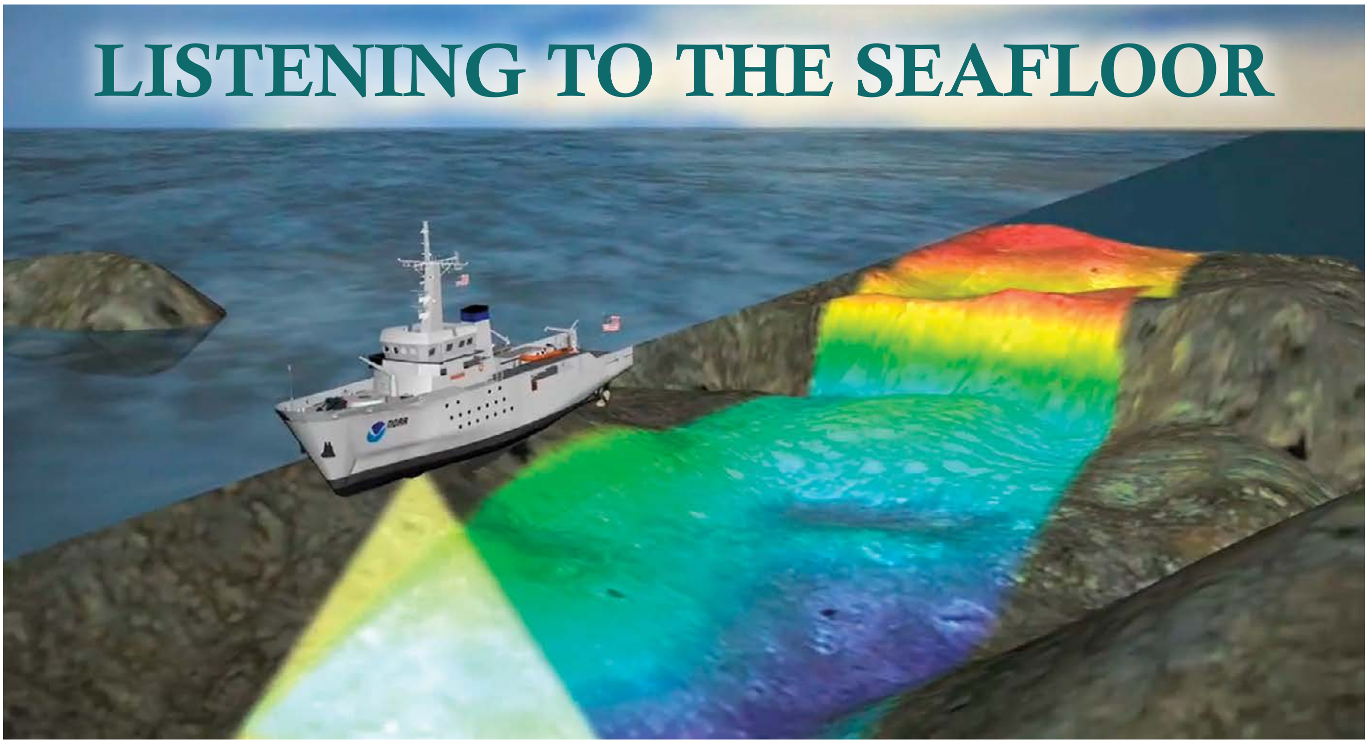
LISTENING TO THE SEAFLOOR



NOAA

Andy Green tells us about the use of sound in marine geological mapping

Despite many years of marine mapping effort, initially for charting and safe navigation purposes and later for scientific and commercial reasons, we still know more about the surface features of Earth's neighbouring planets than the seafloor. The sheer depths of the ocean and the inability of light to penetrate water beyond a few metres, particularly in turbid seas, make it impossible to visually inspect the seabed from the sea surface with any degree of accuracy or precision.

Sonar – an acronym for sound navigation and ranging – overcomes these challenges, and can be used to map seafloors from the shallows of the surf zones to the deepest ocean trenches. Sonar entails directing sound pulses to the seafloor and measuring the time taken from the emission of a pulse to its return after it bounces off the bottom. When coupled with a knowledge of the sound velocity of the water column, this makes for an effective means of measuring depth, and hence understanding the changing elevations of the seabed. Like a bat's echolocation, sonar echosounding establishes a precise distance to a point on the seabed where the depth = time taken from emission to return, multiplied by the speed of sound in water divided by two (to remove one part of the sound pulse's journey, either to or from the seabed).

