

MINI REVIEW



## Marine geology: A deep dive into the earth's underwater frontier

Mohammed Elgarhy

Department of Marine Geology, King Abdulaziz University, Jeddah, Saudi Arabia

### ABSTRACT

Marine geology explores the composition, structure, and dynamic processes of the ocean floor, revealing critical insights into Earth's history and its ongoing geological evolution. This paper delves into the key areas of marine geology, including plate tectonics, seafloor spreading, sedimentation, and hydrothermal activity, highlighting their roles in shaping the underwater landscape. Advancements in remote sensing, submersible technology, and deep-sea drilling have enabled unprecedented access to the ocean's depths, uncovering submerged mountain ranges, vast sedimentary basins, and evidence of past climatic and tectonic events. The study emphasizes the importance of marine geology in understanding natural hazards such as earthquakes and tsunamis, as well as its implications for resource exploration and environmental management. By investigating the hidden features beneath the ocean's surface, marine geology continues to expand our knowledge of Earth's complex systems and the interconnectedness of terrestrial and marine environments.

### KEYWORDS

Seafloor dynamics; Plate tectonics; Sedimentation; Submarine geomorphology; Geohazards

### ARTICLE HISTORY

Received 14 October 2024;  
Revised 20 November 2024;  
Accepted 3 December 2024

### Introduction

Marine geology is the study of the ocean floor, its structure, history, and the processes that shape it. Unlike the land we walk on, the seabed is a hidden landscape filled with mountain ranges, deep trenches, volcanoes, and vast plains. Marine geologists explore these underwater features to understand how they were formed and how they continue to change. The field is a mix of geology and oceanography, using tools and techniques to map the seafloor, collect samples, and analyze the materials that make up the ocean crust and sediments. This area of science covers a wide range of topics. It includes the movement of tectonic plates beneath the ocean, how sediments are transported and laid down, and the activity of underwater volcanoes and earthquakes [1].

Marine geologists also study hydrothermal vents, which are deep-sea hot springs that release minerals and support unique ecosystems. These features help scientists understand not only how the Earth works today but also how it has changed over millions of years. Understanding marine geology is crucial for learning about Earth's history. Much of the evidence for major geological events like the theory of plate tectonics comes from the study of the ocean floor. Layers of sediment on the seafloor hold records of past climates, ocean conditions, and biological activity, acting like a history book of the planet. These layers can tell us about ice ages, mass extinctions, and even how continents have moved over time. In simple terms, marine geology helps us see the bigger picture of Earth's story [2]. By exploring the oceans, we get answers to how our planet works, how it has evolved, and what changes might come. It's a key part of understanding the Earth as a whole.

### Historical Development of Marine Geology

Marine geology has evolved from early observational practices into a cornerstone of Earth science. In the 19th century, limited

technology confined ocean studies to surface-level data and simple depth measurements using weighted lines. A major breakthrough came with the HMS Challenger expedition, which conducted the first systematic study of the deep sea. This mission collected oceanic sediments, measured depths, and revealed that the seafloor was far more varied than previously thought [3].

### Foundations for modern theory

Following World War II, sonar technology developed for submarine detection was adapted for oceanographic research. This led to detailed maps of the seafloor, exposing mid-ocean ridges and deep trenches. These discoveries challenged earlier geological models and laid the groundwork for new ideas [4].

### Proving seafloor spreading and plate tectonics

Seafloor spreading suggests that new crust forms at mid-ocean ridges and spreads outward. Supporting this idea were magnetic anomalies found in the ocean crust, which showed symmetrical patterns corresponding to Earth's magnetic reversals. These patterns confirmed that the ocean floor was actively forming and moving. Marine geology thus played a crucial role in validating plate tectonics, reshaping our understanding of Earth's dynamic crust.

### Key Disciplines within Marine Geology

Marine geology is a multidisciplinary science that draws from several specialized fields to study the structure, composition, and evolution of the seafloor [5]. Each discipline brings unique tools and perspectives, allowing scientists to uncover the complex history of the oceans and the Earth's crust.

