Caitlin Ruby & Georgianna Zelenak

University of Colorado - Boulder (Cooperative Institute for Research in Environmental Sciences (CIRES)) at NOAA National Centers for Environmental Informa tion (NCEI) for NOAA Ocean Exploration

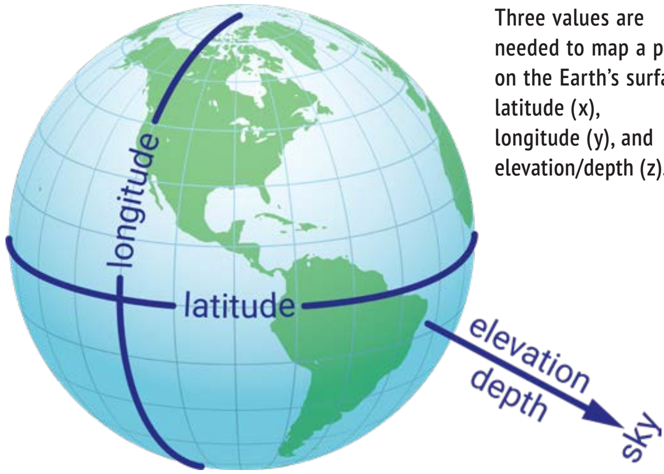
NOAA Ocean Exploration is the only US federal organization dedicated to exploring the deep ocean. By leading national efforts to explore our ocean and make exploration more accessible, we are filling gaps in the basic understanding of deep waters and the seafloor, providing deep-ocean information needed to effectively manage, conserve, regulate, and use ocean resources that are vital to our economy and to all of our lives. Explore with us: oceanexplorer.noaa.gov

Seafloor MAPPING

Our global ocean covers over 70% of the Earth's surface. The marine ecosystem is the largest and most abundant in the world. However, most of the ocean is permanently dark, cold, and incredibly difficult to observe. Only about 20% of the seafloor has been mapped in great detail, and even less has been explored with underwater cameras or submersibles. Mapping the seafloor is the first step in exploring the unknown depths of our global ocean.

What Is a Map?

Maps are a visual representation of objects in space. Maps help us navigate and make sense of the world. They also give order to complex environments by revealing spatial relationships and patterns. The location of anything is mappable using three axes: latitude (x), longitude (y), and elevation or depth (z). **Land elevation** represents land height above sea level. **Seafloor bathymetry** represents land depth below sea level. Topographic maps show the physical shape of dry land using elevation values, while **bathymetric maps** show the physical shape of the seafloor using depth values. Together, topographic and bathymetric maps show the physical features on the Earth's surface. Having a base map of our planet's physical features makes it easier for us to map other things like streets, coral reefs, or your favourite park!



Three values are needed to map a point on the Earth's surface: latitude (x), longitude (y), and elevation/depth (z).

This mid-16th century atlas contained many maps full of sea monsters and ships in distress

History of Mapmaking

The world's most ancient maps date back thousands of years. Geographic information was once painted on cave walls and chiselled into clay tablets. Many civilisations around the world used maps to tell stories. Ancient maps marked trade routes, hunting grounds, socioeconomic trends, natural features, and more. For most of human history, maps were hand-drawn and considered quite artistic. **Cartography** is the art and science of mapmaking. People who make maps are **cartographers**.

