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Radon concentration anomaly characteristics in the North–South seismic belt before strong earthquake

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Abstract. Seismic underground fluids play an important role in earthquake prediction studies and tracking. Nearly 30 years of radon concentration monitoring data at 42 observation sites in the North–South seismic belt (22°-35° N, 100°-110° E) were collected from the National Earthquake Data Center of China Earthquake Networks Center. The possible precursor anomalies of observed radon concentration in the belt before several strong earthquakes were investigated and their spatial distribution, evolution, and variation characteristics were analyzed. The results showed that radon concentration precursor anomalies before several strong earthquakes were high, and the morphological characteristics are relatively complex. The anomaly mainly shows the turning point or accelerating change of trend background change; longer anomaly durations tend to be concentrated around epicenters. The number of observation points with anomalies was positively correlated with the proximity to the epicenter; the measurement points closest to the epicenter exhibited earlier trend anomalies. The research has important practical significance and scientific value for understanding the relationship between radon concentration anomaly and strong earthquake.

1 Introduction

The North–South seismic belt is one of the most intensely seismic regions in mainland China, with 71 recorded earthquakes of magnitude 7 or higher [1]. After the Wenchuan earthquake on May 12, 2008, the North–South seismic belt has entered a new active period of strong earthquakes [2]. According to the earthquake catalog of the China Earthquake Networks Center, twenty-six strong earthquakes of magnitude 6 or higher have occurred in the North–South seismic belt since 2008, including five earthquakes of magnitude 7 or higher, exhibiting characteristics of North–South round-trip migration. After the earthquake, there have been many studies on the possible anomalies of water radon before the earthquake [3-5]. However, water radon, as a means of seismic underground fluid observation, is primarily studied by taking a medium-strong earthquake as an example [6-8] and selecting certain “sensitive” measurement points [9-11] as targets of anomaly information in the local area [12-13]. However, the overall variation characteristics of preseismic radon concentration anomalies and their formation mechanism remain understudied.

Radon is a suitable geochemical component for evaluating tectonic fracture distribution and fault activity and seismic activity [14]. Radon is produced following the decay of radium, thorium, and other radioactive elements. Its chemical properties are stable, and it can migrate not only in the gaseous state in the geological environment but also with the groundwater in the dissolved state and migrate from the deep underground to the surface, it is an indicator of deep earth information and can bring information reflecting the state of underground geology [15, 16]. Radon, as a medium and long-term indicator of geochemical precursors, plays an important role in revealing the relationship between abnormal changes of underground fluids and the preparation and occurrence of earthquake. In the nearly 10 years of past research, most scholars have carried out research work for radon observation at a single station with single measurement. However, For the strong earthquake with great destruction, the study of single station and local area still has some limitations. Carrying out large-scale research is greatly valuable for revealing the overall characteristics and formation mechanism of earthquake precursors.

In this paper, we analyzed the overall variation characteristics of radon concentration anomalies before several strong earthquakes which occurred in North–South earthquake belt in the past 10 years: the magnitude 8.0 Wenchuan earthquake on May 12, 2008, the magnitude 7.0 Lushan earthquake on April 20, 2013, the magnitude 6.6 Minxian–Zhangxian earthquake on July 22, 2013 and the magnitude 7.0 Jiuzhaigou earthquake on August 8, 2017. It is expected to provide further data support for improving the level of understanding of earthquake precursors and earthquake monitoring and prediction.

2 Data collection

In this paper 42 radon concentration measurements of the China Earthquake Networks Center in the study area range

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(22°-35° N, 100°-110° E) were collected and radon concentration anomalies before four strong earthquakes were sorted out to analyze their general characteristics. Figure 1 shows the distribution of radon concentration observations in the North–South seismic belt.