### Geophysical investigations

One of the primary tools in marine geology is geophysics, particularly seismic studies and the analysis of magnetic

\*Correspondence: Dr. Mohammed Elgarhy, Department of Marine Geology, King Abdulaziz University, Jeddah, Saudi Arabia. e-mail: [mohammed.e456@gmail.com](mailto:mohammed.e456@gmail.com)

© 2024 The Author(s). Published by Reseapro Journals. This is an Open Access article distributed under the terms of the Creative Commons Attribution License (<http://creativecommons.org/licenses/by/4.0/>), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

anomalies. Seismic surveys use sound waves to image the layers beneath the seafloor, helping researchers locate faults, sediment layers, and crustal structures. Magnetic studies have revealed patterns of reversed and normal magnetic polarity in oceanic crust [6]. These "magnetic stripes" run parallel to mid-ocean ridges and serve as strong evidence for seafloor spreading, showing how new crust is continuously formed and pushed outward.

### Geochemical analyses

Geochemical methods help decode the chemical makeup of the oceanic crust and sediments. By studying the elements and isotopes present in rock and sediment samples, scientists can trace sources of material, understand hydrothermal processes, and determine the age and origin of seafloor features [7]. This information is crucial for studying volcanic activity and chemical exchanges between the crust and seawater.

### Sedimentology

Sedimentology focuses on the types, sources, and distribution of sediments on the ocean floor. Marine sediments are classified into terrigenous (from land), biogenic (from organisms), hydrogenous (chemical precipitates), and cosmogenic (from space debris). Understanding sediment layers helps reveal past ocean conditions, climate changes, and the movement of tectonic plates.

### Paleontology

Marine paleontology studies fossils preserved in deep-sea sediments. These microfossils, such as foraminifera and diatoms, are sensitive indicators of past environmental conditions [8]. By examining fossil content, scientists can reconstruct ancient ocean temperatures, chemistry, and biological productivity. This is essential for studying long-term climate trends and extinction events.

### Major Features of the Ocean Floor

The ocean floor is far from flat; it is shaped by powerful geological forces that create a diverse and dynamic landscape. Some of the most important features include mid-ocean ridges, abyssal plains, oceanic trenches, and underwater mountains like seamounts and guyots.

#### Mid-ocean ridges

Mid-ocean ridges are long, underwater mountain chains formed by tectonic plates pulling apart. As magma rises and cools, it creates new oceanic crust. These ridges are often the sites of volcanic activity and hydrothermal vents and are key to the process of seafloor spreading.

#### Abyssal plains

Abyssal plains are vast, flat regions that lie between the continental margins and mid-ocean ridges. Covered by layers of fine sediments, they are among the smoothest and most extensive areas on Earth [9]. Despite their calm appearance, these plains offer clues about sedimentation rates and past oceanic conditions.

#### Oceanic trenches

Oceanic trenches are the deepest parts of the ocean, formed where one tectonic plate is forced under another in a process

called subduction. Trenches like the Mariana Trench reach depths over 11,000 meters and are important in understanding earthquakes and tsunamis.

### Seamounts and guyots

Seamounts and guyots are underwater volcanoes. Seamounts are cone-shaped, while guyots are flat-topped, often eroded by waves when they were once above sea level.

### Processes Shaping the Ocean Floor

The ocean floor is shaped by a combination of dynamic geological processes that constantly modify its structure and composition. These include plate tectonics, sedimentation, and hydrothermal activity.

#### Plate tectonics and seafloor spreading

The theory of plate tectonics explains that Earth's outer shell is divided into moving plates. At mid-ocean ridges, these plates diverge, allowing magma to rise and form new crust—a process called seafloor spreading [10]. This movement not only creates underwater mountain ranges but also drives subduction at trenches, earthquakes, and volcanic activity across the seafloor.

#### Sedimentation processes

Sediments accumulate on the ocean floor from various sources. Terrigenous sediments come from land via rivers and wind, while biogenic sediments originate from marine organisms [11]. Hydrogenous and cosmogenic sediments form from chemical reactions in seawater or from space debris. These sediments slowly settle on the seafloor, layering over time and preserving historical records of Earth's climate, ocean conditions, and biological activity.

#### Hydrothermal activity

In tectonically active areas, seawater seeps into the ocean crust, heats up, and emerges through hydrothermal vents. This superheated water is rich in minerals, which form chimney-like structures and support unique ecosystems. Hydrothermal processes contribute to seafloor mineral deposits and influence ocean chemistry.

### Tools and Techniques in Marine Geology

Marine geology relies on advanced tools and technologies to explore and understand the complex and largely inaccessible seafloor. These methods allow scientists to collect data, map structures, and study geological processes in detail.

