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Editorial: From preparation to faulting: multidisciplinary investigations on earthquake processes, volume II

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

1 Aims and content of this Research Topic

This Research Topic "From Preparation to Faulting: Multidisciplinary Investigations on Earthquake Processes - Volume II" is in the series of the research topic "From Preparation to Faulting: Multidisciplinary Investigations on Earthquake Processes," so the two research topics shared the similar aims and contents (Huang et al., 2023a). Recent research progress provides state-of-the-art studies on earthquake processes via multidisciplinary approaches coming from geophysical, geochemical, geodetical, and geological routes, which were mostly exchanged at the annual conference of the China Earthquake Prediction Forum (Huang et al., 2023a; Huang et al., 2023b; Huang et al., 2024). As we have noted (Huang et al., 2023a), in seismically active areas, the best disaster mitigation method is to enhance risk evaluation and prediction skills. Over the last few decades, multidisciplinary studies from small-scale fractures in the laboratory to real seismogenic structures in field test sites have given us opportunities to understand the nature of earthquake processes from preparation to faulting. Pre-earthquake observations, methods, and perspectives can provide an up-to-date view in our knowledge of processes preceding earthquake occurrence in China; modeling, which can be employed to set up earthquake forecasting experiments, aims to verify test site areas, whether large or small, even across the world.

2 Overview on published contributions

There are 15 articles collected for this Research Topic volume II, mostly involving precursors from space view (two articles) and from ground base observation techniques and monitoring networks (2 articles for bore hole strain meter, 2 articles for chemistry of groundwater, 1 article for electromagnetism, 1 article for seismicity, respectively), involving earthquake hazard risk assessment through conventional (two articles) and unconventional (1 article) approaches, involving the seismogenic structure and fault geometry of seismic source (2 article) and numerical modeling (1 article), and specifically involving seismic wave effects of an historical event for the scale of tectonic plate (1 article).

2.1 Precursors of multidisciplinary monitoring networks: from ground base to space view observation techniques

Extracting anomalous changes relevant to earthquake processes from observation systems is the key step for routine earthquake prediction. In the past, research results mainly came from ground-based conventional observation approaches. Nowadays, supported by advanced space science and technology, anomalies from satellite measurements provide space views on earthquake precursors.

Conventional approaches are ground-based observation systems including groundwater measurements, seismograph measurements, deformation measurements, and electromagnetism measurements. Anomalies from hydro-geochemistry of groundwater measurements are generally considered short-term indicators of earthquake occurrence (Chen and Liu, *Groundwater trace element changes were probably induced by the ML3.3 earthquake in Chaoyang district, Beijing*). Through systematically measuring the chemical components from the surface water to groundwater, scientists can trace the chemical evolution of water and obtain clues as to the mechanisms of earthquake precursors (Bao et al., *Stable isotopes and hydrogeochemical evolutions of groundwater from a typical seismic fault zone in the Mt. Lushan region, Eastern China*). By way of the three-dimensional numerical simulation method and the field component composition method, the response of low-frequency pre-earthquake electromagnetic radiation was calculated; the seismogenic resistivity anomaly and pre-earthquake electromagnetic radiation are obtained (Fan et al., *Characteristic identification of seismogenic electromagnetic anomalies based on station electromagnetic impedance*). By using the conventional method of orthogonal expansion in climate change to seismicity data analysis in an innovative way, the research results showed that the temporal indicators from long-term to short-term stages are process-dependent, and the epicenter indicator of future strong earthquakes is closely related to the fault position and the seismic strain contour (Luo et al., *Spatio-temporal characteristics of seismic strain anomalies reveal seismic risk zones along the Longmenshan fault zone and adjacent areas*). From the satellite data on *China's geostationary meteorological satellite FY-2E/G* for weather forecasting, the characteristics of thermal infrared radiation (TIR) anomalous changes prior to deep and shallow earthquakes in Northeast China have been found to be an short-term indicator (Li et al., *Research on thermal infrared anomaly characteristics of moderate strong earthquakes in northeast China*). From satellite data, scientists also derived the pre-earthquake vertical total electron content (VTEC) variations and statistically researched the characteristics of VTEC before 1,522 shallow (≤60 km) strong (Mw ≥ 6.0) earthquakes in the global area, which occurred between 2000 and 2020, and then declaimed the short-term anomalies within decade-days before earthquake occurrence (Ma et al. , *Statistical analysis of ionospheric vertical total electron content anomalies before global Mw ≥ 6.0 shallow earthquakes between 2000–2020*).