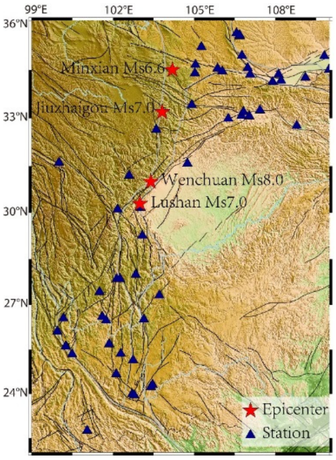

Figure 1. Distribution of radon concentration measurement points in the North–South seismic belt

3 Analysis of monitoring results

3.1 Radon concentration anomalies and earthquake precursors

This paper collected and collated 45 radon concentration measurements before the earthquake from 42 stations within the North–South seismic belt (Figure 1) for nearly 30 years; 23 anomalies before the Wenchuan earthquake (Table 1), 23 anomalies before the Lushan earthquake (Table 2), 14 anomalies before the Minxian earthquake (Table 3), and 26 anomalies before the Jiuzhaigou earthquake were collated (Table 4), and the maximum range from anomalies to the epicenter was between 675 and 1028 km.

Table 1. Information on radon concentration anomalies before the 8.0 Wenchuan earthquake

NO.	Station	Observation items	Epicenter distance /km	Anomaly start time	Anomaly features
1	Tangyu	Water radon	546.81	03/2006	Reversal and rise
2	Gaojiacun	Water radon	507.33	03/2005	Trend rise
3	Hanzhong	Water radon	412.98	04/2005	Trend rise
4	Zhouzhi Xiguan	Gas radon	572.15	05/2008	Sudden drop
5	Tonghai Gaoda	Gas radon	781.07	05/2007	Sudden rise
6	Mile Shiju	Gas radon	751.68	05/2008	Sudden rise, reversal and drop
7	Panzhihua Well No. 05	Water radon	527.69	03/2007	Trend reversal
8	Panzhihua Turtle Well	Water radon	519.1	11/2007	Sudden rise, trend reversal and drop
9	Lixian	Water radon	79.35	11/2007	Reversal and rise
10	Yanyuan	Water radon	437.94	02/2000	Trend reversal
11	Zhaojue	Water radon	338.43	04/2004	Trend reversal
12	Ya’an	Water radon	98.85	09/2005	Trend reversal and drop
13	Ganzi (y)	Water radon	329.12	12/2006	Trend reversal and drop
14	Xichang Taihe	Water radon	370.86	05/2006	Trend reversal
15	Xichang	Water radon	366.81	04/2006	Trend reversal
16	Songpan	Water radon	184.36	01/2003	Drop trend
17	Wudu Diangou	Water radon	304.36	01/2006	Reversal and drop
18	Wushan Spring No. 1	Water radon	434.76	01/2003	Drop trend in 2003, reversal and rise in 2007
19	Wushan Spring No. 22	Water radon	407.24	01/2003	Drop trend in 2003, reversal and rise in 2007
20	Qingshui Hot Spring	Water radon	493.6	01/2006	Drop trend in 2003, reversal and rise in 2007
21	Pingliang Fujianchang	Water radon	588.74	01/2007	Reversal and rise
22	Tianshui Wulipu	Water radon	456.38	01/2001	Reversal and rise
23	Tongwei Hot Spring	Water radon	498.41	09/2007	Trend drop - rise

Table 2. Information on radon concentration anomalies before the Lushan earthquake

NO.	Station	Observation items	Epicenter distance/km	Anomaly start time	Anomaly features
1	Tangyu	Water radon	627.57	07/2012	Sudden rise, reversal and drop
2	Gaojiacun	Water radon	591.41	09/2011	Trend reversal
3	Lintong	Water radon	659.67	10/2012	Reversal and drop
4	Hanzhong	Water radon	490.7	02/2013	V-shaped changes
5	Hanzhong Yangxian	Gas radon	532.41	07/2011	Trend acceleration
6	Mile Shiju	Gas radon	675	11/2012	Trend reversal
7	Panzhihua Well No. 05	Water radon	442	03/2012	Trend rise - drop
8	Panzhihua Turtle Well	Water radon	432.97	02/2012	Sudden rise
9	Yanyuan	Water radon	351.22	10/2012	Increased volatility
10	Zhaojue	Water radon	256.75	05/2012	Trend acceleration
11	Ya’an	Water radon	14.74	04/2012	Sudden rise