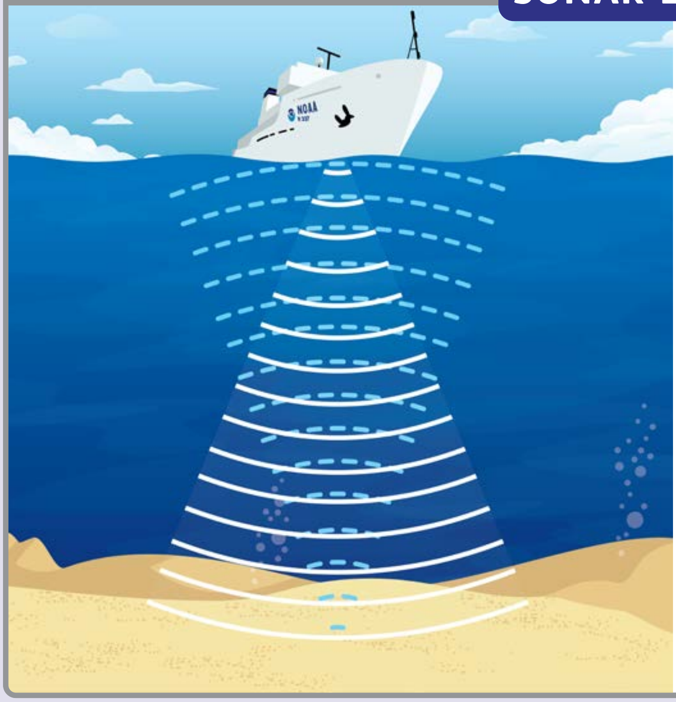
For most of history, what lay below the sea surface and on the seafloor was a mystery. Yet cartographers still searched for ways to include information about the ocean in their maps. Early mariners made maps and calculated their position by visually observing the Sun, stars, and landmarks. However, observing the seafloor proved more difficult. Cartographers resorted to labelling unexplored territories with "Here be dragons." Often, cartographers drew sea monsters to signify unknown but potentially dangerous seas.

Mariners in the early 1800s started using weighted ropes, called lead lines, to measure seafloor depth around harbours. This method was time-consuming and proved more difficult in deeper waters. Considering that the average seafloor depth is about 3.5 km, it's no wonder the seafloor remained a mystery for so long.

Surveyors measuring seafloor depth with a handheld lead line (1942)
Image credit: 1942 Hydrographic Manual

Sonar technology was developed in the 1920s and significantly improved seafloor mapping. Sonar systems emit a sound and then record the time it takes to receive an echo off the seafloor. Seafloor depth is calculated using the time difference from when the sounds are made to when the echoes are heard. Early single-beam sonar systems, called fathometers, were used to measure the seafloor depth beneath a ship. In the 1960s, multibeam sonar systems were developed to measure a larger area using many beams of sound in a fan-shaped pattern. Multibeam sonar can map much broader areas than single-beam sonar.

SONAR EXPLAINED



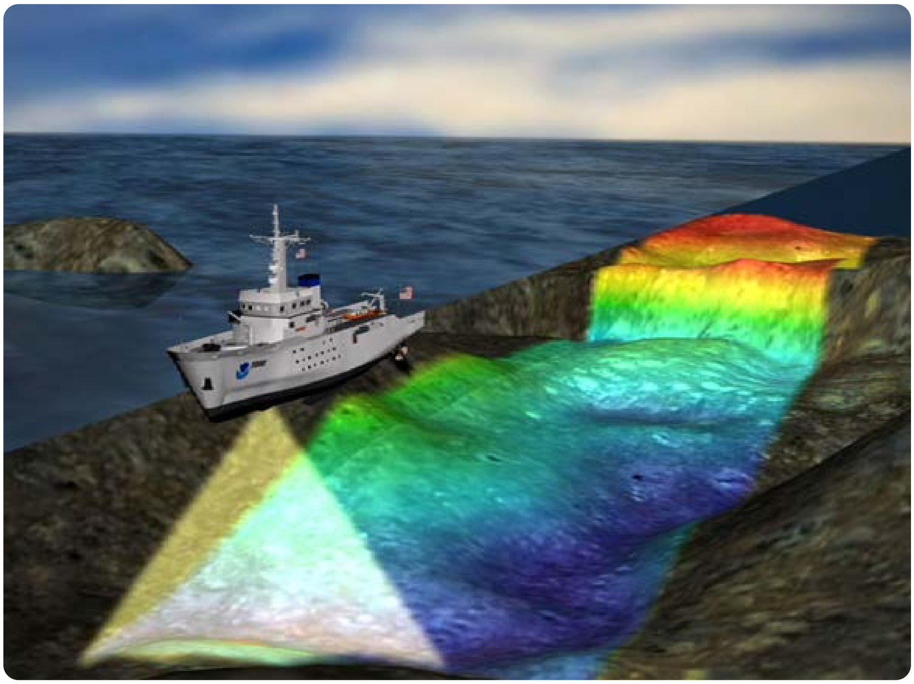
Sonar stands for **So**und **Na**vigation and **R**anging. There are two main types of sonar: active sonar and passive sonar. **Active sonar** systems emit a pulse of sound into the water, which then bounces off the seafloor, creating an "echo." Seafloor depth is calculable using the time difference between creating a sound and receiving its echo. **Passive sonar** systems are quiet. They detect environmental noise made by ships, submarines, and marine life.

