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Article

Characteristic Analysis of the *M*s6.0 Ma'erkang Earthquake Sequence on Jun. 10, 2022

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Abstract: On June 10, 2022, the *M*s6.0 Ma'erkang earthquake sequence occurred in the Bayan Har block. In this paper, the temporal and spatial distribution and attenuation characteristics of earthquake sequence is analyzed based on the regional structure, the temporal and spatial distribution of earthquake sequence, the focal mechanism solution, and the parameters of earthquake sequence, using the data of Sichuan Seismic Network and the temporary stations incorporated into the network. The results show that: (1) The *M*s6.0 Ma'erkang earthquake sequence is generally distributed in NW-SE direction, and the long axis of this series is basically consistent with the nearby Songgang fault. (2) As the earthquake sequence is formed by three large events with *M*s ≥5.0, the frequency of small earthquakes in the earthquake sequence area generally attenuates relatively slowly, while the activity level (magnitude) of aftershocks attenuates rapidly. (3) After the *M*s5.2 earthquake, the sequence parameters obtained show that the h-value is 1.09 and the p-value is stable at 1.02, indicating that the intensity and frequency attenuation of the earthquake sequence are gradually stable and tend to be normal. The b-value is 0.95, indicating that the maximum aftershock magnitude of the series is estimated to be *M*L5.1, and the b-value gradually tended to be stable, indicating that the stress in the region gradually tended to be balanced after the *M*s5.2 earthquake. The *M*s4.4 (*M*L5.0) earthquake that occurred at 4:37 on June 10 (local time) is the largest aftershock after the *M*s5.2 earthquake in the sequence. (4) The Songgang fault with NW-SE trend is presumed to be the main seismogenic tectonics, but the migration of three earthquakes with *M*s≥5.0 may also indicate that the Songgang fault is not a single seismogenic tectonics, which requires further field scientific investigation and analysis.

Keywords: The *M*s6.0 *M*a'erkang Earthquake; Earthquake Sequence; Characteristic Analysis; Source Parameters

1. Introduction

According to the measurement of China Earthquake Networks Center (CENC), on June 10, 2022, at 00:03:24.7 (local time), an *M*s5.8 earthquake occurred in Ma'rkang County, Aba Qiang-Tibetan Autonomous Prefecture, Sichuan Province, China. Immediately after the *M*s5.8 earthquake, at 01:28:34.4 (local time), an *M*s6.0 earthquake occurred, and another *M*s5.2 earthquake occurred again at 03:27:00.5 (local time). The three *M*s≥5.0 earthquakes occurred successively in a short time constitute the M_S6.0 Ma'erkang earthquake sequence. The detailed earthquake source parameters are listed in Table 1. Based on the waveform records, the focal mechanisms of the three earthquakes are determined to be strike-slip events. Based on the earthquake damage investigation and strong motion observation records, the isoseismal lines (intensity) caused by three earthquakes are plotted and determined. The isoseismal line along the NW is elliptical distribution, the highest intensity of the Ma'erkang earthquake sequence is Ⅷ. The Ma'erkang earthquake sequence caused casualties and property losses largely in Aba Tibetan and Qiang Autonomous Prefecture.

Table 1. Basic parameters of the Ma'erkang Eq Sequence.

Time of Eq occurrence	**Location of Eq occurrence**		**Hypocenter depth /km**	**Magnitude /M_S**
	λ_E /°	φ_N /°		
2022-06-10 00:03:24	101.82	32.27	10	5.8
2022-06-10 01:28:34	101.82	32.25	13	6.0
2022-06-10 03:27:00	101.85	32.24	15	5.2

After an earthquake occurs, the distribution characteristics of the time, space, and magnitude of aftershocks include the laws and characteristics of their own breeding, development, and occurrence process, reflecting the complexity between strong earthquakes and regional fault structural systems, and carrying a large amount of information reflecting the laws and characteristics of earthquake evolution process (Jiang et al., 2008) [1]. In this paper, we mainly analyzed the sequence characteristics and parameters of the 2022 M_S6.0 Ma'erkang earthquake sequence by using the regional seismic network records of Sichuan. Based on the known focal mechanism and seismogenic tectonics, we discussed the source characteristics of the Ma'erkang earthquake sequence.