12	Ganzi (y)	Water radon	320.15	12/2012	Sudden rise
13	Xichang	Water radon	281.34	03/2013	Trend reversal
14	Songpan	Water radon	267.38	03/2013	Sudden drop
15	Bayisi	Water radon	114.83	01/2012	Trend reversal
16	Xichangchuan Well No. 32	Gas radon	281.34	08/2012	Sudden rise
17	Xichangchuan Well No. 32	Water radon	281.34	08/2012	Sudden rise
18	Wudu Diangou	Water radon	391.07	09/2011	Trend acceleration
19	Wushan Spring No. 2	Water radon	521.1	05/2012	Sudden rise, trend reversal
20	Wushan Spring No. 22	Water radon	493.73	03/2012	Reversal and rise
21	Pingliang Fujianchang	Water radon	675.28	11/2011	Reversal and drop
22	Tianshui Wulipu	Water radon	542.98	05/2012	Reversal and drop
23	Tongwei Hot Spring	Water radon	584.7	10/2011	Trend reversal

Table 3. Information on anomalous radon concentrations before the Minxian earthquake

NO.	Station	Observation items	Epicenter distance/km	Anomaly start time	Anomaly features
1	Tangyu	Water radon	342.35	05/2013	Big sudden jump, reversal and rise
2	Gaojiacun	Water radon	263.78	06/2013	V-shaped changes
3	Lintong	Water radon	359.92	04/2013	Reversal and drop
4	Zhouzhi Xiguan	Gas radon	370.18	06/2013	Reversal and sudden rise
5	Hanzhong Yangxian	Gas radon	329.25	06/2013	Trend acceleration
6	Zhaojue	Water radon	734.68	05/2013	Reversal and drop
7	Ya'an	Water radon	493.85	07/2012	Sudden rise
8	Songpan	Water radon	213.12	05/2013	Continued drop
9	Wudu Diangou	Water radon	137.06	01/2013	Reversal and rise
10	Wushan Spring No. 1	Water radon	79.73	03/2013	Reversal and rise
11	Wushan Spring No. 22	Water radon	76.98	04/2013	Trend acceleration
12	Pingliang Fujianchang	Water radon	253.33	04/2013	Reversal and rise
13	Tianshui Wulipu	Water radon	152.97	03/2013	Sudden rise
14	Tongwei Hot Spring	Water radon	124.87	10/2011	Trend reversal

Table 4. Information on radon concentration anomalies before the Jiuzhaigou earthquake

NO.	Station	Observation items	Epicenter distance/km	Anomaly start time	Anomaly features
1	Gaojiacun	Water radon	326.88	10/2016	V-shaped changes
2	Lintong	Water radon	417.9	01/2016	Reversal and rise
3	Mianxian	Water radon	273.21	05/2017	Trend reversal, large sudden rise
4	Zhouzhi Xiguan	Gas radon	420.4	03/2017	V-shaped changes
5	Huayin	Gas radon	587.72	04/2014	Sudden rise
6	Longxian	Gas radon	333.33	06/2017	Sudden rise
7	Hanzhong Yangxian	Gas radon	336.29	02/2017	V-shaped changes
8	Hengkou	Gas radon	466.05	05/2017	Reversal and drop
9	Ningqiang	Gas radon	228.84	05/2017	Sudden rise
10	Xiaguan Shuihua	Water radon	911.97	01/2017	Reversal and drop
11	Tonghai Gaoda	Gas radon	1028.43	07/2017	Sudden rise
12	Mile Shiju	Gas radon	997.14	07/2017	Sudden rise
13	Heqing Xianju	Water radon	818.66	05/2015	Trend reversal
14	Panzhihua Well No. 05	Water radon	773.38	07/2017	Sudden jump
15	Panzhihua Turtle Well	Water radon	763.79	03/2016	Trend drop
16	Yanyuan	Water radon	679.42	10/2016	Reversal and drop
17	Yanyuan	Water radon	586.23	03/2017	Trend acceleration
18	Xichangchuan Well No. 32	Gas radon	612.93	04/2017	Trend acceleration
19	Xichangchuan Well No. 32	Water radon	612.93	04/2017	Trend acceleration
20	Wudu Diangou	Water radon	104.54	11/2016	Trend reversal
21	Wushan Spring No. 1	Water radon	197.71	12/2016	Trend reversal and acceleration
22	Wushan Spring No. 22	Water radon	173.74	06/2017	Reversal and rise
23	Pingliang Fujianchang	Water radon	368.85	10/2016	Reversal and rise
24	Tianshui Wulipu	Water radon	240.87	09/2015	Trend acceleration
25	Tongwei Hot Spring	Water radon	259.3	06/2015	Trend acceleration
26	Pingliang Anguo	Water radon	368.35	03/2017.	Trend reversal