#### Deep-Sea drilling

Deep-sea drilling is a fundamental method for studying the composition and history of the ocean floor. Programs like the International Ocean Discovery Program (IODP) use specialized ships to drill into the seabed and extract core samples [12]. These sediment and rock cores reveal valuable information about past climate, plate movements, ocean chemistry, and biological activity over millions of years.

#### Remote sensing and sonar mapping

Remote sensing, especially through sonar technology, has revolutionized the mapping of the seafloor. Multibeam sonar systems emit sound waves that bounce off the ocean floor, creating detailed topographic maps. These maps reveal features

like mid-ocean ridges, trenches, and seamounts, and help identify areas of geological interest. Satellite altimetry is also used to infer seafloor topography based on changes in sea surface height.

### Submersibles and ROVs

Submersibles and Remotely Operated Vehicles (ROVs) allow direct observation and sampling from the ocean floor. These machines are equipped with cameras, robotic arms, and sensors, enabling scientists to explore extreme environments, such as hydrothermal vents and deep trenches, where human access is impossible.

### Applications and Implications of Marine Geology

Marine geology is not just about understanding the seafloor; it has several important real-world applications that impact society, the environment, and our future. Its findings contribute to natural resource management, disaster preparedness, and climate science.

### Resource exploration

#### Oil, Gas, and Mineral resources

Marine geology plays a major role in locating and evaluating offshore oil and gas reserves found in sedimentary basins beneath the seafloor. It also aids in identifying mineral-rich zones, such as polymetallic nodules and hydrothermal vent deposits, which are sources of valuable metals like copper, zinc, and rare earth elements [14].

### Understanding natural hazards

#### Earthquakes and tsunamis

Many powerful earthquakes originate along underwater plate boundaries. Marine geological studies help identify active faults and subduction zones, improving earthquake and tsunami prediction models. This information is crucial for vulnerable regions' coastal planning and early warning systems.

### Climate change studies

#### Sediment core analysis

Seafloor sediments act as natural archives of Earth's climate history. By analyzing the composition, fossil content, and layering of marine sediments, scientists can reconstruct past temperatures, ocean circulation patterns, and carbon cycles [15]. This helps in understanding long-term climate change trends and forecasting future environmental shifts.

### Future Directions in Marine Geology

The future of marine geology is driven by technological advancements and increasing global cooperation, offering exciting opportunities to explore deeper and more accurately than ever before.

### Advancements in technology and methodologies

New technologies are revolutionizing marine geological research. Autonomous underwater vehicles (AUVs) and advanced sonar systems are providing more detailed and real-time data about the seafloor than ever before [16]. The development of robotic drilling technologies is also enhancing the ability to collect samples from extreme depths, making it possible to investigate remote areas of the ocean floor.

Moreover, innovations in remote sensing and satellite altimetry are enabling scientists to monitor large-scale oceanic processes, like plate movements and climate changes, with unprecedented precision.

### Interdisciplinary research and global collaborations

Marine geology is increasingly interdisciplinary, merging with fields like marine biology, climate science, and geophysics [17]. Collaborative efforts between institutions and across countries are strengthening global research networks. These partnerships are essential for tackling global challenges such as climate change, ocean acidification, and natural disaster preparedness. Shared data and joint expeditions are opening new frontiers for understanding the complex interactions between Earth's geological systems and the environment.

### Conclusions

Marine geology is a vital field that significantly enhances our understanding of the Earth's past, present, and future. By exploring the complex processes shaping the ocean floor, such as plate tectonics, sedimentation, and hydrothermal activity, marine geologists uncover the dynamic interactions that have shaped our planet over millions of years. The study of seafloor features, like mid-ocean ridges, trenches, and seamounts, reveals crucial information about tectonic movements, the evolution of Earth's crust, and the history of life in the oceans. Ultimately, marine geology plays a central role in answering fundamental questions about how the Earth works, how it has evolved, and how it will continue to change. It is essential not only for scientific progress but also for ensuring a sustainable future, providing insights into resource management, disaster preparedness, and environmental conservation.

### Disclosure Statement

No potential conflict of interest was reported by the author.