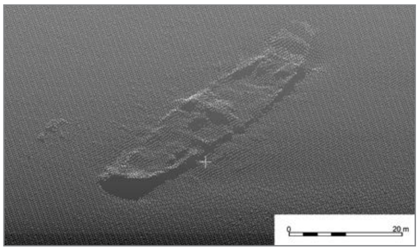
Our modern understanding of plate tectonics in many ways derives from the earliest maps made using sonar. Marie Tharp of the Lamont-Doherty Geological Observatory in the USA was the first to recognise patterns in the changing seafloor depths, especially over the centres of the ocean basins, and to hypothesise that these were related to movements of the Earth's crust. This pioneering work of the 1950s and '60s led to a technological revolution in the way in which the seabed is mapped.

Early sonars used a single, downward-'looking' transducer to emit and then listen for the sonar pulses, termed single-beam echosounding. This was mounted and triggered aboard a ship whilst the vessel sailed back and forth in parallel lines, leaving a breadcrumb trail of soundings, or depth measurements. The ship's position was established using a sextant so the latitude, longitude and depth information could be compiled into a bathymetric chart, where depths were contoured or interpolated between each measured depth point. Naturally, the inferences made between points, especially if the parallel lines of the vessel path were very wide, would introduce some unusual and erroneous readings, and only broad, low-resolution maps of the ocean bottom could be made.

Multibeam echosounders

Today, we have increasingly accurate technology relying on a multibeam approach. With multibeam echosounding, known as MBES, sound pulses are emitted from multiple (up to 512!) individual transducers, creating a fan of sound beams that map a swath of seafloor. This swath can be as much as three times the water depth, essentially creating corridors or swaths of soundings that can be overlapped by successive passes of the ship. As the vessel sails in parallel lines, the seafloor is in effect painted with sound, creating 100% coverage of the bed and allowing for a three-dimensional visualisation of the terrain. When coupled to extremely sophisticated equipment that can compensate for the ship motions (heave, sway, surge, roll, pitch and yaw), as well as tidal changes and varying sound velocity of the water column due to temperature and salinity, the result is an accurate image of the seafloor derived from millions of depth measurements. Sextants have been replaced by differential global positioning systems (GPS) that provide the latitude and longitude of the vessel within one-metre accuracy, making the ability to resolve the seafloor even better. In shallow waters, features of a few centimetres or larger can now be visualised with a great degree of confidence.

Such accurate maps are important for offshore mapping where intricate features on the seabed need to be resolved. This includes, for example, mapping special marine habitats like submarine canyons, conducting seabed exploration for mining, searching for shipwrecks and debris from aeroplane crashes, and identifying safe navigation pathways. The costs, relative complexity of the operation and of the system, and the labour-intensive data-processing that results from the generation of such large quantities of data mean that relatively few institutions have access to multibeam echosounders. The result is a relatively poor, albeit increasingly better coverage of the seabed by higher-resolution multibeam mapping, especially in the territorial waters of countries where this technology is only now becoming more readily available, such as South Africa.



A point cloud representation of multi-beam data showing a shipwreck off the KwaZulu-Natal coast.