3.2 Spatial distribution characteristics of anomalies

Figure 2 shows the spatial distribution of the epicenters and radon anomalies of several strong earthquakes. The water radon in Tianshui Wulipu before the Wenchuan earthquake was first anomalous in 2001, and the gas radon in Zhouzhi Xiguan occurred for the last time 9 days before the earthquake; the gas radon in Hanzhong Yangxian before the Lushan earthquake was first anomalous in 2011, and the water radon in Songpan occurred for the last time 28 days before the earthquake; the water radon in Tongwei Hot Spring before the Minxian-Zhangxian earthquake was first anomalous in 2011, and the gas radon in Zhouzhi Xiguan occurred for the last time 1 month before the earthquake; Water radon in Huayin before the Jiuzhaigou earthquake was first anomalous in 2014, and water radon in Panzhihua Well No. 05 occurred for the last time 23 days before the earthquake.

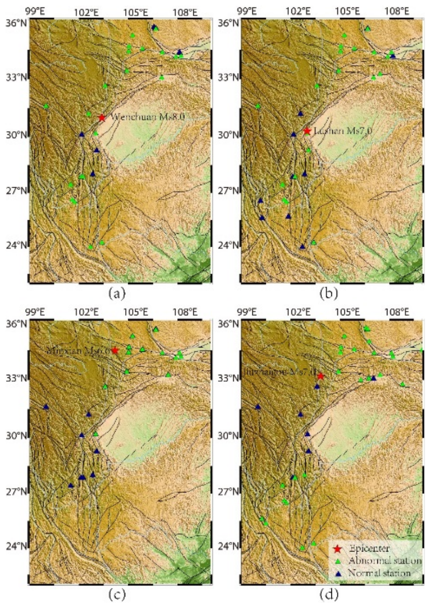

Figure 2. Spatial distribution of radon concentration anomalies in the North–South seismic belt before strong earthquakes

(a)Wenchuan Earthquake; (b)Lushan Earthquake; (c)Minxian Earthquake; (d)Jiuzhaigou Earthquake;

3.3 Characteristics of typical anomalous changes

The number of radon concentration precursor anomalies in the North–South seismic belt before several strong earthquakes is relatively high, and the morphological characteristics are relatively complex. Nonetheless, some regular change characteristics can be observed. The radon concentration anomalies are mainly manifested as reversal or accelerated changes of trend-based background changes. Figure 3 and Figure 4 show some typical curves of radon concentration anomalies. The black curve in the figure is the time series of original water radon observations, the blue straight line is the fitted trend of water radon observations, and the red vertical dashed line is the corresponding moment of earthquake onset. These anomalies show a general drooping or rising trend since the observation, and the trend showed reversal or accelerated changes some time before the earthquake. The water radon in Fujianchang began to rise 5 months before the Wenchuan earthquake. The water radon in Wulipu exhibited a clear dropping trend for many years and began to change approximately 2 years before the earthquake. The water radon in Ya'an exhibited a slower trend approximately 3 years before the earthquake. The water radon in Yangyuan exhibited a clear deviation from the trend approximately 3 years before the earthquake.

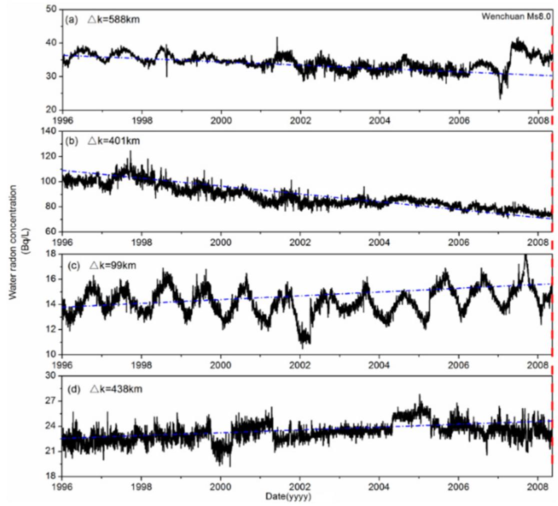

Figure 3. Typical water radon anomaly curves before the Wenchuan earthquake in different observation stations

