Frequency of foreshocks

In February 1975, the Chinese Seismological Bureau successfully predicted a magnitude 7.3 earthquake near Haicheng, Liaoning Province. From their reports, it is obvious that many methods such as radon count, abnormal animal behaviour, seismic velocity, and tilt and telluric current anomalies were considered in making the long term prediction. The short term prediction, however, was based primarily on foreshock activity. That foreshocks were important in the prediction raises the question of how common they are. We here analyse the frequency of foreshocks before shallow earthquakes with magnitudes greater than 7. Our findings show that 44% of all large shallow events in the world from 1950 to 1973 had foreshocks large enough to be teleseismically recorded, and that 21% of the large earthquakes that occurred in China between 1900 and 1949 had foreshocks large enough to be noted in local records.

We used two catalogues to cover the different periods of time. We searched the catalogue of Chinese earthquakes for the period 1900–49 for events preceding and near each earthquake with $M > 7.0$. Since the smallest magnitudes listed are about 4.5, and since they are listed only for the more recent portion of this period, the catalogue does not include many small events that would have been recorded and located with present-day instrumentation. For the period 1950–73, we searched a catalogue of world events compiled by the National Oceanic and Atmospheric Administration (NOAA) for foreshocks before all events in the world with $M > 7.0$ (1950–64), and (1965–1973). The NOAA list includes all events located with teleseismic recordings by US Government agencies (Coast and Geodetic Survey, NOAA and Geological Survey) and by the Bureau Central International de Seismologique. Therefore, only events with $M \geq 4$ are included. The list is complete only for events with $M \geq 5$ (refs 7 and 8) for more recent years.

![Fig. 1 Foreshock activity as a function of time before main shock. For each day before main shock the total number of foreshocks and the number of days before which the foreshock closest in time to the main shock (hatched area) occurred are shown.](image)

For some periods of time and some epicentral areas the location capability was particularly low, and no relatively large foreshocks or aftershocks were located. As we were interested in how many major earthquakes were preceded by foreshocks, we decided not to include events with two or less aftershocks.

![Fig. 2 Map showing earthquakes with $M \geq 7.8$ (circles) and $7.0 \geq M < 7.8$ (triangles) during 1950–1973, exclusive of China, for which 3 or more aftershocks were located. Events for which at least one foreshock (closed symbols) was located and no foreshocks (open symbols) were located are shown. ×. Events with less than 2 teleseismically located aftershocks, but with foreshocks.](image)
listed in this catalogue. Thus, of the 246 events between 1950 and 1973 with $M > 7.0$, we used only 163. In fact, of 83 events with two or less aftershocks, 7 were preceded by at least one teleseismically located foreshock.

Because the source dimensions of earthquakes with $M > 7$ are of the order of 100 km, and, because of expected inaccuracies in epicentral determinations, only events located within 100 km of the main shocks were considered to be foreshocks, even though aftershocks often occurred at greater distances from them. To be classified as a foreshock an earthquake also had to occur within 40 d of the main event. By that criterion, however, 31 of the 72 cases of foreshock activity actually occurred within 24 h of the main shocks and 58 were within two weeks (Fig. 1).

That 44% of the earthquakes with $M \geq 7.0$ and at least three teleseismically located aftershocks were preceded by at least 1 teleseismically located foreshock suggests that foreshocks are a common occurrence. The Chinese have shown that they can be used to predict major earthquakes. The large number of locally recorded foreshocks preceding the 1965 Ceram Sea, 1966 Republic of Zaire, and 1968 Luzon earthquakes\(^{12}\). Evidently, none of these foreshocks was located teleseismically. Although foreshocks were the basis of the prediction of the 1975 Haicheng earthquake, none was teleseismically located by the US Geological Survey. We searched for field reports of the major events between 1950 and 1973, and found documentation of foreshocks in eight cases, for which no teleseismically located foreshocks were listed.

Figures 2 and 3 show the geographical distribution of the main shocks studied, and also show which had teleseismically located foreshocks. Seventy-two of 163 major earthquakes between 1950 and 1973, or 44%, had at least one foreshock in the NOAA list. Of the earlier earthquakes in China, 10 of 48, or 21%, had foreshocks. The lower value for China probably reflects a less complete record for the period 1900-49 than for more recently. In fact, Imamura\(^{9}\) noted in 1937 that “big earthquakes” are preceded by foreshocks only 20% of the time, but anticipated that this percentage would increase as better instrumentation was installed.

It seems that even 44% is too low an estimate. Many earthquakes that had no foreshocks in the NOAA list (and thus not included in the 44%) are, in fact, known to have been preceded by foreshocks. For instance, Richter\(^{10}\) mentioned that a foreshock occurred within 24 h of both the 1952 Kern County, California, and the 1954 Fairview Park, Nevada, earthquakes. There were 35 earthquakes in the two days before the March 1966 earthquake in the Republic of the Congo\(^{11}\), a week of foreshock activity preceding the 1965 earthquake in the Ceram Sea\(^{6}\), and 10 foreshocks within 24 h of the August 1, 1968

Fig. 3: Map of earthquakes in China. Symbols as in Fig. 2.

That 44% of the earthquakes with $M \geq 7.0$ and at least three teleseismically located aftershocks were preceded by at least 1 teleseismically located foreshock suggests that foreshocks are a common occurrence. The Chinese have shown that they can be used to predict major earthquakes. The large number of locally recorded foreshocks preceding the 1965 Ceram Sea, 1966 Republic of Zaire, and 1968 Luzon earthquakes could have provided a data base comparable to that of Haicheng, and with adequate instrumentation may have opened the door to prediction. That is not to say that all earthquakes can be predicted by foreshock activity, as there do not yet seem to be definitive methods for discriminating foreshock activity from background seismicity. Not all earthquakes, in fact, seem to be preceded by foreshocks. The February 9, 1971, San Fernando earthquake ($M = 6.6$) is an example\(^{15}\). Moreover, it is not obvious that the magnitude of an impending earthquake could be predicted by foreshocks alone.

Nevertheless, with the growing evidence of short term premonitory slip before major earthquakes\(^{9,14-18}\), the frequent occurrence of foreshocks may indicate that premonitory fault slip or accelerated deformation in the focal area is a ubiquitous
phenomenon preceding all major earthquakes. Indeed, the rapid increase of seismic activity before major earthquakes (Fig. 1) is similar to that of microfracturing observed in the laboratory. Foreshock activity could well be the cause of many of the reports of anomalous animal behaviour. Together with aseismic deformation it could also be responsible for ground tilt, telluric current, magnetic field and well water level changes in the few days preceding major earthquakes. Thus it seems possible that all short term (and perhaps long term) premonitory phenomena are a consequence of either seismic or aseismic slip before major earthquakes.

We thank W. F. Brace and F. Press for interest and encouragement. This research was supported by an Alfred P. Sloan fellowship and by the National Science Foundation.

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