Surveys in Geophysics
https://doi.org/10.1007/s10712-022-09711-6

# Guest Editorial: Special Issue on "Lithosphere Dynamics and Earthquake Hazard Forecasting"

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Received: 7 February 2022 / Accepted: 13 April 2022


Brilliant scientific ideas coupled with quantitative modelling and laboratory experiments have determined progress in seismology and geodynamics for the last several decades. Methods of nonlinear geophysics, inverse problems, mathematical statistics, extreme theory and data analysis have improved knowledge of the structure of the Earth's lithosphere, earthquake generation, predictability, and seismic hazards.

This Special Issue of Surveys in Geophysics "*Lithosphere Dynamics and Earthquake Hazard Forecasting*" is dedicated to the 100th anniversary of the birth of Professor Vladimir (Volodya) Keilis-Borok (1921–2013), a distinguished mathematical geophysicist. For more than 60 years, the topics of seismology, nonlinear dynamics of the lithosphere, and earthquake prediction were central in Keilis-Borok's research. His scientific contributions covered many challenging areas and problems, including

- the concept of the lithosphere as a hierarchical nonlinear dissipative system, where earthquakes and other geological hazards are regarded as critical phenomena (Keilis-Borok 1990; Keilis-Borok et al. 2001), and new paradigms of the predictability of the critical geological phenomena in the lithosphere (Keilis-Borok 1996; Keilis-Borok and Soloviev 2003);
- the discovery of long-range correlations between processes occurring in distant areas (e.g. Keilis-Borok and Malinovskaya 1964), as well as precursory transformation of the background activity of the system prior to a critical phenomenon (e.g. Keilis-Borok et al. 1980, 1988; Knopoff et al. 1996; Shebalin et al. 2000);
- the development of earthquake prediction algorithms successfully tested worldwide by advance prediction (e.g. Keilis-Borok and Kossobokov 1990; Kossobokov and Shebalin 2003); the M8 algorithm is so far the only reproducible and statistically significant method for predicting large earthquakes (e.g. Ismail-Zadeh and Kossobokov 2020);
- the discovery of mosaic structures around fault intersections, where instability is concentrated and large earthquakes nucleate (e.g. Gelfand et al. 1976);

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Published online: 18 May 2022

- the discovery of the integral measure of a network's instability caused by the collective behaviour of the nodes controlling the nucleation of strong earthquakes (e.g. Gabrielov et al. 1996), and Earth-specific features of precursory phenomena in the models of the fault networks (e.g. Keilis-Borok et al. 1997; Ismail-Zadeh et al. 1999);
- the development of the theory of instability induced by mechanical and chemical rock–fluid interactions (e.g. Barenblatt et al. 1981; Gabrielov and Keilis-Borok 1983); and
- the discovery related to critical phenomena and forecasting in socio-economic systems, such as in presidential (Lichtman and Keilis-Borok 1981) and senatorial (Lichtman and Keilis-Borok 1989) elections in the USA and in economic recessions (Keilis-Borok et al. 2000).

We thought that it would be valuable to produce a commemorative volume inviting prominent scientists, who worked on the same or similar research topics and who have high standards of scientific accomplishment, to contribute. Although not all of Keilis-Borok's colleagues and collaborators could contribute to this Special Issue, the result of the effort is now placed before the reader for his/her perusal. The emphasis is different in each article, but the authors have carefully reviewed relevant topics, highlighted challenges and outlined perspectives.

The Special Issue consists of ten papers. It is trying to answer some challenging questions related to earthquake science, predictability, seismic hazards, and the application of scientific knowledge, public preparedness and awareness in disaster risk reduction. The Special Issue highlights the state of the art in complex dynamic systems, quantitative seismology, geodynamics, earthquake forecasting, and hazard assessments by overviewing past developments and looking at future possibilities and perspectives.

Kovchegov et al. (2022) point up the importance of a hierarchical organisation and the emergence of scaling laws in complex systems, such as the Earth's lithosphere (e.g. Keilis-Borok 1990). They review the results that clarify the appearance, parameterisation, and implications of scaling laws in hierarchical systems. This review provides the theoretical and modelling framework for a unified analysis in complex hierarchical systems.

By a multi-parametric description of earthquake activity, Kossobokov et al. (2022) provide quantitative evidence, and a better understanding of seismic processes, before and after catastrophic phase transitions (earthquakes) in the dynamics of the hierarchically organised system of lithospheric blocks and faults. This study confirms the existence of spatiotemporal patterns and different regimes of regional seismic energy release.

