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Editorial: Broadband seafloor sediment acoustic property and multi-parameter geoacoustic model

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Editorial on the Research Topic
Broadband seafloor sediment acoustic property and multi-parameter geoacoustic model

The seafloor is an important boundary of the ocean sound field, and the acoustic property of seafloor sediment and its spatial distribution are important factors that affect the propagation and variation of sound waves in the ocean. The research of seafloor sediment acoustic property (geoacoustic property) is an interdisciplinary subject involving marine geology, marine geophysics, and marine acoustics. The research of geoacoustic property mainly includes measurement techniques on geoacoustic property, the impacting factors on the geoacoustic property, the relationship between geoacoustic property and the physical-mechanical parameters (geoacoustic model), application of geoacoustic property, and so on. The research of geoacoustics has important practical value and significance in many fields such as ocean sound field prediction, marine engineering construction, marine resources exploration, marine disaster prevention, etc. With the development of new technology such as *in-situ* measurement technology, low-frequency geoacoustic inversion, deep-towed multichannel seismic technology, and prediction methods based on artificial intelligence technologies such as machine learning and neural networks, research on broadband geoacoustic property from low to high-frequency and multi-parameter geoacoustic models have received more attention. In light of these considerations, we have proposed the Research Topic, *Broadband Seafloor Sediment Acoustic Property and multi-parameter Geoacoustic Model*, to compile the latest advancements in the aforementioned critical areas.

This Research Topic comprises 10 original research papers contributed by 63 authors. The research within encompasses a spectrum of Measurement technologies for acoustic and physical properties of seabed sediments, geoacoustic inversion, Artificial intelligence and Multi-parameter Geoacoustic Model. These approaches collectively offer valuable insights into the realms of Seafloor sediment acoustic property and geoacoustic model. In this summary, we highlight key findings derived from the 10 research papers featured in this Research Topic.

Measurement technologies for acoustic and physical properties of seabed sediments

Jiao et al. conducted cyclic shear tests of the natural marine clay of the South China Sea, with varying the cyclic stress ratio (CSR), overpressure consolidation ratio (OCR), consolidation ratio (Kc), and loading frequency. They found that the CSR, OCR, and Kc significantly impact the cumulative dynamic strain in deep-sea soft clay during undrained cyclic dynamic tests. Higher CSR values lead to increased dynamic strain and structural failure risk. They also proposed a dynamic strain-dynamic pore pressure development model, which can effectively capture the cumulative plastic deformation and dynamic pore pressure development, showing correlations with the CSR, OCR, and Kc, thus providing insights into the deformation and pore pressure trends in deep-sea clay under high cyclic dynamic loading conditions. This study not only furnishes essential background information but also addresses a critical gap in understanding the behavior of deep-sea soft clay under cyclic loading, thereby enhancing the safety and stability of seabed structures.

Li et al. presented an array geometry inversion method suitable for complex seafloors to address the challenge of precise source-receiver positioning with deep-towed multichannel seismic systems. An objective function of the deep-towed seismic array geometry inversion was built using the shortest path algorithm according to the travel times of direct waves and seafloor reflections, and the high-precision inversion of the source-receiver position was achieved by using the particle swarm optimization (PSO) algorithm. The results verified the effectiveness of the method proposed in this paper, especially its applicability in scenarios with dramatic changes in seabed topography. This study provides insights into the accuracy and reliability of the proposed geometric shape inversion method for deep-towed seismic arrays in practical applications to meet the requirements of near-bottom acoustic detection for fine imaging of deep-sea seabed strata and precise inversion of geoacoustic parameters.

Wang et al. designed and developed a Seabed Cone Penetration Test (CPT) and Sampling System, which can be used to perform multi-parameter *in situ* testing and low-disturbance sampling of 3000 m deep-sea seabed sediments. The system adopts electrohydraulic proportional position control and a fuzzy PID controller to precisely control the position of the piston of the hydraulic circuit, which can improve the accuracy of the cone test data and reduce the interference of the sampling tube with the original sediment during the sampling process. Moreover, electrohydraulic co-simulation of the hydraulic control system was conducted with AMESim and Simulink software, and the position control and speed control effects of the system were verified. The system was tested on site in the Shenhu Sea area of the South China Sea, and obtained 9 *in-situ* parameters, including physical and chemical parameters, for sediments within a depth range of 2.66 m on the seabed surface at a depth of 1820 m. The testing results of the system accurately and efficiently reflect the property characteristics of seafloor sediments in an *in situ* environment, indicating the system can be widely used in marine engineering geological investigations and measurement of physical parameters of seafloor sediment.

Zhen et al. developed an acoustic reflection measurement system using a self-developed, high-precision, high-frequency shallow stratigraphic profiler to perform the sediment grain size classification. In this study, they utilized this system to analyze six sandy sediments with different grain sizes in the laboratory. The result shows a positive correlation between the amplitude of the acoustic reflection echo and grain size, and the amplitude of the reflection peaks increased with increasing grain size. By analyzing the amplitude of the reflection peaks and echo waveform, sediment grain sizes can be distinguished in a more precise manner. This study provides a valuable guide for the fine-grained classification of sediment grain size.