2. Overview of Earthquake Sequence

The M_S6.0 Ma'erkang earthquake sequence is a major destructive earthquake sequence occurred in the interior of the Bayan Har block. Affected by the northward advancement of the Indian plate, the Qinghai-Tibet Plateau continued to uplift and compress in the SE and NE directions. As a result, Bayan Har block has formed a new sub block with extremely strong tectonic and seismic activities in the plateau. The area and boundary of the block are destructive seismically active areas. The latest earthquake in the adjacent area was the M_S6.9 Heishui earthquake occurred in the southwest segment of the Songgang fault on Oct. 8, 1941. The M_S6.0 Ma'erkang earthquake sequence is about 76 km away from the historical earthquake. On April 16, 1989, the M_S6.6 Xiaojin earthquake occurred in the southwest area of the Songgang fault and the Fubianhe fault. The M_S6.0 Ma'erkang earthquake sequence is about 115 km away from the M_S6.6 Xiaojin event (Fig.1).

After the occurrence of the earthquake sequence, no trace of surface rupture was found. Combining with the fault information already know, the Songgang fault is considered as a possible seismogenic fault of the M_S6.0 Ma'erkang earthquake sequence. The southern end of the Songgang fault is adjacent to the Fubianhe fault, forming a structural pattern that is close but not connected. The length of the Songgang fault is about 100 km and the strike orientation is NNW-SSE. The direction of the general tendency to NE direction, dip angle between 50°～70°. No M_S≥7 earthquake was recorded along the fault in history. Early results along the Songgang fault is the fault in the early pleistocene, but the active fault survey project of Sichuan province (2018-2022) in the survey found that the fault of south the section sells for signs of new activities, the average horizontal slip rate is estimated to be 1.01～1.29mm /a, and the average vertical slip rate is estimated to be 0.1～0.13mm/a.

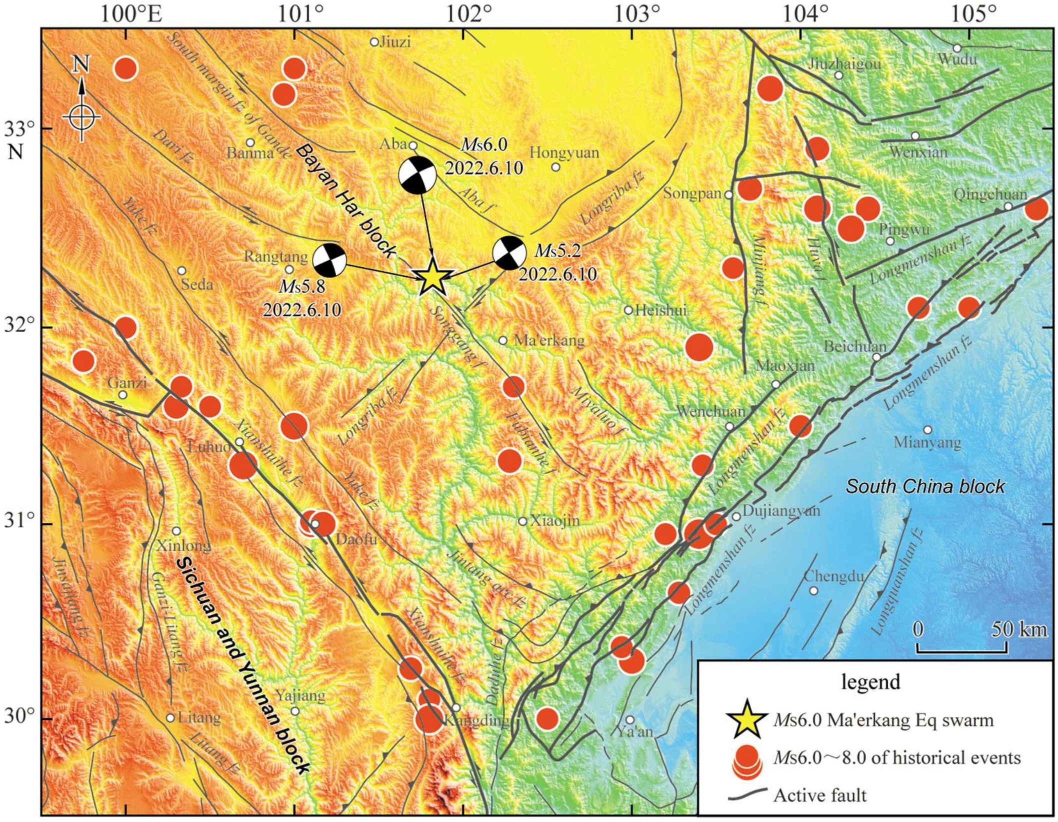


Fig.1. Distribution of historical earthquakes with Ms≥6.0 and geological tectonic around the Ms6.0 Ma'erkang Eq Sequence.