Today it's easy to feel as though we know everything about the shape of the world around us. Our phones can guide us to our destination, and Google Earth shows us our world in incredible detail. All digital maps, including those on our phones, are made possible by geographic information systems (GIS). Digital maps are more accurate, easier to manage, and can accommodate more information. As GIS allows people to analyse patterns and relationships in spatial data, many modern professions use this technology in city planning, business decisions, disaster response, ocean science, and more.

Understanding the Seafloor Today

Contemporary seafloor mapping is often conducted using multibeam sonar systems on ships and other marine vessels. Multibeam systems produce **high-resolution data**, meaning that there are many data points per area. More data points means you can see more details. Multibeam bathymetric maps are suitable for many applications including safe navigation and studying benthic habitats. **Benthic habitats** are those closest to the seafloor, or the **benthos**. Unfortunately, it is remarkably difficult and expensive to send vessels to map the most remote parts of the ocean. Due to cost and logistics, only about 20% of the seafloor has been mapped in high resolution as of 2022.

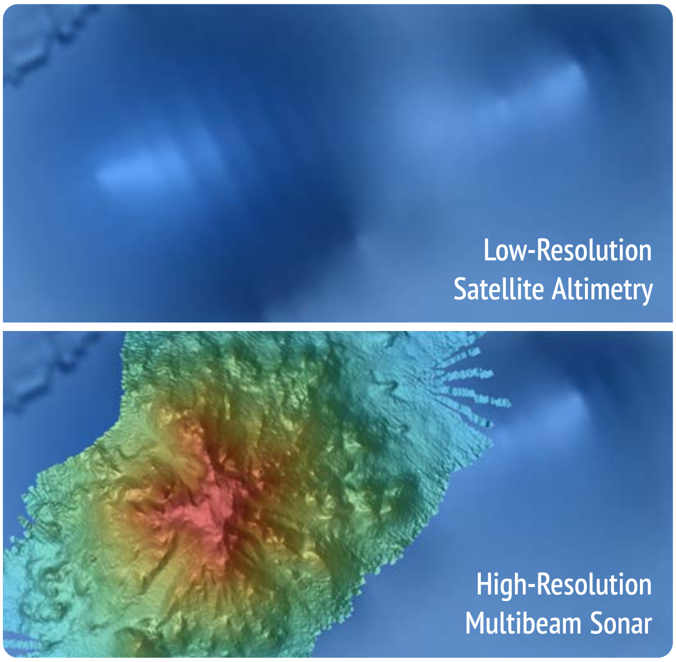
NOAA ship collecting seafloor depth using a multibeam sonar system >



While researchers would rather have high-resolution data in all regions, modern bathymetric maps use a combination of high- and low-resolution data. Although low-resolution data is not the best, it is still better than nothing. Low-resolution data can still help us understand ocean environments.

