The correlation between variation of radon content in groundwater and earthquakes (*)

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Summary. — During the last 30 years, multidisciplinary studies of earthquake precursors have been performed in China. This paper introduces some results of the research on the correlation between variation of radon content in groundwater and earthquakes and the general features and complexity of earthquake precursors. After the 1966 Xingtai $M_S = 7.2$ earthquake, using radon content variation in groundwater to predict earthquakes has been systematically studied in China. In the last 30 years a lot of observational data on earthquake precursors have been accumulated, and researches on the correlation between the variation of radon content in groundwater and earthquakes have been carried out.

PACS 91.30.Px – Phenomena related to earthquake prediction.
PACS 91.25.Ey – Interactions between exterior sources and interior properties.
PACS 92.40.Kf – Groundwater.
PACS 01.30.Cc – Conference proceedings.

1. – The correlation of radon variation with seismic activity

We have studied radon anomalies, comparing with seismic activity before and after strong earthquakes in North China [1-4].

It was noted that the seismic activity of $M_S \geqslant 3.0$ before and after the three strong earthquakes in North China was closely correlated with the fluctuation of the trend anomalies in radon content (fig. 1). The monthly earthquake frequency before Bohai earthquake (July 18, 1969; $M_S = 7.4$) rose gradually with increasing radon content, which indicates a good correlation between them. Similar pictures had also been demonstrated before the Haicheng earthquake (February 4, 1975; $M_S = 7.3$) and Tangshan earthquake (July 28, 1976; $M_S = 7.8$). While the crustal stress within a large area further strengthened before these strong earthquakes [5], the earthquake frequency increased, and the radon content also increased in the same area. This indicated that the variation in radon content is closely related to the crustal stress.

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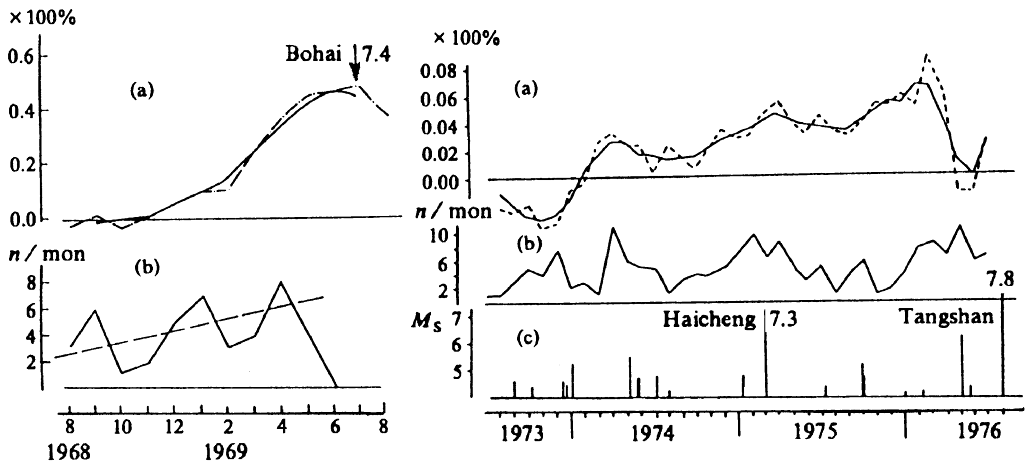

Fig. 1. – The correlation between the radon content trend anomalies and the seismic activity before Bohai, Haicheng and Tangshan earthquakes: (a) Compounded monthly rate of radon content from 6 sites in the northern most part of North China; (b) monthly earthquake frequency (*n*/mon) with $M_S \geqslant 3.0$ in North China; (c) earthquake sequence with $M_S \geqslant 4.0$ in North China.

We have calculated the monthly frequency of earthquakes with $M_L \geqslant 2.0$ (excluding the aftershocks of Bohai's earthquake) from January 1973 to July 1976 in the Beijing-Tianjin-Tangshan area (38–41 °N, and 116s–120 °E). It has been noted that the monthly earthquake frequency had a certain correlation with the monthly average radon content in groundwater in the Angezhuang and Tiantan wells which are located near the epicenters of the Tangshan $M_S = 7.8$ earthquake (epicentral distance of 40 km and 50 km, respectively) and its strong aftershock with magnitude of $M_S = 7.1$ (epicentral distance of 10–25 km). The statistics (table I) showed a good correlation between the monthly earthquake frequency and the monthly average radon content one month before (*i.e.* the correlation coefficient γ is higher than the theoretical value with a confidence level of $\alpha = 0.05$). It is of precursory interest since radon anomalies appear ahead of seismic activity.