3. Seismic Monitoring and Magnitude Completeness

The Ms6.0 Ma'erkang earthquake sequence occurred in the area with good seismic monitoring capabilities. There are 35 seismic stations within 300 km and 7 seismic stations within 100 km. The distance between the epicenter of the earthquake sequence and the Ma'erkang seismic station is approximately 27 km. To improve the ability of aftershock monitoring and positioning, three temporary seismic stations were erected and connected to the monitoring network on June 12, 2022 (Fig.2). The distribution of seismic stations is dense relatively around the earthquake sequence. The source area has formed the good bearing cover, ensures the integrity of the sequence directory.

A small change in the magnitude completeness (Mc) is very important for earthquake sequence analysis, especially the minimum magnitude completeness of small earthquakes occurring within the first 24 hours after a major earthquake, which has a significant influence on the reliability of parameter calculation results (Jiang et al., 2015) [2]. Therefore, the Mc value of earthquake calculation within 24 hours after the Ms5.8 earthquake at 0:03 on June 10 is calculated by the maximum likelihood method, which is used to calculate the magnitude-frequency distribution (FMD) of G-R relationship. The frequency N of different magnitudes is calculated with 0.1 magnitude as the magnitude interval. The Mc calculated by the ZMAP program (Wiemer, 2001 [3]; Woessner & Wiemer, 2005 [4]) is 1.6 within 24 hours after the occurrence of the main earthquake (Fig.3), which is consistent with the distribution of monitoring capacity of the whole province provided by the Sichuan seismic network.

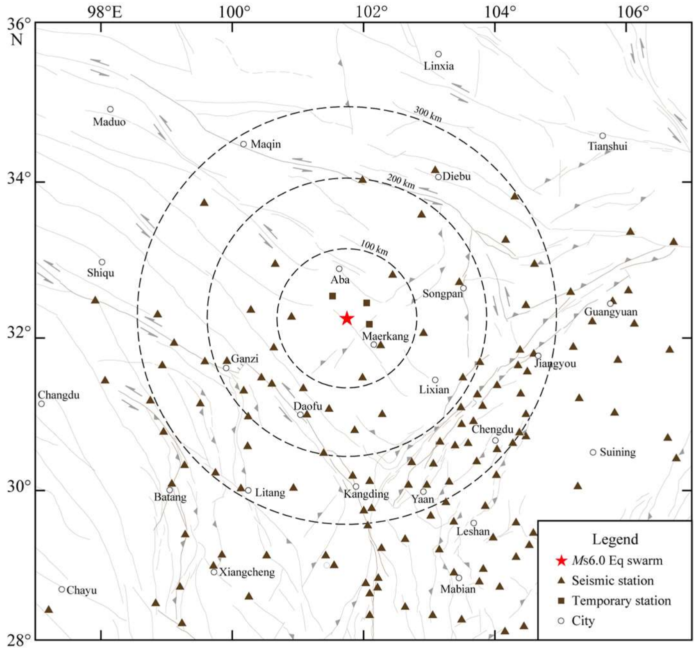
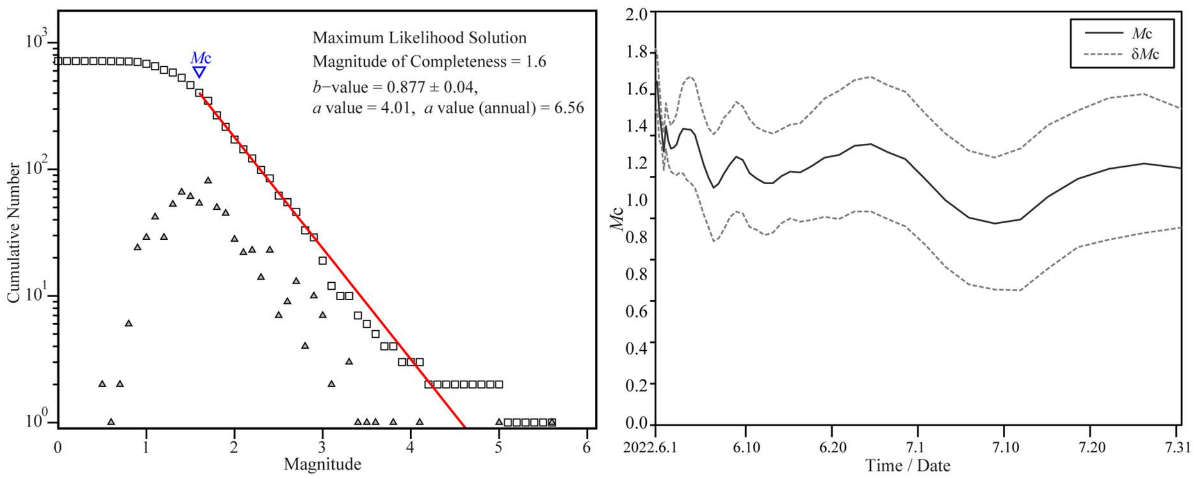


