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Editorial: Frontiers in marine geomorphometry

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Editorial on the Research Topic
Frontiers in marine geomorphometry

Marine geomorphometry is the science of quantitative terrain characterization applied to the seabed. Like many geospatial applications, techniques used for marine geomorphometry have been sourced from the terrestrial sciences. Through progress in the fields of seabed mapping, marine geomorphology, benthic habitat mapping, and marine ecology, scientists have realized new and unique requirements for characterizing the seafloor terrain. Simultaneously, great advances in seafloor mapping technologies have revolutionized our capacity to map the oceans in high detail. The widespread uptake of swath mapping technologies – namely, multibeam echosounders – enables the production of spatially continuous high-resolution bathymetric surfaces, akin to those produced using electromagnetic remote sensing on land. In parallel, new methods for satellite-derived bathymetry and the increasing availability of bathymetric LiDAR products provide new digital surface models of underwater coastal environments. These innovations, coupled with the unique data requirements of marine science, provide opportunities for innovation within the burgeoning field of marine geomorphometry.

This Research Topic on Frontiers in Marine Geomorphometry is a forum through which to communicate the latest innovations within this field. Here, we invited contributions addressing all aspects of geomorphometry that introduce new knowledge or approaches to improve understanding of seafloor environments – from the coast to the abyss. The United Nations has declared 2021-2030 the Decade of Ocean Science for Sustainable Development, and corresponding efforts to map the global oceans have accelerated greatly. The influx of ocean data creates unprecedented opportunities to study and characterize the seafloor. Our goal in establishing this Research Topic was to support the dissemination of novel approaches and applications of quantitative analysis of seafloor mapping datasets to enhance our ability to understand, monitor, and manage the oceans.

Marine geomorphometry applications

Marine geomorphometry has become well-established within the last decade. The fields of marine geology, geomorphology, and habitat mapping were early adopters of geomorphometric approaches (Wilson et al., 2007; Lecours et al., 2016), which remain the most represented fields in this Research Topic. Studies by Durán et al., Hillman et al., Le Saout et al., Recouvreur et al., and Sklar et al. each utilize geomorphometry to link morphological characteristics to substrate or geological interpretations. Arosio et al., Huang et al., Linklater et al., Nian et al., and Sklar et al. present different approaches to identifying submarine features based on various terrain attributes. These studies represent general geomorphometry – the analysis of a surface as a spatially continuous field – to inform specific geomorphometry classifications. Specific geomorphometry is the characterization of discrete surface entities, or landforms. Klein et al. and Lucieer et al. use geomorphometry in this way to identify known geomorphological seascape features from bathymetric data. Marine geomorphology and habitat mapping are often closely linked, as Fallati et al. demonstrate by associating geomorphic units to habitat types such as bacterial mats and tubeworms. Studies by Arosio et al., Hillman et al., Huang et al., Lucieer et al., and Sklar et al. map extensive seabed areas, often with the aim of optimizing conservation and management efforts.

Marine geomorphometry applications are diverse. Mogstad et al. and Nian et al. employ it as a predictive ecology tool while Durán et al. and Sklar et al. focus on mapping geomorphology. Relatedly, Klein et al. utilize geomorphometry for characterizing volcanic islands that may be at risk of tsunami events through the comparison of geomorphometric parameters. By using data sourced from the General Bathymetric Chart of the Oceans (GEBCO) and ship-based bathymetry, their analysis reveals that morphometric parameters describing island size and slope may be useful for assessing geohazard in areas where high-resolution bathymetric data are lacking. Fallati et al. focus on both ecological and geoscience concepts to explore relationships between geomorphic units and benthic habitats using a combined ROV-based multibeam mapping and underwater photogrammetry approach. This workflow facilitates a deeper understanding of the role that geomorphic variability plays in structuring benthic habitats in extreme settings such as cold seeps.

State of the art approaches

This Research Topic highlights new trends and techniques in marine geomorphometry. We observe decisive progress towards establishing deep learning approaches for the automation of marine geomorphometric and morphological analyses. Semi-supervised and rule-based classifications remain commonplace for the (semi-)automated mapping of marine morphology with bathymetric data, yet new methodologies based on the implementation of convolutional neural networks (CNN) indicate the potential for increased automation and precision. Arosio et al. demonstrate for the first time the application of deep learning CNN models for the accurate semantic segmentation of marine morphological features. Using this approach, they show that these models may "learn" to identify and segment seabed morphological features from bathymetric data according to an accepted and standardized vocabulary with a relatively small number of human annotations over a regional extent. Nian et al. also explore the application of deep learning to classify the seafloor according to observed morphological classes using multibeam bathymetric data. They indicate the potential for developing online and adaptive path selection for underwater vehicles, based on environmental context. Relatedly, Mogstad et al. utilize CNNs for the automated classification of autonomous underwater vehicle acoustic data, but for the purpose of identifying cold-water coral reefs. They mobilize a suite of acoustic and spectral sensors to investigate the morphology of these important habitats across the Tautra Ridge marine protected area, Norway. Here, deep learning enabled the automatic identification of corals from very high-resolution (4 cm) synthetic aperture sonar (SAS) backscatter data at an impressive level of detail and accuracy, providing a basis for morphometric characterization of cold-water coral reefs. These studies suggest the emergence of deep learning as a groundbreaking marine geomorphometry tool; they are amongst the first examples of how artificial intelligence may enhance the efficiency and accuracy with which morphological features are mapped on the seafloor.