TABLE I. – *Correlation coefficient γ between monthly earthquake frequency N and monthly average radon content A.*

Names of the wells	γ with confidence level $\alpha = 0.05$	Correlation coefficient γ between N and A		
		between N and A in the same month	between N in a month and A one month before	between N in a month and A one month after
Angezhuang	$n = 38$* $\gamma_{0.05} = 0.321$	0.045	0.431	0.046
Tiantan	$n = 41$* $\gamma_{0.05} = 0.308$	0.207	0.337	0.056

* *n* represents the number of months involved in statistics.

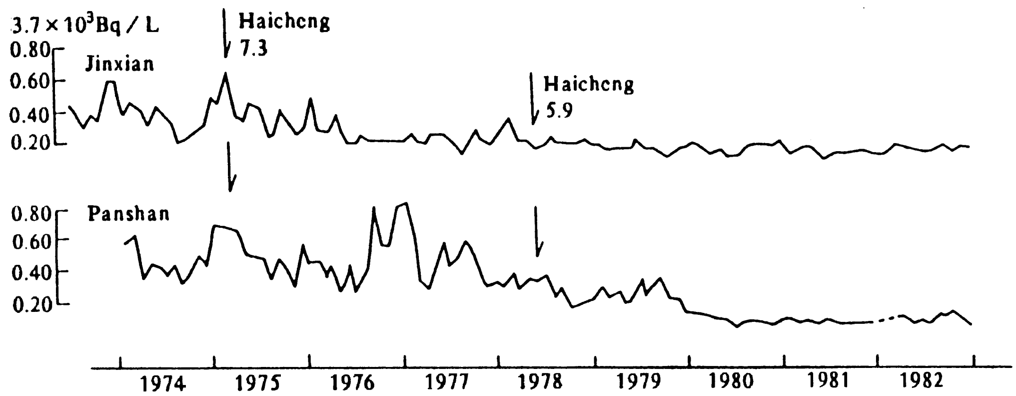

Fig. 2. – Monthly average of the absolutely daily derivative of radon content in groundwater at Panshan and Jinxian stations.

Figure 2 shows the monthly average of the absolutely daily derivative of radon content in groundwater from 1973 to 1982 at Panshan and Jinxian stations in the Liaoning province, which are 80 km and 200 km away from the epicenter of the Haicheng earthquake, respectively. It can be seen from fig. 2 that the radon content at both

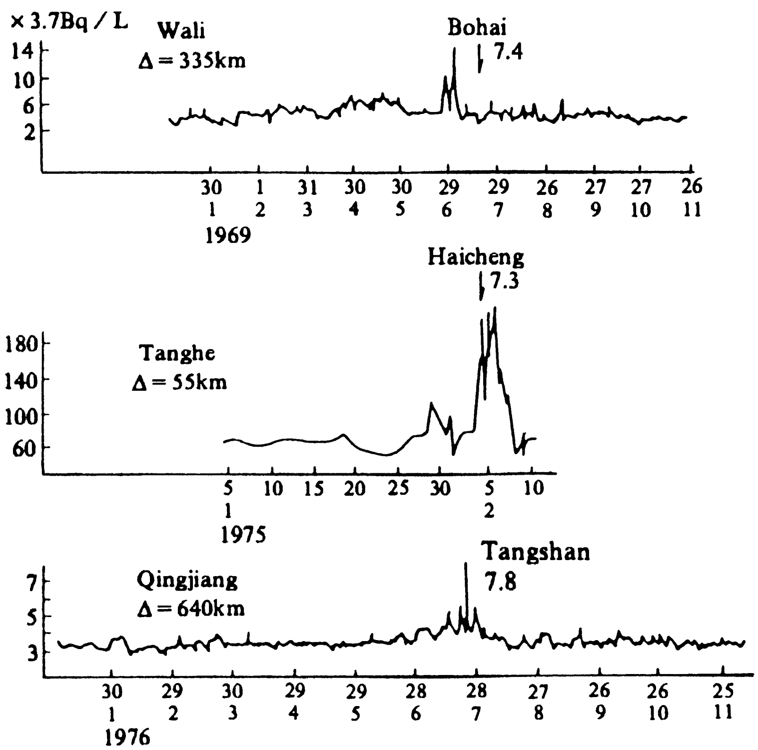

Fig. 3. – Imminent abrupt changes of radon content in groundwater before three strong earthquakes in North China.

