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Editorial: From preparation to faulting: multidisciplinary investigations on earthquake processes

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Editorial on the Research Topic
From preparation to faulting: multidisciplinary investigations on earthquake processes

1 Aims and content of this research topic

In seismically active areas (e.g., Han et al., 2022), the best way for disaster mitigation is to enhance the skills of risk evaluation and prediction (Shao et al., 2023). What happens before an earthquake occurs? Which are the physical processes that take place in the Earth's crust before the earthquake nucleates? How can we observe, describe, and model them statistically, numerically, and physically in multi-scales from laboratory samples to tectonic earth plates? Those questions are fundamental but have not been completely solved (Geller, 1997; Pritchard, et al., 2020).

Over the last few decades multidisciplinary studies have attempted to answer these fundamental questions (e.g., King, 1978; Ma, 1987; Kanamori and Brodsky, 2001). In the early days, the Institute Physics of the Earth (IPE) model (dry) (Myachkin et al., 1975) and the Dilatance Diffusion (DD) model (wet) (Scholz et al., 1973) were proposed for earthquake processes. Like Schrödinger's cat, an earthquake is unpredictable—according to the IPE model, yet it can be predictable—according to the DD model (Ma, 1987). Recently, with advanced techniques, some scientists have discovered the meta-instable stage before failure to slip (Ma et al., 2012) and assuredly claimed that there are precursors to be used for earthquake forecasting (Ma, 2016), which envisages new opportunities to study earthquake precursors (Pritchard, et al., 2020).

An understanding of the governing laws (e.g., King, 1978; Zöller et al., 2010; Shi et al., 2020; Chen et al., 2022), from long-term tectonic loading (Zhang et al., 2022) and nucleation to rapid rupture propagation (Yang et al., 2022), is significant to earthquake forecasting and demands a comprehension of the stress state and evolution during the time of geophysical observations around seismically active areas (Zhao et al., 2020; Zhao et al., 2022). The evidence from multiscale experiments (Ma and Guo, 2014; Huang et al., 2019; Huang et al., 2020; Martinelli et al., 2020), multidisciplinary monitoring system networks (Huang FQ. et al., 2017; Martinelli et al., 2021), numerical modeling (Barbot et al., 2012; Huang FQ. et al., 2017; Ben-Zion, 2017), and field investigations (e.g., King, 1978), are the keys to advance our understanding of earthquake mechanics.

Earthquakes do not occur everywhere. Fault geometry and the physical properties of fault zones (namely, seismogenic structure), geological and tectonic settings (Wang et al., 2014; Dascher-Cousineau et al., 2020; Gong et al., 2020), as well as crustal movement and the geodynamic environment, play pivotal roles in the seismic patterns (e.g., King, 1978; Ikeda, 2009; Luo et al., 2023). A variety of geophysical and geochemical observations, ranging from ground-related deformation patterns (GPS, SAR, *etc.*) (Bürgmann et al., 2000; Zhao et al., 2020) to pre-earthquake changes (geochemical, electromagnetic, hydro-geological, geodetic, or thermodynamic) (Huang F. Q. et al., 2017; Zhou et al., 2020; Chen et al., 2021; Martinelli et al., 2021; Zhou et al., 2021), recorded by ground-based (Li et al., 2022) or satellite-based techniques (Li et al., 2020) may be related to stress variations in the lithosphere (Luo et al., 2023) prior to an eventual large earthquake (Zhao et al., 2022). Even though much effort has been invested, the earthquake "elephant in the room" is still in the process of being understood.

This Research Topic aims to provide state-of-the-art studies on earthquake processes via multidisciplinary approaches from geophysical, geochemical, geodetical, and geological routines which are mostly exchanged at the annual conference of the China Earthquake Prediction Forum (Huang et al., 2023). Pre-earthquake observations, methods, and perspectives, can provide a current view in the knowledge of processes preceding earthquake occurrence in China, which can be possibly employed to set up earthquake forecasting experiments, aimed at their verification Test Site areas, whether large or small.

2 Overview on published contributions

There are eleven articles collected for this Research Topic, involving precursors of monitoring networks and earthquake prediction methods (four articles), stress state of the geodynamic environment inferred from recent earthquakes (two articles), seismogenic structure and fault geometry from deep to surface (four articles) and models for earthquake risk assessment of the National Test site (one article).

2.1 Precursors of monitoring networks and earthquake prediction method

Extracting anomalous changes relevant to earthquake processes from observation systems is the key step to routine earthquake prediction. Here we have collected one article based on laboratory work that involves judging rock instability by enhanced LURR (short-term to imminent before "earthquakes," by Zhang et al., *The evolution characteristics of rock fracture instability under cyclic loading on the basis of the enhanced LURR*), and three articles involving the extraction of anomalous changes before strong earthquakes on the China Mainland from seismograph observation systems from the long-term to the short-term stage. Frequency field (Luo et al., *Pre-quake frequency characteristics of Ms ≥7.0 earthquakes in mainland China*), b-value (Bi et al., *Strong aftershocks traffic light system: A case study of the 8 January 2022 MS6.9 Menyuan earthquake, Qinghai Province, China*) and anomalous quiet or enhanced processes of small to moderate earthquakes before the strong earthquakes (Gao et al., *Low-intensity anomaly involving ML≥4 events preceding strong earthquakes in Tibet*) are the main items to be discussed.