Much of this low-resolution data comes from **satellite altimeters**. Large underwater features, like seamounts larger than 1.5 km, have enough mass to affect the gravitational force in a given area. This change in gravity creates tiny bumps and dips on the sea surface. Satellite altimeters are sensitive enough to detect and measure these changes.

> **Scientists then use these measurements to estimate the general shape of the seafloor. This low-resolution map is what you see on Google's terrain, or satellite, view of Earth. It allows us to see the global seafloor, but if you look closer you will find that many of the details are blurry.**



High-resolution data contain more data points and give more insight into how the seafloor is shaped

What Have We Learned about the Seafloor So Far?

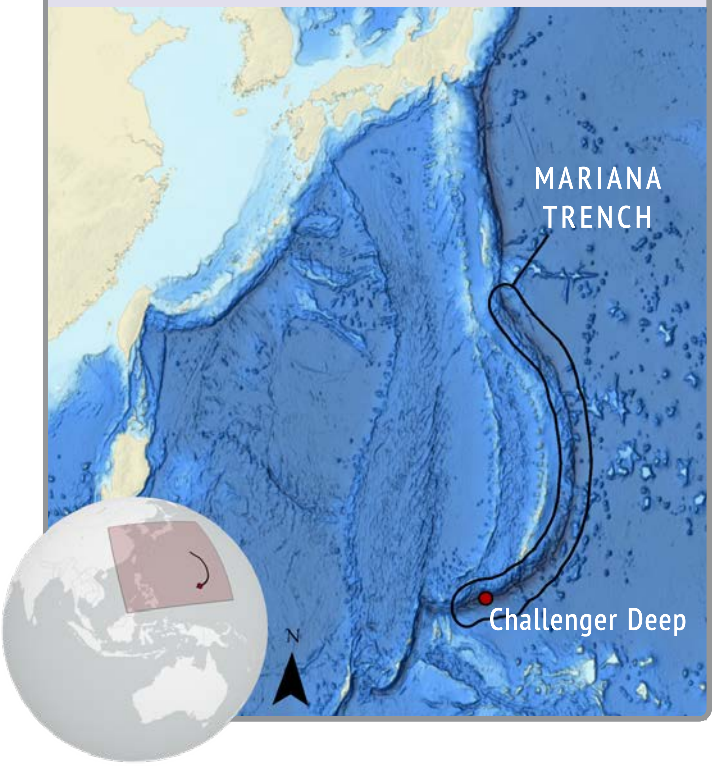
Thanks to sonar mapping systems and satellite altimetry, we are now starting to understand the complexity of the seafloor. Much like the dry land we live on, the seafloor contains physical features like mountains, valleys, and plains. At approximately 65,000 km, the **mid-ocean ridge** is technically the longest mountain range on Earth. The deepest point in the ocean drops an incredible 11,000 m beneath the sea surface—that is deeper than Mount Everest is tall! These remarkable features, and others still awaiting discovery, play a critical role in life on Earth. Bathymetric maps are fundamental to understanding our ocean's history, marine archaeology, ocean currents, and benthic habitats such as deep-sea coral reefs.

WHY STUDY SHIPWRECKS?

Maritime archaeology is the study of underwater cultural heritage sites to gain a better understanding of human cultures from the past. Shipwrecks in particular can reveal a lot about the way people lived and how important historical events occurred. Shipwreck artefacts—like glass bottles, gold coins, and artillery cannons—shed light on the social and economic state of past mariners, trade networks, and life at sea. Maritime archaeology also includes the study of underwater prehistoric sites and paleo landscapes. Bone or stone tools, clay pottery, and evidence of human occupation can be found at these formerly dry sites, which are thought to have been submerged due to either water inundation into cave systems or the rise of sea levels since the last ice age.

HOW DEEP IS THE OCEAN?

The Mariana Trench is the deepest trench in the world, located in the western Pacific Ocean near Guam and the Mariana Islands. The deepest part of the trench is named Challenger Deep after the British ship HMS *Challenger*, whose crew first sounded, or measured seafloor depth, in 1875. Scientists recently reevaluated its depths using multibeam data and updated the deepest known point to approximately 10,935 m.



