Image of seismological anomaly before the February 18, 2020 Changqing M4.1 magnitude earthquake

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Abstract: An earthquake of magnitude M4.1 occurred in Changqing County, Shandong Province (36.46°N, 116.65°E) on February 18, 2020. In this paper, we found from the image analysis of seismic activity and wave velocity ratio calculation before this earthquake that the magnitude M4.1 (No special markings on the magnitude of the earthquake: M for magnitude 5 (including magnitude 5) and above, M_L for below magnitude 5) in the 1-year scale before the Changqing M4.1 earthquake, inland Shandong and in the Bohai Sea, there is an orderly distribution of magnitude 2 earthquakes, multiple small earthquake sequences, a concentration with activity of magnitude 3 earthquakes, the Changdao “earthquake window” “open” several times, and an abnormally low value of wave velocity ratio etc. Phenomena.

1. Introduction
An earthquake of magnitude M4.1 occurred in Changqing County, Shandong Province on February 18, 2020. The original epicenter of this earthquake was near the April 17, 1622 Changqing earthquake of magnitude 5.5, indicating that the earthquake occurred in the old epicenter. There were five historical earthquakes of magnitude 5 or greater within 100km of the epicenter, the largest being the 6.0 magnitude earthquake that occurred on September 18, 1668 in Tai'an, Shandong Province. Since 1970 to February 17, 2020 there were five earthquakes of magnitude 3 or higher within 50 km of the epicenter of this earthquake, with the largest earthquake of magnitude 3.3 in Qihai, Shandong, on September 17, 1986, the closest being the 3.0 magnitude earthquake in Dong'a, Shandong, on October 19, 2003, and the closest in time being the 3.0 magnitude earthquake in Chiping, Shandong, on August 21, 2014. The longest time interval of magnitude 3 earthquakes within the area near the epicenter 50 km is 10.9 years, indicating that the area near the epicenter of this earthquake belongs to a modern area with weak seismic activity. In 2019, five consecutive magnitude 3 earthquakes occurred in the Luzhong uplift region of Shandong, indicating a seismically active phenomenon in the Luzhong uplift region, and in this context, the M4.1 magnitude earthquake in Changqing, Shandong, on February 18, 2020 occurred, indicating the continuation of seismic activity in the Luzhong uplift region. Two earthquakes of M_L5 or higher occurred in the main inland area of Shandong since 1970, namely the Qufu M_L5.0 on August 10, 1970 and the Cang Shan 5.2 on September 20, 1995. Huanpeng Zhou[1] and Xiqiang Liu[2] found that there were anomalies in seismic activity images in the area near the epicenter before the CangShan earthquake and low values of wave velocity ratio anomalies in the Yishu Fault Zone area for six months before the earthquake, Xinglan Zhao[3] found that anomalous images of seismic activity also existed before the 5.9 magnitude earthquake in Heze. Although the magnitude of the Changqing M4.1 earthquake did not reach magnitude 5, it was the most significant earthquake in the region since 1970. Therefore, the calculation of the seismic activity image evolution and wave velocity ratio before this earthquake and the analysis of the seismological anomaly characteristics before the Changqing earthquake are of...
practical and social significance for the short- and medium-term earthquake forecasting and earthquake emergency work.

2. Orderly distribution of magnitude 2 earthquakes in inland areas of Shandong

Definition of seismic strip: when $M_L<3$, the number of earthquakes composing the seismic strip is $N \geq 6$, and the strip length $L>200$km; or when $M_L \geq 3$, $L>400$km, and the strip length-to-width ratio $L/D \geq 4$, and its maximum empty section does not exceed 1/3 of the total length. Since 2019, until the Changqing $M_4.1$ earthquake occurred, the magnitude 2 earthquakes in the inland area of Shandong showed an NNE-oriented strip distribution, with length is about 180km and the width is about 70km. There were 28 earthquakes of magnitude 2 or higher in this strip since 2019, including 3 earthquakes of magnitude 3, as shown in Figure 1. According to the definition of seismic strip, this seismic activity image does not conform to the definition of seismic strip, which can be called strip-like ordered distribution. The Changqing $M_4.1$ magnitude earthquake did not occur inside the strip-like distribution or at both ends of the strip, but the phenomenon is also noteworthy. Figure 1 shows its spatial distribution.

