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PREFACE

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Special issue "structures, earthquakes and tsunami hazards in the Sea of Japan"

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The Sea of Japan covers the back-arc basins of the Japanese island arc and shows intense tectonic activities. The formation of the back-arc basins in the Sea of Japan is believed to be related to the subduction of the Pacific and Philippine Sea plates. Coastal areas of the Japanese islands facing the Sea of Japan are positioned at the edge of the back-arc basins (Sato 1994). In the past, large earthquakes with magnitudes larger than 7 occurred in the coastal areas of the Sea of Japan and caused damages to societies repeatedly by strong ground motions and large tsunamis (e. g. Abe 1975; Satake 1985; Tanioka et al. 1995). On March 11, 2011, large tsunamis and strong ground motions from the 2011 Tohoku-oki earthquake caused devastating damage on the Pacific coasts of the Japanese islands, and it motivated research on seismic and tsunami hazards of the entire Japanese coasts. MLIT (2014) constructed the largest tsunami source fault models in the coastal areas of the Sea of Japan, for calculating tsunami inundation prediction. However, the knowledge and information for distribution and geometries of offshore active faults, crust–mantle structures, and the history of past tsunamis in the coastal regions of the Sea of Japan were limited and not sufficient for more accurate estimation of future earthquake and tsunami hazards. The research project named "Integrated Research Project on Seismic and Tsunami Hazards Around the Sea of Japan" (the Japan Sea project) had been carried out by the Ministry of Education, Culture, Sports, Science and Technology, Japan, for eight years since 2013 (MEXT 2021). As a result of the Japan Sea project, the seismic source fault models along the coast of the Japan Sea were constructed (Sato et al. 2021). Under these backgrounds, research on the structures of the crust and upper mantle, seismic activities, tsunamis, and active tectonics in the Sea of Japan and its coastal regions has made significant progress, and seismic and tsunami hazards can be constrained more quantitatively. In addition, research on databases for scientific results and social scientific studies on the hazards view had been performed. In this special issue, 13 papers discuss state-of-the-art methods and results of geophysical and geological observations and modeling, and outcomes of earthquake and tsunami hazards from a background in both earth sciences and social sciences.

Seismic velocity structures provide fundamental information for other geophysical and geological studies. Matsubara et al. (2022) conducted a seismic tomography study for the entire Japanese islands including the Sea of Japan and the Pacific Ocean, using arrival times from reflection surveys and the permanent seismic networks. The shallow structures below the Sea of Japan from the off-Yamagata region to the Noto Peninsula were obtained by using controlled seismic source data. They found that the past large earthquakes in the coastal area of the Sea of Japan occurred at the boundary between high-Vp and low-Vp zones. A deep structure beneath the Sea of

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Japan is indispensable for consideration of tectonics and studies using model simulation. The lithosphere–asthenosphere boundary (LAB) beneath back-arc basins in the Sea of Japan was identified using S-wave receiver functions (RF) (Akuhara et al. 2021). The obtained LAB depths were approximately 45 km beneath the Japan and Yamato Basins and about 70 km beneath the Yamato Rise. The seismic structure estimated using controlled seismic sources has high resolution. Shiraishi et al. (2022) applied reverse time migration (RTM) to offshore wide-angle seismic data acquired with airgun shots and sparsely deployed ocean bottom seismographs (OBSs) for reflection imaging of the Moho discontinuity in the eastern margin of the Sea of Japan. They confirmed that reflections observed in the long offset range were effective in imaging the deep structures. The reflectors could be confirmed to depths of the Moho discontinuity. Their method is effective to identify existing faults for the construction of fault models.

Estimation of shallow seismic structure such as sedimentary layer is also important for seismic hazard estimation. Kagawa and Noguchi (2022) investigated issues of the predominant period of ground motion and derived an underground velocity structure model. They estimated velocity structure from the spectrum ratio of horizontal and vertical components (H/V) of earthquake ground motion to study predominant periods of ground motion in a small plain such as the Tottori plain. It was concluded that the interaction of close predominant periods due to the different layer boundaries may amplify seismic ground motion. In the Hakodate Plain, Hokkaido, small-to-large-sized microtremor array surveys were conducted at five sites to estimate the S-wave velocity structure down to the seismic bedrock for each site (Asano et al. 2022). The new three-dimensional velocity structure model of the Hakodate Plain was developed by integrating the results of microtremor array surveys and other existing geophysical exploration data. The numerical ground motion simulation demonstrated that the amplification and long duration observed in the western part of the Hakodate Plain were reproduced effectively by the new velocity model.