Our understanding of the seafloor has come a long way from the early days of lead lines and tales of sea monsters. However, global efforts to map the seafloor are far from complete. In 2005, the USS San Francisco, a nuclear submarine, collided with an uncharted seamount. The current nautical charts in the area were not detailed enough for navigators to see the underwater mountain. Luckily, the submarine was able to safely surface and no one was severely injured. This incident highlighted the need for high-resolution multibeam bathymetry data across the entire ocean.

What's Next for Seafloor Mapping?

In the United States, there is an entire organisation, NOAA Ocean Exploration, dedicated to exploring the deep ocean and filling the gaps in our understanding of the world's deep waters and the seafloor. Using NOAA Ship *Okeanos Explorer*, NOAA Ocean Exploration has mapped over 2 million km^2 of seafloor. However, mapping the seafloor with multibeam sonar is time-consuming. A ship must move slowly and systematically to ensure there are no gaps. It has been calculated that it would take one ship nearly 1,000 years to map the entire ocean at all water depths.

Scientists and governments around the world recognise the importance of making a high-resolution global map of the seafloor. An international collaboration called the Nippon Foundation-GEBCO Seabed 2030 Project aims to produce a high-resolution global map of the seafloor by 2030. Another global initiative, led by the International Hydrographic Organization, aims to increase the use of crowdsourced bathymetry, enabling mariners to share depth measurements collected with standard navigation instruments during normal operations. Cruise ships, fishing boats, and even yachts are contributing to a better global bathymetric map. In the United States, there is an effort to fully map the **Exclusive Economic Zone (EEZ)**, or area of water around the coastline. A country's Exclusive Economic Zone is where that country and its citizens can fish, drill, and perform other economic activities.

New healthy coral reef near Tahiti
Image credit: Alexis Rosenfeld

Mapping the entire seafloor by 2030 is an ambitious goal. This global effort is too big a task for one ship or one nation to tackle alone, so governments are collaborating to map the seafloor as efficiently as possible. Technology is being pushed to new limits. Organisations are inventing new vessels and leveraging the use of autonomous vehicles. Geographic information systems (GIS) are allowing people to visualise the seafloor like never before. Look for the next Ocean Exploration article focusing on marine technology!

Why Map the Seafloor?

A new global bathymetric map will benefit us all. Using GIS, we will be able to accurately view entirety of the Earth's surface for the first time in history. Having this data layer will improve global prediction models related to weather and climate, tsunami impact zones, and sea-level rise. Countries will be able to prioritise conservation efforts to improve fish stocks and coral reefs. Seeing the seafloor with such clarity will reveal more information than we can imagine. Many underwater discoveries have been made just in the last year alone: the well-preserved 1915 shipwreck *Endurance* was recently found in the icy Antarctic waters, and a new healthy coral reef was just uncovered near Tahiti. Who knows what future discoveries are yet to come?

MAPPING CAREERS

Today, many professions need geographers, cartographers, engineers, and data scientists. GIS is necessary in many aspects of our society, including public works projects, business decisions, disaster response, epidemiology, and so much more. Additionally, many industries require seafloor mapping experts for the implementation and evaluation of offshore wind farms, petroleum platforms, and submarine communication cables. NOAA Ocean Exploration hosts an Explorer-in-Training program that allows students and early career scientists to learn seafloor mapping and other aspects of ocean exploration. Learn more about the Explorer-in-Training program here:

Endurance
Image credit: National Geographic

NOAA NCEI, the National Centers for Environmental Information, partners with NOAA Ocean Exploration to manage, archive, and disseminate data collected on its expeditions. NCEI maintains one of the most significant data archives on Earth, providing the public with comprehensive oceanic, atmospheric, and geophysical data.