We observe continued innovation within the field of marine geomorphometry, and several new tools are presented within this Research Topic for the first time. Two of these are aimed at facilitating efficient morphological classification through semi-automated workflows. Huang et al. present a new toolbox for rule-based classification of bathymetric position features (i.e., highs and lows), as defined by the recent morphology features glossary of Dove et al. (2020). They provided open-source Python tools within ArcGIS that enable the flexible classification of features over multiple scales using only bathymetric data as input, and the authors prove the efficiency and extensibility of these at different and varied study sites. Linklater et al. have also developed a semi-automated toolbox that enables the classification of continental shelf bedforms within ArcGIS. Their toolbox differs notably from that of Huang et al. by focusing on a different set of features at the scale of continental and island shelves. They demonstrate classification of these features using high resolution (2 – 20 m) multibeam and bathymetric LiDAR datasets. Each of these new semi-automated morphological toolboxes were developed in Australia, and we note some interesting methodological congruences such as an initial automated bathymetric segmentation step that is subsequently classified and reviewed by the user.

Additional novel approaches presented within this Research Topic facilitate visualization of geomorphometric data. Gross et al. present an asset-based framework for realistic representation and visualization of geomorphometric data within a virtual environment. They demonstrate how modern game engines such as Unreal Engine 5 may be leveraged to apply realistic lighting and physics to a classified digital surface model to produce an immersive outreach and communication tool. Novak et al. also provide an innovative geomorphometric visualization resource, called the Relief Visualization Toolbox (RVT). They discuss how these tools may enable tailored solutions for bathymetric applications using advanced hillshade and multiscale terrain functions, relief models, and additional methods for "blending" these. The authors make these tools widely and freely available through ArcGIS, QGIS, Python, and standalone executable implementations.

In addition to the new geomorphometry tools presented by Linklater et al. and Huang et al., there is a conspicuous movement towards improving the standardization and objectivity of marine morphological classifications. Lucieer et al. propose a systematic and repeatable approach for the broad-scale mapping of morphological features across 37 Australian Marine Parks to produce consistent data products that may support regional science, planning, and conservation. They demonstrate how this approach enables morphological characterization and comparison of the parks using a standardized and accepted classification scheme. Sklar et al. implement an alternative data-driven approach to mapping morphological features in the Gulf of St. Lawrence, Canada. They derive representative geomorphometric features from broad-scale bathymetry, which were ordinated and clustered to produce a set of discrete morphological features that were interpreted and labelled according to established and standardized definitions from the literature. Recouvreur et al. also demonstrate the advantages of automated and objective approaches to regional mapping of bedrock areas across the northeast Atlantic Irish continental margin. Again, such approaches are enabled through characterization of the terrain using geomorphometry and the calculation of terrain attributes from bathymetric data.

Conclusions

Marine geomorphometry was recognized in 2015 as a distinct sub-discipline of geomorphometry by the International Society for Geomorphometry. It is now a well-established discipline, yet this Research Topic demonstrates continuous evolution of tools and approaches. While "traditional" marine geomorphometry techniques remain highly relevant for studying the marine environment, new approaches are fast developing, such as deep learning and structure-from-motion photogrammetry (Arosio et al., Fallati et al., Mogstad et al.). These are now being used to analyze an increasing diversity of mapping datasets from satellite and drone systems (Gross et al.), AUV/ROV multibeam (Le Saout et al.), bathymetric LiDAR (Linklater et al.), and synthetic aperture sonar (Mogstad et al.). Compared to terrestrial datasets though, these data remain scarce, and there is a strong need to increase discoverability and accessibility of ocean mapping data. The Ocean Decade and other large-scale efforts to compile bathymetric data are promising, but increased data sharing by individual groups has potential to accelerate ocean science, and to benefit the scientific community at large. The trajectory of marine geomorphometry research currently suggests that characterization of seafloor features and habitats are likely to become increasingly automated, while novel geovisualization techniques show great potential to improve interpretation by managers and stakeholders. As the field continues to progress, we look forward to continued innovation that will push the frontiers of marine geomorphometry.

Author contributions

BM: Writing – review & editing, Writing – original draft. VL: Writing – review & editing, Writing – original draft, Conceptualization. MP: Writing – review & editing, Writing – original draft. MG: Writing – review & editing, Writing – original draft. TA: Writing – review & editing, Writing – original draft.

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Conflict of interest

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