Fig.2. Distribution of seismic stations around the M_S6.0 Ma'erkang Eq Sequence.

It can be seen from the change of *M*c over time that, within a few hours after the main earthquake, *M*c was in a relatively unstable state due to the superposition of aftershock sequence waves. Until June 12, when the four temporary seismic stations were connected to the monitoring network, *M*c began to decline, which was relatively stable at about 1.2. However, as the four temporary seismic stations were stopped, the degree of integrity changed again (Fig.3).



(a) G-R relationship fit. **(b)** M_C-curve.

Fig.3. G-R relationship fit and M_C-curve in the area around the M_S6.0 Ma'rkang Eq Sequence.

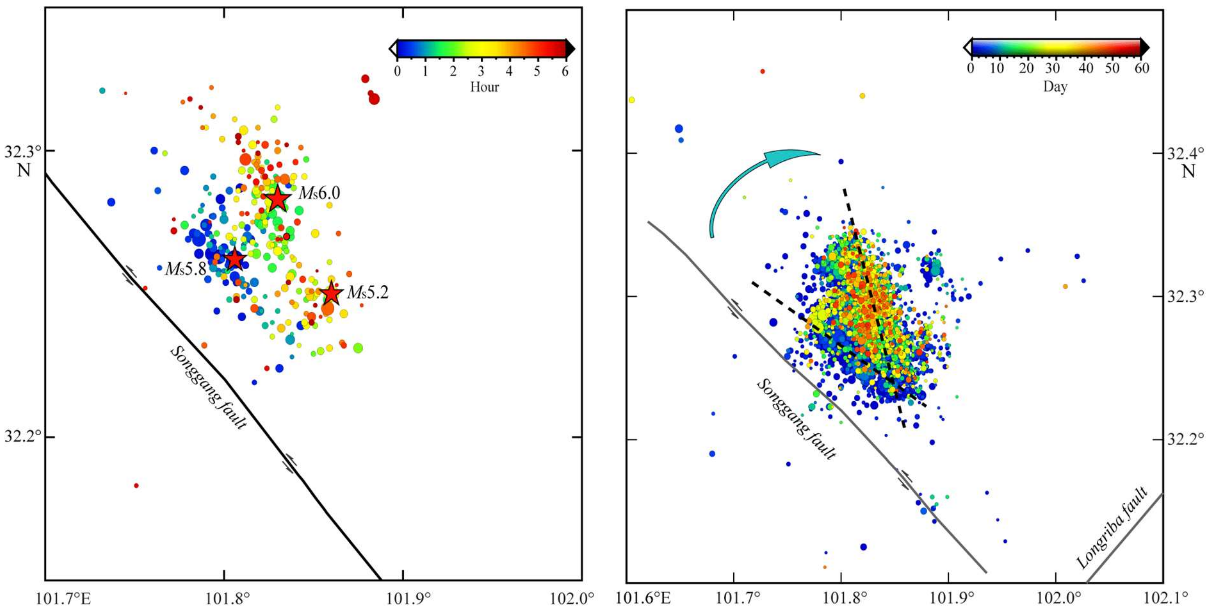
4. Results

According to the catalog of Sichuan Seismic Network, As of July 31, 2022, 4005 earthquakes with M_L≥1.0 of the M_S6.0 Ma'erkang earthquake sequence have been recorded, including 3294 events with M_L1.0～1.9, 624 events with M_L2.0～2.9, 77 events with M_L3.0～3.9. There are 10 events with M_L≥4.0 (Table 2). The M_S5.8, M_S6.0, and M_S5.2 earthquakes in the sequence all occurred within 3.5 hours of June 10, 2022 (Table 2).