![Figure 1 January 1, 2019 - February 17, 2020 Strip map of magnitude 2 inland earthquakes in Shandong.](image)

3. Several small earthquake sequences occurred in Shandong inland and in the Bohai Sea

Since 2019, four small earthquake sequences have occurred in Shandong inland and in the Bohai Sea, namely, the 2019 Ningyang and Xintai small earthquake sequences, the December 2019 Laiwu small earthquake sequence, and the two Bohai Sea 3.1 earthquake sequences in June 2019 and January 2020. The following describes the details of these 4 sequences and give the timing diagram.

3.1. Ningyang small earthquake sequence

A total of 68 small earthquakes have been recorded in the Ningyang area since 1970, of which only the 1.7 magnitude earthquake on October 2, 1977 was recorded before 2009. After the 2.1 magnitude earthquake on September 23, 2009, the maximum annual frequency of small earthquakes in Ningyang up to 2016 was no more than 3, with a relatively low frequency of earthquakes. The maximum earthquake not December 25, 2014 was 2.9, which was also the The frequency of small earthquakes in the area was 5 and 6 in 2017 and 2018, respectively, with an increase in the frequency of small earthquakes. 33 earthquakes occurred in the area in 2019, of which the frequency of small earthquakes in September
reached 8, significantly higher than the background value in the area, forming a sequence of small earthquakes, including 8 earthquakes of magnitude 2 or higher, the largest of which was on February 14 2.6 magnitude. Figure 2 is the Time-series diagram.

![Figure 2 Time-series diagram of small earthquake sequence in Ningyang.](image)

### 3.2. Xintai small earthquake sequence
No earthquakes were recorded in the Xintai area from 1970 to 1980. 27 small earthquakes have been recorded in the area since 1981, of which 2 earthquakes were recorded before 2007, with magnitude 1.7 on January 18, 1981 and 1.7 on October 4, 1987. 25 small earthquakes have been recorded in the area since 2007, with an average annual frequency of 2 small earthquakes. In particular, six earthquakes were recorded in the region in 2019, with the largest earthquake of magnitude 3.1 on August 23, 2019. Prior to this earthquake, the region was dominated by small earthquake activity of about magnitude 1-2, with the largest earthquake of magnitude 2.4 on February 24, 2012, indicating the strongest active seismic activity in the region in 2019 since 1970. Figure 3 is the Time-series diagram.

![Figure 3 Time-series diagram of small earthquake sequences in Xintai area.](image)

### 3.3. Small earthquake sequence in Laiwu area
A total of 31 small earthquakes have been recorded in the Laiwu area since 1970, of which 23 were recorded before 2019, with an average annual frequency of less than 1. The frequency of earthquakes is
relatively low, with the largest earthquake of magnitude 3.4 on June 25, 2013. Against the background of weak activity in the region, two consecutive small earthquakes of magnitude 1 occurred in April and May 2019, and five consecutive small earthquakes of magnitude 2 occurred from November to December 2019, with a significant increase in seismic activity compared to the past. Figure 4 is the Time-series diagram.

3.4. Bohai Sea small earthquake sequence
Two earthquake sequences of magnitude 3.1 on June 19, 2019 and 3.1 on January 3, 2020 occurred in the Bohai Sea waters since 2019. 11 earthquakes were recorded in the 3.1 earthquake sequence on June 19, 2019, which occurred within one day only on June 19, with the largest earthquake of magnitude 2.3 on June 19 at 08:15 a.m. The sequence on January 13, 2020 sequence original epicenter area occurred again in the 3.1 magnitude sequence, which recorded a total of 24 earthquakes, with the largest earthquake of magnitude 3.2 on January 15. The small earthquake activity in this sequence lasted until January 28, followed by the Changqing M4.1 earthquake 21 days later. Figure 5 is the Time-series diagram.
4. The central Shandong uplift area is concentrated with active 3 magnitude earthquakes in 2019

Six earthquakes of magnitude 3 or higher occurred in the inland area of Shandong in FY2019, three of which occurred at the edge of the Luzhong Uplift area and two of which occurred inside this uplift area, showing that the tectonic block is in a seismically active state, while the northwestern edge of this tectonic zone shows a lack of seismicity, and the Changqing M4.1 magnitude earthquake that occurred on February 18, 2020, happened to be located at the northwestern edge of the Luzhong Uplift (Figure 6). The analysis suggests that the earthquake location fills the absence of seismicity in the region and energetically belongs to an undulating enhancement of this seismic activity.

