Analysis of foreshock sequences in the Iranian plateau

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Abstract

We analyze foreshock activity in the Iranian plateau by investigating the occurrence patterns for isolated M>5.5 earthquakes from 1968 to 2018. Among the 165 mainshocks with M>5.5 (after excluding 12 aftershocks, 8 swarms and 9 foreshocks) 18 percent are preceded by at least one foreshock within 30 days and 20 km. However, the number of events in each foreshock sequence is significantly higher in the last ten years of the catalog. This difference is partly explained by the rapid expansion of the Iranian national seismographic network in the recent years. Based on our analysis, the completeness of the catalog was reached at 3.4 (2016-2018) from 4.1 (1968-1998). Foreshock occurrence appears correlated with mainshock faulting type and depth; however, it is not correlated with mainshock magnitude. These results suggest that foreshock occurrence is largely controlled by the regional tectonic stress field and fault zone properties. In special cases, foreshock activity is considered as one of the most promising precursory changes for the main shock prediction in the short term; however, foreshock properties are not reliably predictive of the magnitude of the eventual mainshock.

Introduction

In an earthquake sequence, foreshocks are earthquakes that occur prior to the main shock. The foreshock activity often shows significant differences compared with the ordinary seismicity and migration and acceleration prior to the mainshock (e.g., Marsan et al., 2014). Temporal distributions of foreshocks are quite variable. Mogi (1965) classified the foreshock sequences into two types, C and D. In type C sequences, the activity increases gradually toward the mainshock. In type D sequences, the mainshock occurs after the foreshock activity dies down. Although no detailed statistics are available, type D seems to form a majority of foreshock sequences.

A point of controversy, however, is the definition of the short-term foreshocks and the recognition of foreshocks in seismic catalogues strongly depends on the definition adopted. Spatial-temporal restrictions may exclude foreshock events occurring outside the preselected narrow space-time limits, thus leading to biased results. Pre-selected foreshock definitions may partly explain why only some mainshocks are preceded by short-term foreshocks. On the other hand, the occurrence of foreshocks very likely depends on a variety of geophysical factors, such as the style of faulting, the focal depth, and the degree of small-scale crustal heterogeneity (Cheng and Wong, 2016). The completeness of the catalogue is also an important factor. In seismic catalogues, particularly the ones produced by routine procedures, small foreshocks usually are overlooked and are not catalogued (Papadopoulos et al., 2006). To use foreshocks as a potential tool for the short-term earthquake prediction, it is of great importance to discriminate between foreshocks and other types of seismicity clusters, e.g., swarms and main-shock-aftershock sequences, which again depends on the foreshock definition.

History of earthquake monitoring in Iran

Institute of Geophysics of the Tehran University (IGUT) established the first modern seismic station in Iran in Tehran in 1951; the service was expanded to the capital. In 1960s, the number of IGUT seismic stations increased to six, including one local station in Sefid-Rud (1962) and four others in Shiraz (opened in 1963/30). Kermaniash opened in 1965/54, Tabriz (opened in 1965/08) and Mashhad (opened in 1965/03). Three stations in Tabriz, Mashhad and Shiraz were a subset of the World-Wide Standardized Seismographic Network (WWSSN). In January 1978, the Iranian Long Period Array (ILPA) comprised of seven wideband borehole seismometers began its operation in southwest of Tehran (Akhshai et al., 1976). ILPA is considered as the first digi/analog seismic recording facility in the country which was operational until the early 2000s. Also, in the early 1980s five new IGUT analogue recording stations were opened in Brojen, Minudasht, Mahabad, Ghasem-e-Kashan and Chahal-Ghazi.

The era of digital seismography in Iran was started in 1996 by the completion of two isometric local networks around the large cities of Tehran and Tabriz. Seismic stations were equipped with the capability of real-time short-period, medium-band or broad-band seismometers. Today, the Iranian seismological network (operated by the IGUT) is comprised of 20 local networks with 13 seismic stations (in total) which covers most of the earthquake-prone regions of the country.

In addition to the IGUT seismic network, International Institute of Earthquake Engineering and Seismology (IIEES) that was founded in 1962 with the aim of seismological activity such as service equipped with broadband sensors. Also a provincial network of eight stations (KHSN) in northeast of Iran is maintained by the Ferdowsi University of Mashhad.

Data and Analysis

We search for isolated mainshocks with M>5.5 using three catalogues that exclusively dedicate to earthquakes in the Iranian plateau including the national (IGUT) catalog, IIEES catalog and the revised catalog of Farahbod & Alahyarkhani (2000). M is the homogenous estimate of moment magnitude (Kishida et al., 2019). Magnitude of completeness (Mc) of the compiled catalog is estimated (Zapata & Wismer 2001) between 5.1 (1968) and 3.4 (2008-2018). To reduce potential catalog incompleteness issues for smaller earthquakes and as a compromise, we use events with M>3.0 in this study. We select mainshocks that are relatively isolated from other large events, i.e., events that are not part of aftershock sequences or immediate foreshocks of larger events. In this regard, we exclude earthquake swarms and doublet sequences around similar magnitude (instantaneously). Considering foreshock characteristics of a few documented cases in the past, we define foreshocks in this study as immediate precursory activity within 30 days and 20 km of the mainshock.

Results

Among the 165 mainshocks that we identified from 1968 to 2018 with M>5.5 (after excluding 12 aftershocks, 8 swarms and 9 doublets). 18 percent are preceded by at least one foreshock within 30 days and 20 km. However, the number of events in each foreshock sequence is significantly higher in the last ten years of the catalog. This difference is partly explained by the rapid expansion of the Iranian national seismographic network during the recent years. Based on our analysis, the completeness of the catalog was reached at 3.4 (2016-2018) from 4.1 (1968-1998). Foreshock occurrence appears correlated with mainshock faulting type and depth; however, it is not correlated with mainshock magnitude. These results suggest that foreshock occurrence is largely controlled by the regional tectonic stress field and fault zone properties. In special cases, foreshock activity is considered as one of the most promising precursory changes for the main shock prediction in the short term; however, foreshock properties are not reliably predictive of the magnitude of the eventual mainshock.

Conclusions

In the Iranian plateau most of the tectonic displacement is accommodated by the Zagros mountain belt, through strike-slip faults in Central Iran, the shortening of the Alborz mountain in the north, the shortening across the eastern Kopet Dagh in the northeast, and the Makran subduction zone in the southeast. Considering the limited time window of this study (50 years), incompleteness of the compiled catalogue (specifically in the first 30 years) and relatively high location uncertainty of the events, we conclude that foreshock activity in the Iranian plateau is largely controlled by the regional tectonic stress field and fault zone properties.