Not only main shocks but also their aftershocks can pose a significant hazard. Baranov et al. (2022) provide an overview of the basic models of the aftershock occurrences and advanced methods used to forecast post-seismic hazard, providing the physical mechanisms for aftershock generation and time-dependent models of aftershock processes. They review the methods for assessing the magnitude of the largest aftershock and the duration of strong aftershocks. The authors show that the critical role in assessing post-seismic hazard is earthquake productivity, which describes the ability of earthquakes to produce subsequent shocks.

The earthquake cycle—stress generation, localisation and release—is essentially associated with the elastic rebound hypothesis (Reid 1910). Rundle et al. (2022) discuss two methods to image the earthquake cycle by means of proxy variables, which are based on correlations in patterns of small earthquakes that occur nearly continuously in time. As both methods provide almost equivalent information on the rise and fall of earthquake correlations associated with major seismic events in California, the authors conclude that the resulting time series can be viewed as proxies for the cycle of stress accumulation and release associated with major tectonic activity.

Numerical modelling of the lithospheric block-and-fault dynamics and earthquake occurrences have been reviewed by Ismail-Zadeh and Soloviev (2022). They clarify how the blocks and faults react to the plate motion, how stresses are localised and released in earthquakes, how rheological properties of fault zones exert an influence on the earthquake dynamics, where large seismic events occur, and what is the recurrence time of these events. A few key factors influencing the earthquake sequences, clustering, and magnitudes are identified including lithospheric plate driving forces, the geometry of fault zones, and their physical properties.

Gorshkov et al. (2022) provide an overview of the problem of intraplate seismicity and summarise studies on the identification of potential earthquake sources in continental regions exhibiting different levels of seismic activity. A pattern recognition method is used for morphostructural data analysis. It assumes that the nucleation of strong earthquakes occurs at morphostructural nodes forming at the intersections of faults and other lineaments. Particulars of the nodes capable of generating strong seismic events provides important information required during seismic hazard analysis.

Another important parameter in seismic hazard studies is the maximum possible earthquake magnitude (Mmax). Pisarenko and Rodkin (2022) review the problem of Mmax assessment and analysed statistical, historical and paleoseismic aspects of it. They consider and classify various estimators of Mmax used in seismological practice, including the maximum likelihood, the moment method, the Bayesian formalism, the extreme value theory and the estimators using order statistics.

In probabilistic seismic hazard analysis, an assessment of the mean activity rate and Gutenberg–Richter b-value in addition to Mmax is essential. Several assessment procedures have been developed over the years, each with its particular advantages and disadvantages. The typical estimation techniques for the mean activity rate and the Gutenberg–Richter b-value are discussed and estimated independently from those designed for Mmax. Kijko et al. (2022) focus on systematically constructing joint distributions for the three recurrence parameters for complete and incomplete seismic event catalogues.

Not only natural earthquakes but also anthropogenic seismic events due to gold/coal mining, geothermal and natural gas/oil production, filling of artificial water reservoirs and high-pressure fluid injection present hazards. The reservoir-triggered seismicity is most prominent, where earthquakes may exceed magnitude 6, claiming human lives and the destruction of properties. Gupta (2022) reviews common characteristics and the mechanisms of such reservoir-triggered seismic events which discriminate them from tectonic earthquakes.

The collection of the papers in this Special Issue would be incomplete without a discussion about society's participation in and the societal impacts of hazard forecasting, preparedness and public awareness (e.g. Keilis-Borok and Kossobokov 1990; Ismail-Zadeh and Takeuchi 2007; Davis et al. 2012; Ismail-Zadeh 2021). Notably, public participation in earthquake monitoring and forecasting and public preparedness for disaster risk reduction (P4) can contribute to earthquake prediction research. Wu and Zhang (2022) review some key critical issues related to public participation and preparedness and conclude that public participation in earthquake science is an emerging field in the era of big data, and the P4 task needs a new approach, guidance and technical supports.

We hope that this Special Issue will be of interest to those readers who can inspire further studies of the interdisciplinary research topics that have been reviewed, their significance and shining perspectives.

**Acknowledgements** Without the diligent and diplomatic efforts of Michael Rycroft, Editor-in-Chief of the journal, it would have been very hard to translate the idea into reality (this published Special Issue). Also, we are grateful to Petra van Steenbergen, Executive Editor at SpringerNature, for her care of the Special Issue's quality.

**Funding** Open Access funding enabled and organized by Projekt DEAL.



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