(a) Fujianchang, (b) Wulipu, (c) Ya'an, (d) Yanyuan

The water radon in Panzhihua deviated significantly from the trend approximately 3 years before the Jiuzhaigou earthquake, that in Gaojiacun expressed a significant trend reversal approximately 4 years before the Wenchuan earthquake and showed a slower trend about 2 years before the Jiuzhaigou earthquake, and that in Yangyuan and Diangou deviated from the trend approximately 3 years before each earthquake.

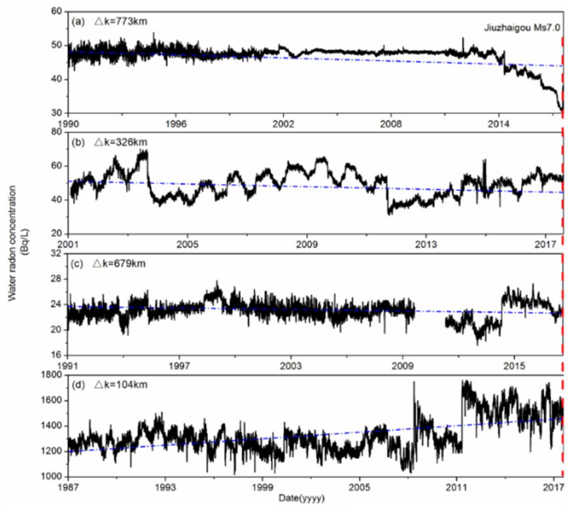

Figure 4. Typical water radon anomaly curves before the Jiuzhaigou earthquake in different observation stations

(a)Panzhihua, (b)Gaojiacun, (c) Yanyuan, (d)Diangou

4 Conclusion

In this paper the radon concentration anomalies of the

North–South seismic belt (22°-35° N, 100°-110° E) before the Wenchuan earthquake (8.0 N, May 12, 2008), the Lushan earthquake (7.0 N, April 20, 2013), the Minxian-Zhangxian earthquake(6.6 N, July 22, 2013), and the Jiuzhaigou earthquake (7.0 N, August 8, 2017) were collated. The variation characteristics, spatial distribution characteristics and spatiotemporal evolution characteristics of radon concentration anomalies were studied. The following conclusions were drawn:

(1) Among the 45 radon concentration measurement items nearly 30 years in the study area, The proportion of anomalies before the Wenchuan earthquake was 82%; the proportion of anomalies before the Jiuzhaigou earthquake reached 72%; the proportion of anomalies before the Lushan earthquake was 67%; the proportion of anomalies before the Minxian earthquake was low; and the distance between radon concentration anomalies to the epicenter ranged from 14 to 1028 km.

(2) The anomalies appeared several days to several years before the related earthquakes. In Wenchuan earthquake, the anomaly appeared in 2001 at the earliest and 9 days before the earthquake at the latest; The anomaly appeared in 2011 at the earliest and 28 days at the latest before the Lushan earthquake; Before the Minxian earthquake the anomalies appeared in 2011 at the earliest and 1 month at the latest; and the anomalies from 2014 at the earliest to 23 days at the latest before the Jiuzhaigou earthquake. The longer anomaly trends exhibit migration toward the epicenter: the closer to the epicenter area, the more observation points recorded anomalies. The measurement points closer to the epicenter showed anomalies earlier than surrounding points.

(3) The morphological characteristics of anomalies are quite complex and generally show the characteristics of trend-based anomalous changes. That is, for dropping or rising trends, they deviated from the multi-year linear trend to with accelerated changes within 1–3 years before the earthquake.

(4) The results of this study show that underground fluid precursor anomalies at large spatial and temporal scale may be observed before large earthquakes, which has important reference significance for improving our understanding of precursor observation data. Although this study is limited as a retrospective earthquake case study, it has important practical significance and scientific value for the in-depth understanding of the relationship between radon concentration anomalies and strong earthquakes and their formation mechanisms, requiring the accumulation of observation and seismic case data for further in-depth study.

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