2.2 Stress state of the geodynamic environment inferred from recent earthquakes

Stress state is significant for the geodynamic environment of seismic source. The measurement of *in situ* stress state is quite difficult. Inference from existing earthquake sequences is an effective way. The article entitled *Seismogenic structures and spatiotemporal seismicity patterns of the 2022 Ms6.0 Maerkang earthquake sequence, Sichuan, China* (Feng et al.) investigates the seismogenic structures and mechanics of this sequence by relocating the earthquake sequence, inverting for the focal mechanisms, and calculating the rupture directivity of the Maerkang earthquake sequence. The paper of *Eastward expansion of the Tibetan plateau: Insights from stress drops of the 2021 Ms 6.4 Yangbi, Yunnan and Ms7.4 Maduo, Qinghai earthquake sequences in China* (He et al.) estimates the stress drops of the Yangbi and Maduo earthquake sequences for all M ≥ 3.0 events from the Lg-wave spectra. The results of the stress drops of two sequences are very likely linked with patterns of crustal motion and deformation in the eastern Tibetan Plateau.

2.3 Deep to surface seismogenic structure and fault geometry

Geometry and movement are the main objectives, which can be used in prediction models. We collected four articles investigating the deep to surface seismogenic structure and fault geometry, which deal with inference from seismic waves of natural earthquakes, active seismic sources or ambient noise (Li et al., *High resolution upper crustal velocity and seismogenic structure of the Huoshan "seismic window" in the Dabie orogenic belt*), and from electric resistivity of the mass beneath the earth surface (Yan et al., *Deep electrical structure of the hinterland of Yunkai magmatic arc in South China and the seismogenic environment of the 2019 Beiliu earthquake*), from relocations of earthquake sequences observed in a permanent station and portable dense array (Zeng et al., *Investigation of the 2015 Ms5. 8 Alxa Left Banner earthquake sequence: Aftershock evolution* *and seismogenic structure* by here), as well as from field investigations of surface fault trace in detail (Ma et al., *Active faulting of the Nanhe fault and relation to the Anninghe Fault Zone in late Quaternary, eastern Tibetan plateau*).

2.4 Models for earthquake risk assessment of national test site

The straightforward dedicated models are significant for earthquake risk assessment (Zhang et al. *Statistical evaluation of earthquake forecast efficiency using earthquake-catalog and fault slip rate in the Sichuan-Yunnan region, China*). The works indicate that the model-driven and hyper-parameter controlled mode is a promising approach to implement operational earthquake forecasting at the National Test site of China.

All the above progress is based on advanced observation techniques and monitoring systems from ground to space currently operated in China.

3 Discussion and perspectives

3.1 The physical nature of the empirical operation routine for earthquake prediction

Since the 1966 Xingtai earthquake, routine prediction operations have been practiced continuously in China. The progress was named as a step-by-step strategy from long-term, medium-term, short-term to imminent relevant to ≤10 years, 1–3 years, 3 months to 1 year and days to 3 months respectively, which were summed from an operational process of empirical earthquake prediction activities (Ma et al., 1989) and tested *a posteriori* by experiments of tectonophysics (Ma, 2016). Here in this volume, the works of Luo et al., Gao et al., Bi et al. provide practical evidence to support the results from tectonophysics experiments, the works of Zhang et al. provided new kind of criteria to judge the meta-instable stage. How to transfer the empirical operation routine into a physical operation process may be a prospective road guiding to physical earthquake predictions in numerical modelling.

3.2 How to use engineering disaster events to understand the physics of natural earthquakes calls for further investigation

Stress state and focal mechanisms supply a wide view with which to understand the nature of the earthquake process. In practice, events with a depth of within 5 km are generally considered as events induced by human activities, e.g., mining exploration and reservoir pounding, and so on. Thus, the significance of shallow earthquakes, namely, “engineering disaster events,” is overlooked. No matter how deep the event occurs, the stress state is the main factor to understand the physics of rock failure and fault slip in nature (Chen et al., 2022). Research into the stress state and the geodynamic environment from shallow to deep is welcome in the future, being useful to understand the unified nature of earthquakes.

3.3 What controls the precursor patterns for different earthquake relevant to earthquake modeling aimed at earthquake prediction?

From a general view, seismogenic structure and stress state control the earthquake process. Fault geometry and movement are the main objectives, which can be used in prediction models. In fact, in the short-term to imminent stage before earthquake occurrence, the correlation between precursors and the targeted earthquake is not unique (Ma et al., 1989). What controls the precursor patterns for different events relevant to earthquake modeling aimed at earthquake prediction? At the very start of this Research Topic, the difference between IPE (dry model) and DD (wet model) models is the fluid involved. Do rock fluids control the precursor pattern for different earthquakes? More articles related to this Research Topic are welcome in the future.

Author contributions

FH and GM revised the paper. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher’s note

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