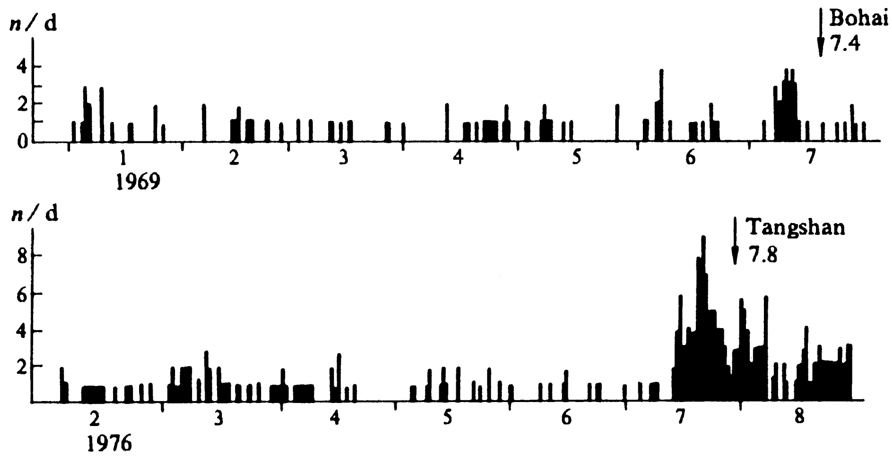

Fig. 4. – The daily frequency (n/d) of abrupt radon content changes in the wells in North China before the Bohai and Tangshan earthquakes.

stations changed distinctly before the $M_S = 7.3$ earthquake, and anomalies at both stations appeared simultaneously in 1974-1976, and the curves became smooth after the last strong aftershock with magnitude of $M_S = 5.9$ (May 18, 1978). Since the aftershock, no anomaly appeared up to now and also no such strong seismicity like the Haicheng and Tangshan earthquakes occurred in this region as well.

Before a strong earthquake imminent abrupt anomalies can appear near and far from the future epicenter. Figure 3 shows the abrupt changes of radon content in groundwater before three strong earthquakes in North China. For example, the abrupt changes of radon content in the Tanghe well appeared half an hour before Haicheng earthquake with maximum amplitude about 10 times greater than normal fluctuation. Although an abrupt change of radon content at a single site may be random, the abrupt changes at several sites increase the reliability of anomalies. Figure 4 gives the daily frequencies of abrupt increases in radon content in the several wells of the Beijing-Tianjin area during the period of half a year before the Bohai earthquake and at 50 observational sites in North China before the Tangshan earthquake. It shows that the daily frequency of abrupt changes of radon content increased distinctly 10 days before those strong earthquakes.

The above phenomena also show that there may be some inner link between radon content and seismic activity. The trend anomalies and abrupt increases in radon content possibly reflect the variation of regional stress in North China and the stress from the impending earthquake. Therefore there is a possibility to use them in earthquake prediction. Analysis of changes in seismic activity and in radon content could increase the reliability of earthquake prediction.

2. – The general features and complexity of earthquake precursors

Zhaocheng Zhang and other 45 researchers have resorted the multidisciplinary data of 60 earthquake cases of $M_S \geqslant 5.0$ from 1966 to 1985 in the Chinese mainland, with the emphasis on the precursors of these earthquakes [6-8]. 927 multidisciplinary precursory anomalies were observed before them, including 127 radon content anomalies before 36 earthquakes. Radon is one of the most important items for precursory observation. In summary, various precursors showed dynamic pictures of development with several phases in time and uneven distribution in space in a large area with relative concentration near the future epicenters. These data substantiated that the precursors do exist prior to most earthquakes although they could be quite complicated.

We have also studied observational data of more than 80 earthquakes obtained in the area where radon observational stations exist in China. Those data also confirm the above-mentioned general features of anomalous variation. Within a distance of 0–640 km from the epicenter and for several years before strong earthquakes, the precursory anomalies of radon content appeared, relatively concentrated within 200 km near the epicenter of future earthquakes. The epicentral distance and duration of anomalies for earthquakes with magnitude of 5–6 (M_S) are much smaller than that for strong earthquakes. Those spatio-temporal processes obviously related with earthquakes, and may be closely linked with the process of earthquake preparation.

However, the anomalous variation of radon content we observed belongs to earthquake precursors in a broad sense [5]. We believe that there are two types of precursors. The broad that scale anomalies are observed over a large area (500 km or greater) and appear to reflect a general increase in tectonic activity, including seismic activity. These are useful in identifying a large area where there is an increased probability of earthquake occurrence. The small-scale anomalies (200 km or less) are more closely associated with an impending earthquake. They could contain the information from a single seismic focus. At present we may detect anomalies, but it has been difficult to distinguish among them the anomalies caused by tectonic movement (they are referred to as "tectonic precursors") and the information from a concrete seismic source (called "focal precursors"). Therefore, the relationship between precursors and concrete earthquake has a certain indefiniteness, and earthquake precursors are very complicated. One of the important scientific challenges for further study is to identify tectonic precursors from focal precursors.

3. – Conclusions

Our thirty years of studying earthquake precursors have thus led us to some important conclusions:

1) Anomalies of radon content in groundwater have been observed before a lot of moderately strong earthquakes. They are related with earthquakes.

2) At least some earthquakes, especially strong earthquakes, possess precursors, although they can be quite complicated.

3) These precursors can be used to predict earthquakes in some cases.

4) There has been certain progress, but it is a long way to go.

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