An earthquake with a magnitude of 6.7 occurred off Yamagata prefecture in the Sea of Japan on June 18, 2019. The precise activity of the aftershocks was essential to consider earthquake generation in this area. Shinohara et al. (2022) developed a simple anchored buoy-type OBS for shallow water depths and performed the seafloor aftershock observation for approximately one week. The aftershocks were distributed at a depth range of 2.5 to 10 km and along a plane dipping to the southeast, which was believed to correspond to the fault of the mainshock. Heat flow data are also essential information to estimate the thickness of the seismogenic layer. New heat flow data were obtained (Matsumoto et al. 2022) from the temperature profiles of the boreholes of the High Sensitivity Seismograph Network (Hi-net). They recognized low heat flow on the forearc side, high heat flow along the Ou Backbone Range, in the Tohoku region, and low heat flow in the alluvial plains on the back-arc side, and confirmed a good correlation between the estimated temperature structure and the lower limit of the seismogenic layer.

Coastal areas along the Sea of Japan, especially in Northeast Japan had repeatedly damaged by tsunamis generated by past large earthquakes. Chiba and Nishimura (2022) conducted geological surveys to investigate tsunami deposits and identified that the deposits were brought by the tsunami generated by the 1983 Nihonkai-Chubu earthquake. In the past half of the twentieth century, it is known that four large earthquakes occurred, and tsunamis were generated by the earthquakes in the Sea of Japan. Murotani et al. (2022) examined the causative faults of these large earthquakes in the Sea of Japan using seismic and tsunami data. They found that the examined faults of the past earthquakes were consistent with the fault models developed by the Japan Sea project, although the data were insufficient to estimate the causative faults for some earthquakes.

Active faults in the coastal and marine areas were recently modeled by the Japan Sea project. Satake et al. (2022) investigated the effects of fault parameter uncertainty on the deterministic assessment of tsunami hazards for the submarine and coastal active faults in the Sea of Japan. The fault slip amount is usually calculated from empirical scaling relations and plays an important role in the scenario-based tsunami assessment. Four methods were adopted to estimate the fault slip amounts and compared the coastal tsunami heights from the slip amounts obtained by two different empirical relations. Consequently, it is critical to select an appropriate scaling relation and approximate the fault slip angles and geometries to reduce the uncertainty of coastal tsunami height estimates.

From a social point of view, tsunami disaster mitigation strategies have not been sufficiently developed for coastal communities along the Sea of Japan. Yamanaka and Shimozono (2022) estimated the tsunami inundation characteristics for three major coastal cities along the Sea of Japan using comprehensive simulations for tsunami propagation and inundation based on earthquake and tsunami source scenarios. As a result, the enhancement of existing infrastructure such as breakwaters and river levees should be the priority measure within tsunami risk-mitigation strategies.

Compilation and visualization of geotechnical databases for information such as geophysical and borehole data are useful for studies of various fields on subsurface structures, which can be displayed using a Geographic Information System (GIS). Nishimura et al. (2022) developed a geotechnical information database for the San'in region in southwestern Japan to display the database on a map in a web browser, which is useful for not only earthquake scientists and engineers but also stakeholders. For prevention and mitigation of disaster by large earthquakes and tsunamis, research from a social scientific viewpoint is also essential. Saito et al. (2022) summarize the findings of an attitude survey focused on people's perceptions of seismic hazard maps, which illustrate the risk of an earthquake in each location throughout Japan. From their survey analyses, the general perception of the necessity of countermeasures grew as seismic intensity in the seismic hazard maps increased. The perception of the need for countermeasures depends on the ages of inhabitants and presentation methods of the risks. They proposed that more detailed analysis should be developed to clarify the perception of the transmission of basic risk information.

All 13 papers in this special issue contribute toward advancing various aspects of mitigating seismic hazards for coastal areas of the Sea of Japan. In addition, research on the prevention and mitigation of disasters of large earthquakes and tsunamis should be accelerated by progress in research projects across various fields including social science.

On January 1, 2024, a large earthquake with a magnitude of 7.6 occurred beneath the Noto Peninsula and caused strong shaking and damages in the source area. The event triggered a destructive tsunami that caused widespread damage both within the source area and along the coast of Toyama and Niigata prefectures. Fujii and Satake (2024) inverted the tsunami waveforms and the GNSS data to estimate the slip amount and seismic moment on each of active faults modeled by the Japan Sea project, and indicated a possibility that some faults had small slip amounts during the mainshock. The source area of the mainshock extended to the marine area. The rapid response seafloor seismic observation showed that the aftershock distribution was consistent with the fault model constructed by the Japan Sea project (Shinohara et al. 2025). These results indicate that construction of fault models for large earthquake generation is useful for research for prevention and mitigation of seismic and tsunami disasters. We must continue to develop research in various fields for the coastal areas facing the Sea of Japan and in marine region close to the coast.

Abbreviations

Hi-net	High sensitivity seismograph network
H/V	Ratio of horizontal and vertical components of ground motions
GIS	Geographic information system
LAB	Lithosphere–asthenosphere boundary
MEXT	Ministry of Education, Culture, Sports, Science and Technology, Japan
MLIT	Ministry of Land, Infrastructure, Transport and Tourism, Japan
OBS	Ocean bottom seismometer
RF	Receiver function
RTM	Reverse time migration
Vp	P-wave velocity

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