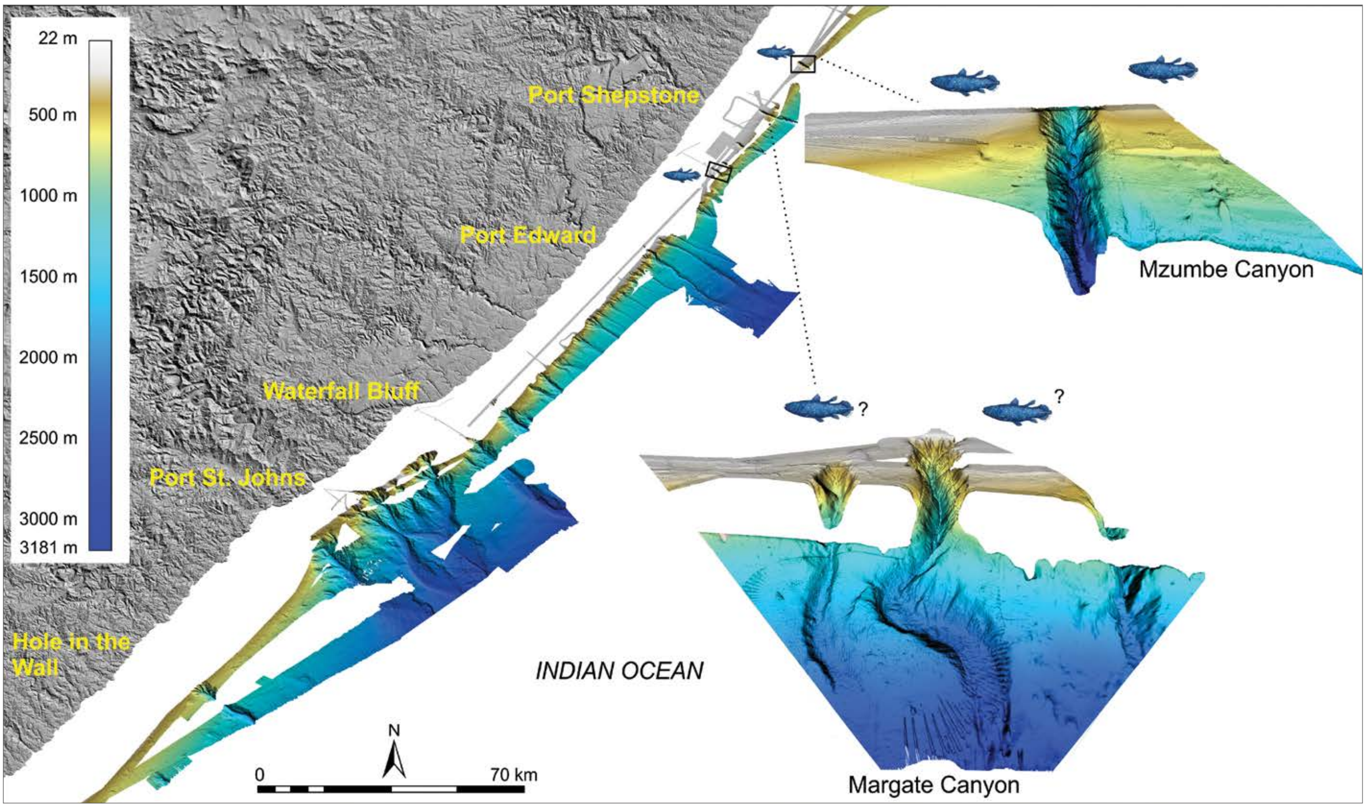
Acoustic backscatter

As sound pulses are reflected back to the transducer, they are returned with varying intensities based on the physical properties of the seafloor. The return of the sound pulse in the direction from where it originated is referred to as acoustic backscatter. Changes in backscatter allow for a qualitative assessment of the seafloor properties, such as hardness and roughness – harder seafloor will produce a higher backscatter intensity (with characteristic backscatter signatures), allowing for an interpretation of the seafloor composition. Grain sizes and shapes of sediment may also affect the degree of backscatter received, so it is possible to create maps of the seabed showing various sediment types. Subsequently, physical inspection using grab samplers, dredges, corers or even tethered or remotely operated cameras allow interpretations to be confirmed.

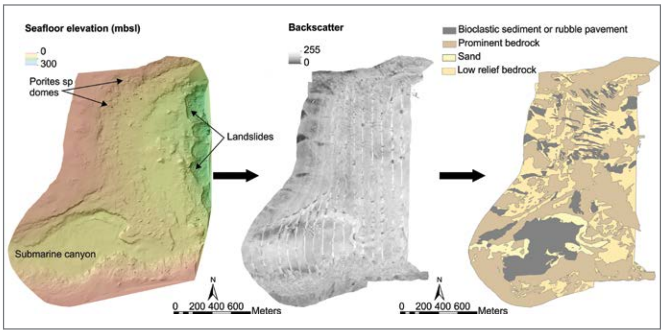
Acoustic backscatter has become an increasingly important tool in our quest to delineate marine habitats. Benthic (bottom-dwelling) and even pelagic (open-ocean) fish and other organisms have habitat preferences with regards to substrate types. Identifying substrates using this remote-sensing technique is thus helpful for habitat mapping and plays a key role in marine spatial planning for fisheries and conservation areas. Today, powerful computing packages coupled with machine learning techniques can auto-classify and help predict where particular habitats may occur, allowing for quicker and more spatially inclusive decisions to be made for ocean resource management.

Seismic surveying

Not only are people interested in what lies on the seabed, but also what lies below. Using the same principles as echosounding, seismic reflection surveying utilises sound pulses to get an impression of the seabed, while also gaining an understanding of the underlying strata. In this case, sound is emitted at a lower frequency and does not just bounce off the seafloor, but penetrates into the underlying strata, where it is reflected back from subsequent layers of different physical properties. The lower the frequency, the deeper the sound waves can