Table 2. The earthquakes with $M_L \geq 4.0$ of the $M_S6.0$ Ma'erkang Eq sequence.

No.	Date	Time	Location of Eq occurrence		Magnitude		Hypocenter depth/km
	Y-M-D	H:M:S	λ_E	φ_N	M_L	M_S	
1	2022-06-10	00:03:24	101.81°	32.26°	6.3	5.8	17
2	2022-06-10	00:04:01	101.81°	32.26°	4.8	-	14
3	2022-06-10	00:06:44	101.79°	32.26°	4.6	4.1	15
4	2022-06-10	00:19:44	101.79°	32.27°	4.0	-	16
5	2022-06-10	00:21:17	101.79°	32.27°	5.2	4.4	21
6	2022-06-10	01:28:35	101.83°	32.28°	6.5	6.0	13
7	2022-06-10	03:27:00	101.86°	32.25°	5.6	5.2	15
8	2022-06-10	04:37:27	101.86°	32.24°	5.0	4.4	15
9	2022-06-10	04:54:32	101.81°	32.30°	4.1	-	15
10	2022-06-14	18:11:11	101.80°	32.27°	4.8	4.4	5

4.1 Spatial Distribution of Seismic Sequences



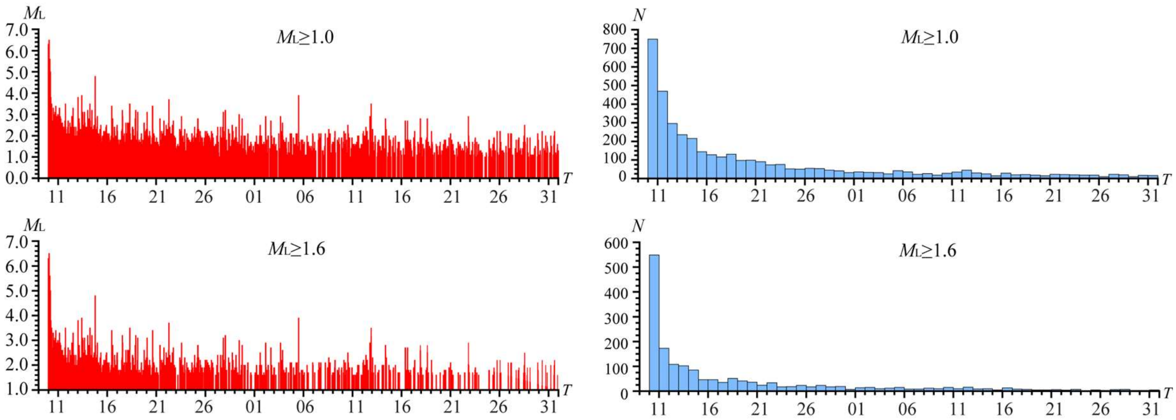
(a) Events within 6 hours after the $M_S5.8$ earthquake. **(b)** Events from June 10 to July 31, 2022.

Fig.4. Distribution of the $M_S6.0$ Ma'erKang Eq Sequence.

The distribution of three $M_S \geq 5.0$ earthquakes reflects the spatial migration characteristics of the series of earthquakes over time. The $M_S5.8$ event occurred in the area adjacent to the Songgang fault. The $M_S6.0$ earthquake is in the NW direction of the $M_S5.8$ earthquake, while the $M_S5.2$ earthquake is located to the south of the above two earthquakes (Fig.4a). Overall, almost all events of the $M_S6.0$ Ma'erkang earthquake sequence is distributed on the northeast side of the Songgang fault, along the northwest direction, with a total length of about 15km. Overall, almost all events of the $M_S6.0$ Ma'erkang earthquake sequence is distributed on the northeast side of the Songgang Fault, along the northwest southeast direction, with a total length of about 15km. Among them, the distribution of aftershocks is relatively scattered in the northwest section of the sequence, while it is more concentrated in the southwest section of the sequence, with the widest part being about 8 kilometers and the narrowest part being about 5 kilometers. As time goes on, the spatial distribution of small earthquakes shows the characteristics of migration from NW to NNW (Fig.4b).

