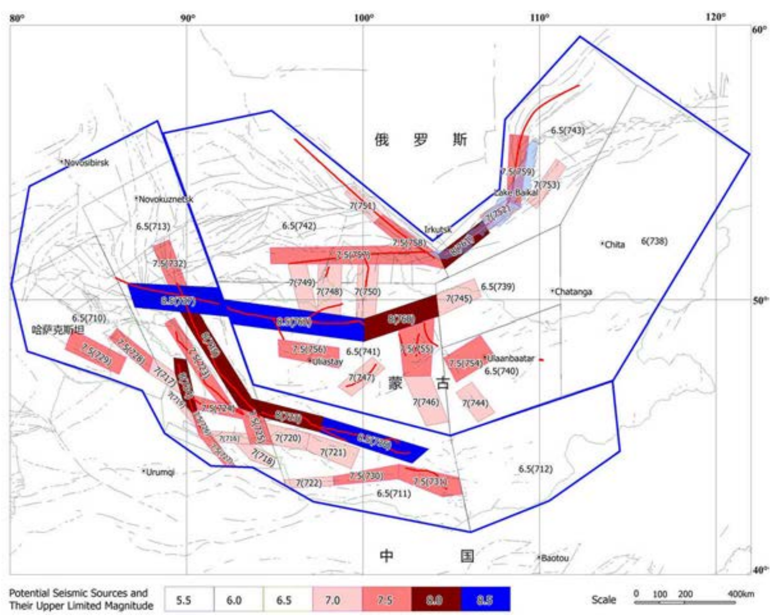

Fig. 6 - Determination of Seismic Belts and Potential Sources

Figure 7 shows the cumulative magnitude-frequency curve of the two seismic belts, which are determined by statistics based on the relative complete catalogue periods. It shows that the b-values of magnitude-frequency relationship for the whole areas are between 0.6 and 0.7 based on the uniform catalogue, 0.677 for the Altay seismic belt and 0.699 for the Bolnay-Baikal seismic belt. Furthermore, the annual occurrence rates of earthquakes with magnitude 4 or greater for the two seismic belts are determined, 9.153 for Altay seismic belts, and 11.066 for Bolnay-Baikal seismic belt based on the data period from 1900 to 2012.

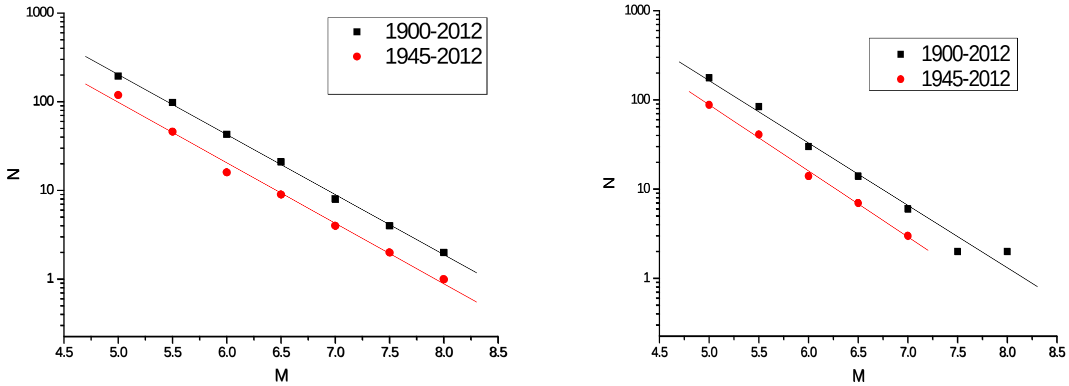

Fig. 7 - The cumulative magnitude-frequency curve of the two seismic belts

6. Probabilistic Seismic Hazard Analysis and Seismic Zoning

Using the China probabilistic seismic hazard analysis method, seismic hazard in China – Mongolia arc areas is calculated based on the determined potential sources and their seismicity parameters. Mongolia is closely connected with the mainland of China and the study area is located within Eurasia Plate, earthquakes in this areas are characterized by intraplate earthquakes, just like the mainland of China, so, effective peak acceleration attenuation relations used in seismic zoning map of China （2001）[20] are adopted directly in the above calculations of probabilistic seismic hazard analysis.

Figure 8 is the effective peak acceleration zoning map of China-Mongolia arc areas with exceeding probability of 10% in 50 year under the condition of average soil. Comparing to the seismic intensity zoning map of Mongolia (Figure 9), we can see that there are some differences in zoning shape, especially in the areas arround Ulaanbaator city.