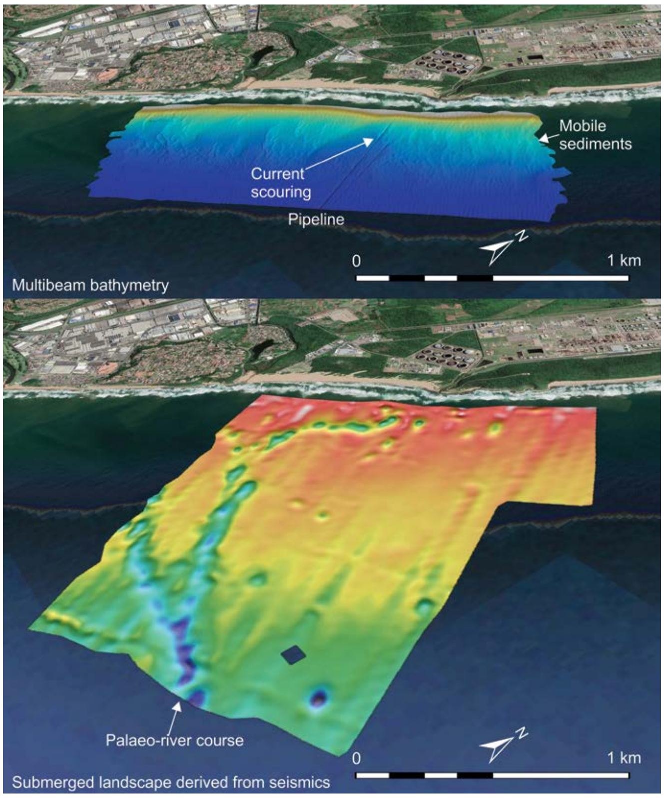
Multibeam bathymetry along South Africa's east coast revealed a multitude of deeply incised submarine canyons, many of which extend into waters less than 100 m deep. Some are known to be home to coelacanth, the 'living fossil' fish.



Multibeam data collected from the head of a submarine canyon (left) and co-acquired backscatter data (middle). The combined use of these datasets can produce an interpretative seafloor composition map (right). High levels of backscatter (white) signify harder substrates, with lower backscatter (black) indicating absorption of the sound pulse by the seafloor. Bioclastic sediment (shells), bedrock and sand can be delineated accordingly.

penetrate. Conversely, higher-frequency sound waves penetrate shallowly, but allow for a great deal more resolution between layers. Increased resolution means that successive layers with smaller spacings between them can be differentiated.

Sound is either emitted by a transducer similar to a depth echosounder, or from systems towed behind the vessel, where the sound source and listening devices are separated. In these cases, the return signal is detected by one or more hydrophones, and the sound pulses are of lower frequency, generated by either the explosive release



Multibeam bathymetry of the seabed off the Durban coastline (top). Mobile sediments are transported over a pipeline where scouring occurs. Seismic data are used to reveal the underlying bedrock morphology (bottom). By stripping off the overlying sediment, the paleo-landscape entrenched into the bedrock can be examined. Here it shows a meandering river system, formed 18 000 years ago when sea levels were ~ 120 m below present and the shoreline was located ~ 20 km seaward of today.

of compressed air into the water column, or by creating a seismic pulse from an electrically operated diaphragm, which claps together to generate the sound.

Seismic surveying is synonymous with oil and gas prospecting in marine basins, but it has become an increasingly important tool in understanding the evolution of the seafloor over time – it essentially looks back in Earth's history with every layer it uncovers. High-resolution and high-frequency seismic surveying is now a staple in habitat mapping, helping to uncover buried river courses and areas with different degrees of sediment accumulation. Together with multibeam bathymetry, high-resolution seismic surveys are a key tool for the identification of cold-water coral accumulations. Seismic surveying is also heavily utilised in the siting of pipelines and telecommunication cables, where knowledge of the depth to bedrock is essential.

Densely spaced seismic surveys can also help to reveal older landscapes that are now buried by sediment. The overlying sediment cover can be stripped away using geophysical computing software and a picture of the underlying horizons generated. This has particular importance to marine geoarchaeological studies investigating areas used by humans when sea levels were lower. Similarly, this technique has aided in the search for diamonds in the ocean, because they accumulate along irregular bedrock surfaces that are easily revealed in high-resolution seismic surveys.

Looking to the future

Geological mapping of the seabed gives a window into the evolution of a piece of seafloor, transporting the observer back in time and allowing them to relate the modern oceanographic, biological and anthropogenic processes that currently affect the area to its overall development. From a purely scientific perspective, the seafloor is one of the final frontiers of exploration. Mapping helps us to answer big scientific questions such as what the magnitude and rates of large-scale sea-level changes were over the last several million years, how these affected coastlines and coastal sedimentary systems, and how changing sea levels may affect coasts today. Likewise, the expansion of the global blue economy is underpinned by accurate seafloor maps that highlight possible resources, in addition to staking claims for coastal nations' Exclusive Economic Zones. More investment by the South African government into academia, student training and research is needed to harness the potential of seafloor mapping, and put our marine geological programmes on a par with those of other developing nations.

Professor Andrew Green is chair of marine geology and sedimentology and heads the Marine Geology Research Unit at the University of KwaZulu-Natal. His research within the DSI/NRF-funded African Coelacanth Ecosystem Programme (ACEP) helped support the expansion of South Africa's Marine Protected Area (MPA) network in 2019.

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