### References

1. Mitchell NC. Aspects of marine geoscience: a review and thoughts on potential for observing active processes and progress through collaboration between the ocean sciences. *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences*. 2012 Dec 13;370(180):5567-612. <https://doi.org/10.1098/rsta.2012.0395>
2. Berger WH. Geologist at sea: Aspects of ocean history. *Annual Review of Marine Science*. 2011 Jan 15;3(1):1-34. <https://doi.org/10.1146/annurev-marine-120709-142831>
3. Manzella GM, De Strobel F, Pinardi N, Emery W. A narrative of historical, methodological, and technological observations in marine science. In *Ocean Science Data* 2022 Jan 1 (pp. 3-64). Elsevier. <https://doi.org/10.1016/B978-0-12-823427-3.00004-9>
4. Gràcia E, Martínez-Loriente S, Díez Tagarró S, Gómez de La Peña L, Sánchez-Serra C, Bartolome R, Sallarès V, Lo Iacono C, Perea H, Urgeles R, Grevemeyer I. A tribute to Marie Tharp: Mapping the seafloor of back-arc basins, mid-ocean ridges, continental margins and plate boundaries. [https://ui.adsabs.harvard.edu/link\\_gateway/2020EGUGA...22.3676G/doi:10.5194/egusphere-egu2020-3676](https://ui.adsabs.harvard.edu/link_gateway/2020EGUGA...22.3676G/doi:10.5194/egusphere-egu2020-3676)
5. Beck JW, Récy J, Taylor F, Edwards RL, Cabioch G. Abrupt changes in early Holocene tropical sea surface temperature derived from coral records. *Nature*. 1997;385(6618):705-707. <https://doi.org/10.1038/385705a0>
6. Xu M, Tivey MA. Investigation of a marine magnetic polarity reversal boundary in cross section at the northern boundary of the Kane Megamullion, Mid-Atlantic Ridge, 23° 40' N. *J. Geophys. Res. Solid*

- Earth. 2016;121(5):3161-3176. <https://doi.org/10.1002/2016JB012928>
7. Walter GE. Processes that Regulate Trace Element Distribution in the Ocean. *Elements*. 2018;14(6):391-396. <https://doi.org/10.2138/gselements.14.6.391>
8. Naik GR, Kulkarni MN, Indap MM. Understanding Role of Foraminifera in Environmental Studies: A Review. *Int J Ecol Environ Sci*. 2023;49:457-471. <https://doi.org/10.55863/ijees.2023.2882>
9. Sowers DC, Masetti G, Mayer LA, Johnson P, Gardner JV, Armstrong AA. Standardized geomorphic classification of seafloor within the United States Atlantic canyons and continental margin. *Front Mar Sci*. 2020;7:9. <https://doi.org/10.3389/fmars.2020.00009>
10. Ridge PM. Mid-ocean ridge tectonics, volcanism and geomorphology. *Geology*. 2001;26(455):458. <https://doi.org/10.1006/rwos.2001.0094>
11. Ozerova DA, Zolkin AL, Bityutskiy AS, Malikov VN, Shevchenko KO. Classification and distribution of oceanic sediments. In *AIP Conference Proceedings*. 2023.
12. Michibayashi K. History of deep-sea ocean basement drilling programs and contributions to the Earth sciences. *J Geogr (Chigaku Zasshi)*. 2021;130(4):461-482. <https://doi.org/10.5026/jgeography.130.461>
13. McLean DL, Parsons MJ, Gates AR, Benfield MC, Bond T, Booth DJ, et al. Enhancing the scientific value of industry remotely operated vehicles (ROVs) in our oceans. *Front Mar Sci*. 2020;7:220. <https://doi.org/10.3389/fmars.2020.00220>
14. Wong LJ, Kalyan B, Chitre M, Vishnu H. Acoustic assessment of polymetallic nodule abundance using sidescan sonar and altimeter. *IEEE J Oceanic Eng*. 2020;46(1):132-142. <https://doi.org/10.1109/JOE.2020.2967108>
15. Henderson GM. New oceanic proxies for paleoclimate. *Earth Planet Sci Lett*. 2002;203(1):1-3. [https://doi.org/10.1016/S0012-821X\(02\)00809-9](https://doi.org/10.1016/S0012-821X(02)00809-9)
16. Sungheetha A. Optimized deep learning models for AUV seabed image analysis. 2023.
17. Doel RE. The earth sciences and geophysics. In *Science in the twentieth century* 2013. 391-416p.