5. Changdao “earthquake window” “open” several times

The “earthquake window” are generally located in special structural parts of geological units and can reflect the changes of regional stress field in the form of small and microseismic activities. Since the area near Changdao has been historically hit by many strong earthquakes and belongs to an old earthquake zone, the manifestation of recent stress release is mainly in the form of small earthquakes with a “window” effect. Therefore, the area centered on Changdao seismic station (37.95°N, 120.73°E) with a radius of 40km is called the Changdao “earthquake window”. The “earthquake window” opening standard of this “earthquake window” is 8 earthquakes of magnitude 1 or more in one consecutive month within this “earthquake window”.

A small 2.0 magnitude cluster of earthquakes occurred in the window of Changdao “earthquake window” on June 18, 2019. And in July 4 to reach the Changdao “earthquake window” opening standards, a new “window opening” exceptions appear, and July, August, October continuous “window opening”, “Window opening” againthe day before 17, 2020, that is, Changqing M4.1 earthquake before one day. Although the magnitude of the earthquake is smaller than according to the “window opening” prediction criteria of the Changdao “earthquake window”, the phenomenon is also of concern.

6. Low values of wave velocity ratios in the Yishu Fracture Zone area

Since seismic waves originate directly from the source, they carry a lot of information about the changes of the source and propagation path media. The wave speed of seismic waves has a direct relationship with the medium of the earthquake source, so the changes of the seismic wave speed can directly reflect the changes of the source medium. According to the previous earthquake case studies, there are often some abnormal changes in seismic wave velocity before the occurrence of large earthquakes, and the low value of wave velocity ratio relative to the average value in the region is generally recognized as abnormal. The average wave velocity ratio of small earthquakes in the Yishu Fault Zone area had a low value of 63% six months before the 5.2 magnitude earthquake in Cang Shan on September 20, 1995.
The epicenter of the Changqing M4.1 earthquake (36.46°N, 116.65°E) was located in the northwestern part of the Yishu Fault Zone area (34º-37.5ºE, 117.5-120.5ºN), the selected region for calculating the wave speed ratio. From the tracked results of the average wave velocity ratios of earthquakes with $M_L \geq 1.5$ in the Yishu Fault Zone area (excluding some earthquakes in Jiangsu and the sea) since 2008. We find that the average wave speed ratios of 15 small earthquakes in the region were calculated from December 16, 2019, until February 18, 2020, two months before the M4.1 earthquake, and the results showed that there were 10 low values with average wave speed ratio values below 1.69, and the low values of wave speed ratio accounted for 66.7% of the total (According to Zhou Huanpeng et al [1], the mean value of wave speed ratio in this area is $R=1.72$. Taking the mean value $\pm 0.03$ as the base value, the normal value of wave speed ratio in Yishu Fault Zone area is $R=1.72\pm0.03$, $R \geq 1.75$ is the high value of wave speed ratio and $R \leq 1.69$ is the low value of wave speed ratio.). By the second day of February 20, 2020, the day after the Changqing M4.1 earthquake, it recovered to near the mean value, and the area near the epicenter showed a significant low value of wave speed ratio 2 months before the earthquake. Figure 7 shows the wave speed ratio variation.

Figure 7 Time-series curves of $M_L \geq 1.0$ seismic wave velocity ratio variation in the Yishu Fault Zone region.

7. Conclusions and Discussion
Based on the seismic activity images and wave velocity ratios calculated before the Changqing M4.1 earthquake, it is found that there are some seismological image anomalies in the scale of one year before this earthquake: 1) the magnitude 2 earthquakes in the inland area of Shandong show a NNE-oriented strip distribution; 2) several small earthquake sequences occur in the inland area of Shandong and the Bohai Sea; 3) several magnitude 3 earthquakes occur in the uplifted area of Shandong's inland; 4) the Changdao window has many “windows opening” anomalies; 5) The average wave speed of earthquakes in the Yishu Fault Zone area was significantly lower than that in the two months before the earthquake.

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