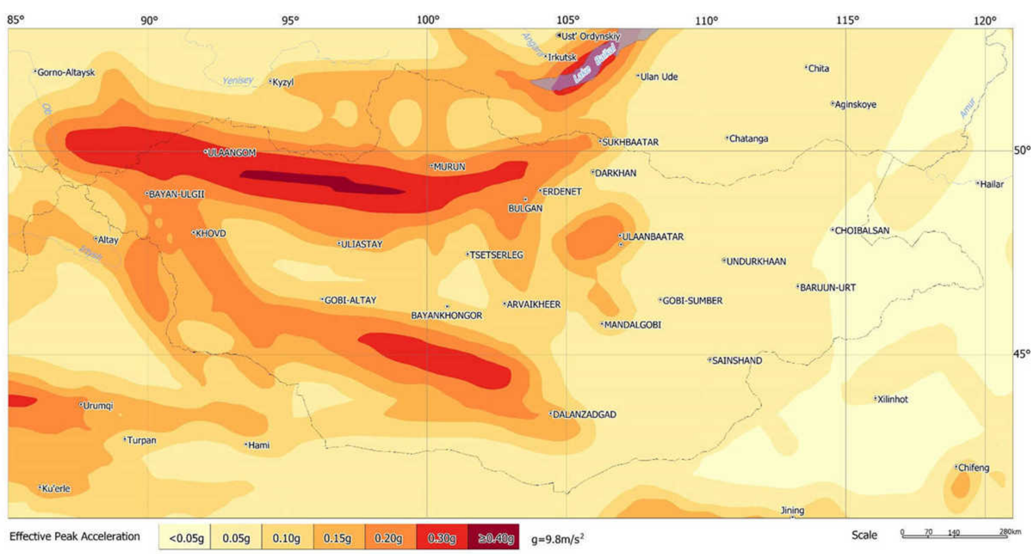

Fig. 8 - Seismic Zoning Map of China-Mongolia Arc areas (with exceeding probability of 10% in 50 years)

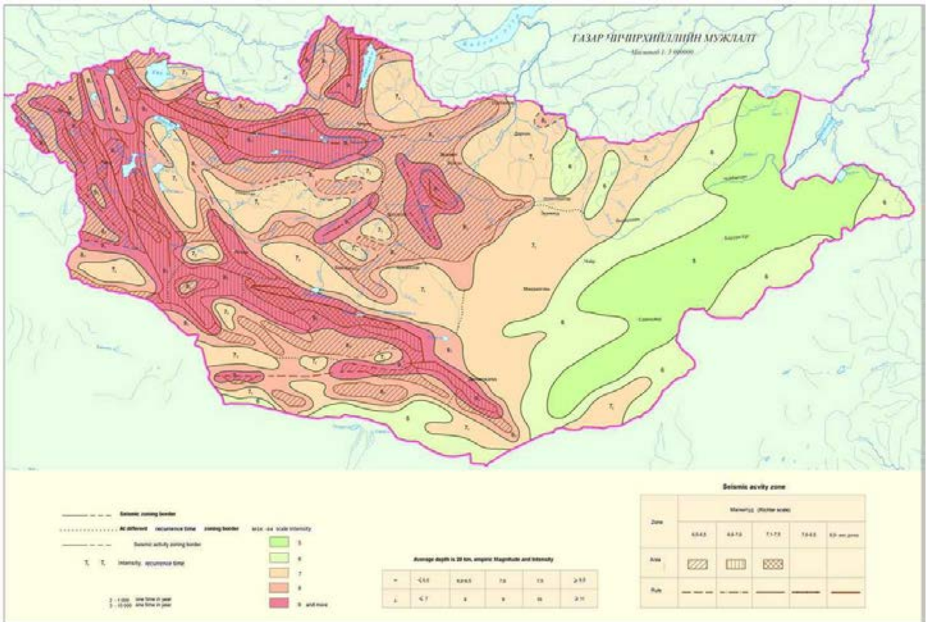

Fig. 9 – Seismic Intensity Zoning Map of Mongolia[7]

7. Discussion

Firstly, the origin of tectonic stress field of the study area is the collision and pressure of the India Plate to Eurasian Plate, passing from the Qinghai-Tibet Plateau. This is the reason why the seismicity is higher in the west than in the east, and all of earthquakes with magnitude 8 or greater occurred in the west. Secondly, the determination of the 2 arc seismic belts, Altay seismic belt and Bolnay-Baikal seismic belt, are reasonable in terms of their geotectonic location, geodynamic origin and seismicity characteristics. Finally, there are some differences between this result and the Mongolia Intensity Zoning map published in 1985[7] in terms of shape of seismic zoning map, especially in the areas near Ulaanbaatar. We argue that this result is more reasonable if we take into account the data use of recent study of active faults and their parameters, so it can be used as a reference for seismic design.

8. Acknowledgements

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