4.2 Time Evolution of the Earthquake Sequence

As of July 31, 2022, the *M*-T diagram of the M_S6.0 Ma'erkang earthquake sequence is shown in Fig.5. Combined with the corresponding frequency statistics, the series showed a slow decay overall, but the frequency of earthquakes above M_L1.6 decreased significantly after June 14, earthquakes above M_L3.0 mainly occurred on the day of the earthquake, and earthquakes above M_L4.0 mainly occurred within 5 hours after the earthquake. After the M_L4.8 earthquake occurred on June 14, there was no seismic activity above M_L4.0 in the series. The attenuation of earthquake series with different magnitudes indicates the occurrence of an earthquake, and the attenuation time of earthquake series increases with the decrease of magnitude.



(a) *M-T* Diagram. **(b)** *N-T* Diagram.

Fig.5. M-T and N-T Diagram of the M_S6.0 Ma'erkang Eq Sequence.

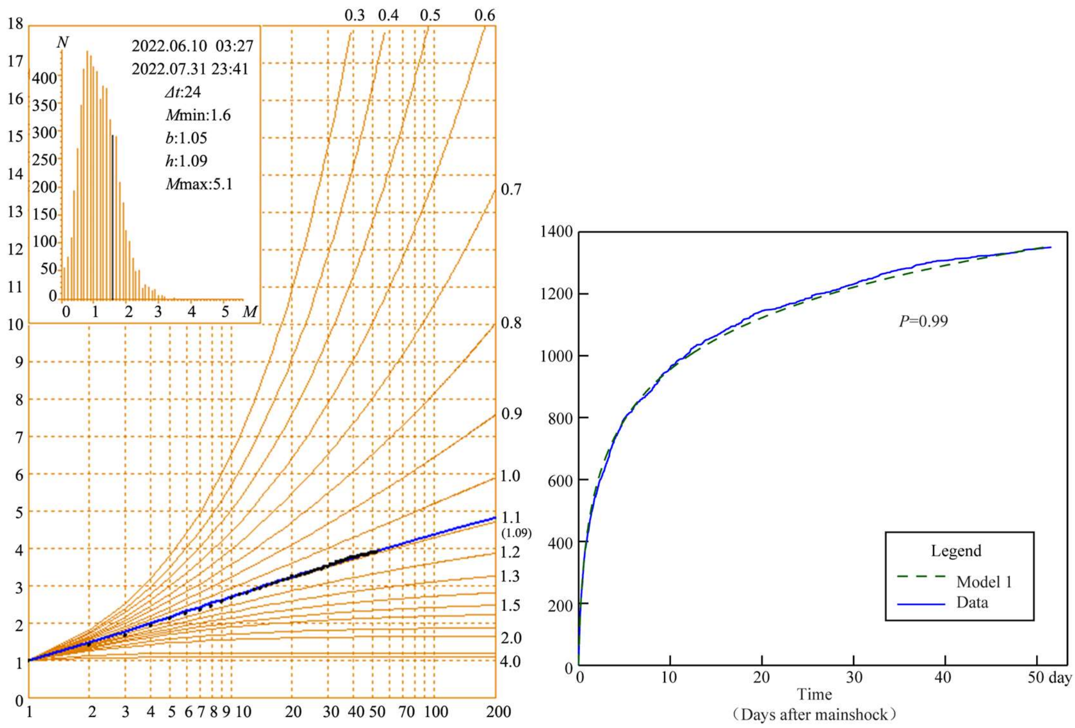
5. Parameter Calculation and Analysis

After the M_S5.8, M_S6.0 and M_S5.2 earthquakes, track the development of the earthquake sequence is one of the issues concerned, and it is also an important guarantee for how to carry out earthquake relief. The seismological parameters of the sequence are effectively used to determine the type of strong earthquake sequence and its development trend. For example, the p-value can reflect the law of seismic frequency attenuation with time, and the b-value and h-value can be used to determine whether it has the characteristics of foreshock sequence in a short time.

The h-value based on the modified Omori formula (Liu et al., 1979 [5]; Liu, 1984 [6]) is often used to study the attenuation of aftershock frequency. The h-value represents the attenuation coefficient of the number of aftershocks (daily frequency of aftershocks) with time. For example, when $h<1$, the energy of the main shock has not been completely released, which indicates that a larger or similar earthquake may occur in the sequence. When $h>1$, the energy release of the main shock is relatively fully displayed. Subsequently, the magnitude of the largest aftershock can be estimated from the h-value. Using the sequence data from 3:27 a.m. on June 10, 2022， to 23:00 a.m. on July 31, 2022 (local time), taking M_L1.6 as the starting magnitude and 1 day as the step size, the h-value of Ma'erkang earthquake sequence is calculated. The h-value is greater than 1, which is 1.09. the normal attenuation of sequences is shown after the *M*S5.2 event.