Geoacoustic inversion

Lee et al. estimate the geoacoustic parameter values at low frequency for the two-layer geoacoustic bottom model by comparing the dispersion curves extracted from the replicas predicted by the KRAKEN normal-mode program with dispersion curves extracted from airgun sounds received in the East Siberian Sea. The result revealed the best-fit values for the sediment sound speed and density in the surficial layer to be approximately 1422.4 m/s and 1.58 g/cm^3, respectively. For the lower layer, these values were estimated to be 1733.6 m/s and 1.84 g/cm^3, respectively, and the surficial sediment thickness was estimated to be ~ 4.1 m. Subsequently, the distances between the airgun and the receiver system in the 18.6 to 121.5 km range were calculated by comparing the measured modal curves and the model replicas predicted using the estimated geoacoustic parameters. In order to mitigate the distance errors, they employed an adiabatic approximation for model propagation in the range-dependent environment. The modeled modal travel times were calculated by dividing the source-receiver distance into range-independent segments, each based on a 1-m change in water depth, and then summed. The result shows that the re-estimated distance error is reduced to within 10%, indicating the method of geoacoustic inversion presented in this study is effective.

Artificial intelligence

Meng et al. established a machine learning model for predicting the shear wave speed of seafloor sediments in the northwest South China Sea, using the eXtreme Gradient Boosting (XGBoost) algorithm. By optimizing the hyperparameters of the model, the best fit of the XGBoost algorithm is obtained when the n_estimator and max_depth are 115 and 6, respectively. The mean absolute error and the goodness of fit between the predicted values and validation data are 3.366 m/s and 9.90%, respectively. They compared the multi-parameter shear wave speed prediction model established in this study with the single-parameter prediction models, the dual-parameter prediction models, and the GS prediction model, and the result indicates that the multi-parameter shear wave speed prediction model based on the XGBoost algorithm has the lowest MAE and MAPE between the test data and the predicted values, which are 4.04 m/s and 14.3%, respectively. This study indicates that the multi-parameter shear wave speed prediction model based on the XGBoost algorithm has a higher accuracy for predicting the shear wave speed in the northwest South China Sea.

Multi-parameter geoacoustic model

Zou et al. established a porosity-based effective density fluid model (P-EDFM) to analyze the variation of acoustic properties with the porosity of seafloor sediments. They employed P-EDFM to investigate the influence of physical parameters, including porosity and density, as well as temperature environment, and measurement frequency on the *in situ* sound velocity and sound attenuation coefficient of seafloor sediments. According to the P-EDFM, the *in situ* sound velocity ratio decreases with increasing bulk porosity and with decreasing bulk density. After considering the influence of temperature in the P-EDFM, the prediction of *in situ* sound velocity aligns well with the measured dataset. The acoustic attenuation coefficient exhibits an inflection point, increasing initially and then decreasing with changes in porosity, similar to the observed pattern in Hamilton's observation and estimation. Overall, P-EDFM can predict the *in situ* sound velocity and sound attenuation coefficient under different temperatures and frequencies, with a lower prediction error for sound velocity compared to the sound attenuation coefficient.

Tian et al. measured the acoustic and physical properties of marine cold spring carbonate rock samples gathered from the Chaoshan Depression in the South China Sea, which is different from the ordinary seafloor sediments and can be regarded as a special type of sediment distributed on or in the ordinary seafloor sediments. In this study, the Wyllie time-average equation, Voigt model, Reuss model, and Voigt-Reuss-Hill model were used to predict the characteristics of the sound speed for four states of seafloor sediments containing cold spring carbonate mineral particles or rocks. For these four states of marine cold spring carbonate mineral particles existing on or in seafloor sediments, the sound speed and reflection coefficient of a mixture of seafloor surface sediments containing cold spring carbonate mineral particles or rocks decrease with an increase in the volume ratio of the seafloor sediment. This method for predicting the reflection coefficient provides evidence to explain the high and low reflection coefficients observed in Chirp sub-bottom profiles of cold spring seepage areas.

Liu et al. compared the deviations between the sound velocities of seafloor sediments measured on-site(on the deck of the research vessel) and in the laboratory ($V_{p\text{-}f}/V_{p\text{-}l}$) and analyzed their mechanisms by combining the on-site and laboratory measurements obtained in the southern Huanghai Sea in 2009 with that acquired in 2014 from the northern Huanghai Sea and Bohai Sea. The result shows that the deviations of the ratio of $V_{p\text{-}f}/V_{p\text{-}l}$ among different sediment types were significant and the changes in temperature and disturbance during the transport of the samples were the key environmental factors causing deviations to exist in the measured sound velocities. The dynamic liquefaction, re-consolidation, and thixotropic resumption processes that occurred during transport and the standing of samples were the most important dynamical mechanisms of acoustic deviations, all of which were caused by disturbances during sample transport. Sandy silts and silty sands exhibited dynamic liquefaction and re-consolidation, while the clayey silts exhibited thixotropy, and resumption and the silts showed dynamic liquefaction, re-consolidation, thixotropy and then resumption. The dynamic formation mechanisms of the deviations between on-site and at-laboratory measured sound velocities were the changes in the properties of sediments by external actions.

Zhang et al. analyze the influence of physical parameters (including density, porosity, and grain size) on the acoustic velocity of the sediments in the land slope of the northern South China Sea (SCS). The single-parameter and dual-parameter regression equations based on the data from all of the sites in the whole land slope of the northern SCS are established to further examine this influence. Further, this study also establishes single-parameter and dual-parameter regression equations suitable for the upper, middle, and lower land slopes to better study the relationships between each parameter. The results show that the influence of each parameter on the prediction of the acoustic velocity of the sediment is in the following order: porosity>density>grain size. This study analyzed and revealed the reason why the seafloor sediments in the local area cause the acoustic properties to change greatly, which may be caused by changes in the sediment type, and lithology along depth. And the other reason is the development of inter-layer in the land slope of the northern SCS.

Author contributions

GK: Writing – original draft, Writing – review & editing. BL: Writing – original draft, Writing – review & editing. XG: Writing – original draft, Writing – review & editing. JW: Writing – original draft, Writing – review & editing.

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