2.2 New views from conventional observation data: borehole strain meter

The borehole strain meter is widely used to observe the strain changes so that the stress-related earthquake precursors can be derived. The co-seismic oscillations of borehole observation data had been neglected due to the low-frequency sampling observation techniques. With high-frequency sampling data, scientists have found a new approach to infer the parameters of the seismic source (Tang et al., *The apparent focal depth, emergence angle, and take-off angle of seismic wave measured by YRY-4-type borehole strainmeter as one kind of strain seismograph*). This result provides support of the comparison of a fiber seismogram with a conventional seismogram, which promotes the conventional techniques for seeking precursors to new application views. In addition to borehole strain meter observation, through the hypothesis of fluid flow, the mechanisms of remote triggering can be understood (Canitano, *Sensitivity limits for strain detection of hypothetical remote fluid-induced earthquakes (Mw ≥ 4): a case study in Taiwan*). This is the first attempt to analyze strain time-series for detecting pre-earthquake strain anomalies related to fluid-induced earthquakes and illustrate the challenges in detecting and characterizing intermediate-to far-afield earthquake precursors caused by the fluid flow in active regions.

2.3 From seismogenic structure and fault geometry to co-seismic deformation of the seismic source: useful arrays and powerful modeling techniques

Fault geometry and movement are the main objectives which can be used in prediction models. With a dense array of seismometers and ambient noise or micro-seismic events, the fault structure of the seismic source can be detected (Zhou et al., *The 3-D shallow velocity structure and sedimentary structure of 2017 Ms6.6 Jinghe earthquake source area derived from dense array observations of ambient noise;* Ma et al., *Micro-seismic events detection and its tectonic implications in Northeastern Hainan Province*). With the finite element method and clear material heterogeneity and geometric complexity, the co-seismic deformation of earthquakes can be inferred through numerical modeling (Shi et al., *Crustal heterogeneity effects on coseismic deformation: numerical simulation of the 2008 MW 7.9 Wenchuan earthquake*). This supplies an approach

suitable to understand the mechanism of earthquake processes and is a significant step forward for the road map of numerical earthquake prediction in China (Huang et al., 2017a).

2.4 Models for earthquake risk assessment: from conventional to unconventional approaches

With the model of probabilistic seismic hazard analysis (PSHA), a global seismic hazard map was created to be widely used in the social economy. This is a kind of expression of long-term forecasting where the earthquake potential model plays a crucial role. The probabilistic seismic hazard function (PSHF) of the model is region-dependent due to the regional data quality based on the regional research level of tectonic settings and seismic events recorded. The map will be modified after regional strong events. Here, we collected one article on PSHF for Sumatra Island (Triyoso, *Probabilistic seismic hazard function based on spatiotemporal earthquake likelihood simulation and Akaike information criterion: The PSHF study around off the west coast of Sumatra Island before large earthquake events*). The neo-deterministic seismic hazard assessment (NDSHA) is the new multi-disciplinary scenario and physics-based approach for the evaluation of seismic hazard and safety—guaranteeing "prevention rather than cure." We collected a review article introducing this new model (Bela et al., *Seismic Rigoletto: Hazards, risks and seismic roulette applications*). They are conventional approaches to the seismic hazard mostly based on earthquake catalogs. Some scientists have found an unconventional approach to the hazard map mainly based on the areas characterized by the occurrence of thermal waters and/or by the release of deep-seated gases, as traced by the isotope composition of associated helium (see Martinelli et al. , *Geofluids as a possible unconventional tool for seismic hazard assessment*).

Based on seismological methods, the impact of seismic wave effects generated by meteorite impacts over 66 million years ago on the solid Earth itself has been quantitatively explored. The research results show that this event promoted the formation of the Indian Ocean plate, which is of great significance for improving our understanding of spatial distribution patterns of the global disaster risk from outer space, as well as for the development of plate tectonics theory (C. LI, *Influence of the Yucatan earthquake event*).

All the above progress in this Research Topic volume is largely based on advanced observation techniques and monitoring systems from ground to space which currently operate.

3 Discussion and perspectives

The progress of geosciences sinks its roots in advanced observation techniques. Through advanced laboratory experiment techniques, various scientists have reported that earthquakes are accompanied by possible precursors that can be used for prediction (e.g., Ma, 2016). The long-term cumulated precursors have supplied opportunities to understand the preparation processes of strong earthquakes (Huang et al., 2017b; Martinelli et al., 2021). By way of co-seismic oscillations observed from the borehole strain meter, seismic source parameters can be extracted (see the works of Tang et al. in this volume), the mechanisms of remote triggering can be explained based on the fluid flow hypothesis (see the works of Canitano in this volume). Based on comprehensive analysis of parameters related to geofluids, the stress evolution, and the global seismicity, an unconventional approach of geofluids can be added to the list of fundamental geological parameters to be considered in the hazard assessment (see the works of Martinelli et al. in this volume). Many innovative ideas are included in the articles of this volume, which will play a role in understanding the nature of earthquake processes.

The question as to how can machine learning techniques be used for extracting the precursors from long-term cumulated observation data is raised. The time for earthquake precursors (e.g., Pritchard et al., 2020) is now ripe! Let us broaden our perspectives and make it happen!

Author contributions

FH: writing–original draft, writing–review and editing, conceptualization, and investigation. JL: writing–original draft and writing–review and editing. GK: writing–original draft and writing–review and editing. GM: writing–original draft and writing–review and editing. MM: writing–original draft and writing–review and editing. PS: writing–original draft and writing–review and editing.

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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.

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