Gutenberg and Richter (1994) [7] first proposed and used the empirical formula of magnitude frequency to describe the differences of seismicity in various regions of the world. The formula of lg*N*=ɑ-b*M* is called G-R relation for short. In the formula, *N* and *M* represent the frequency of M±ΔM earthquakes occurring in a certain period between small areas with magnitude *M* as the center, and the ɑ and b are constants. The ɑ-value represent the level of seismic activity in the statistical time region. The b- value represents the proportional relationship between the number of large and small earthquakes in the area. When the number of large events is relatively large, the b -value is small. The b-value is related to the medium strength and stress in the area. In this paper, the region seismic data of the Ma'erkang earthquake sequence from 3:27 on June 10, 2022, to 23:00 on July 31, 2022 (local time) are selected. *M*L1.6 is determined as the minimum complete magnitude. The maximum likelihood method is used to calculate and the b-value of the sequence after the *M*S5.2 Ma'erkang event is 0.95. It is speculated that the maximum aftershock magnitude of this sequence is *M*L5.1. This is equivalent to the *M*L5.0 earthquake at 4:37 (local time) on June 10, 2022.

The p-value is called the attenuation coefficient of the earthquake sequence and also the attenuation coefficient of the earthquake frequency. The p-value is not related to the magnitude of the main event in the earthquake sequence, but to the attenuation law of the earthquake frequency with time in the earthquake sequence. When p> 1, it reflects the normal attenuation of the earthquake sequence, and when p< 1, it reflects the slow attenuation of the earthquake sequence. With the same parameters, the p-value of the earthquake sequence is 1.01, which indicates that the Ma'erkang sequence tends to decay normally.



(a) *h*-value after the *M*S5.2 event. **(b)** *p*-value after the *M*S5.8 event.

Fig.6. *h*-value and *p*-value of sequences after the Ma'erKang Eq Sequence.

6. Discussion and Conclusions

The Ma'erkang *M*S6.0 earthquake on June 10, 2022, occurred near the Songgang Fault. Based on the understanding of the integrity of the earthquake sequence, this article focuses on analyzing and discussing the spatiotemporal characteristics of the earthquake sequence and explores the early trend determination problem using b-values and h-values. Through analysis, the following conclusions are drawn:

The M_S6.0 Ma'erkang earthquake sequence is generally distributed in NW-SE direction, and the long axis of this series is basically consistent with the nearby Songgang fault. However, the distribution of small earthquakes is relatively discrete in the northwest of the sequence, and relatively compact in the southeast. The spatial distribution of small earthquakes shows that they migrate from NW to NNW over time.

As the earthquake sequence is formed by three large events with M_S≥5.0, the frequency of small earthquakes in the earthquake sequence area generally attenuates relatively slowly, while the activity level (magnitude) of aftershocks attenuates rapidly. The sequence seismicity of this sequence is relatively rich and intensive in time and space, but mainly small seismicity below M_L2.0.

The sequence type earthquake sequence is composed of 3 events with M_S≥ 5.0. After the M_S5.2 earthquake, the sequence parameters obtained show that the h-value is 1.09 and the p-value is stable at 1.02, indicating that the intensity and frequency attenuation of the earthquake sequence are gradually stable and tend to be normal. The b-value is 0.95, indicating that the maximum aftershock magnitude of the series is estimated to be M_L5.1, and the b-value gradually tended to be stable, indicating that the stress in the region gradually tended to be balanced after the M_S5.2 earthquake. The M_S4.4 (M_L5.0) earthquake that occurred at 4:37 on June 10 (local time) is the largest aftershock after the M_S5.2 earthquake in the sequence.

The study of aftershock sequences and their physical mechanisms is one of the important ways to understand earthquake processes. The M_S6.0 Ma'erkang earthquake sequence exhibits obvious migration characteristics, combined with focal mechanism solution, tectonics and small event activity of earthquake sequence in the near source area, the Songgang fault with NW-SE trend is presumed to be an seismogenic tectonics, but the migration of three earthquakes with M_S≥5.0 may also indicate that the Songgang fault is not a single seismogenic tectonics, which requires further field scientific investigation and analysis.

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Conflicts of Interest: The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

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