Bet you've never heard of

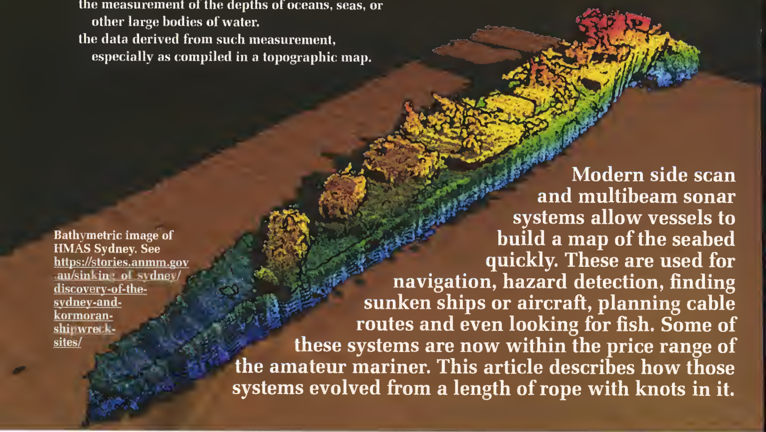
bathymetry *[buh-thim-i-tree]*

noun

the measurement of the depths of oceans, seas, or other large bodies of water.

the data derived from such measurement, especially as compiled in a topographic map.

by Dr David Maddison



Bathymetric image of HMAS Sydney. See https://stories.anmm.gov.au/sinking-of-sydney/discovery-of-the-sydney-and-kormoran-shipwreck-sites/

Modern side scan and multibeam sonar systems allow vessels to build a map of the seabed quickly. These are used for navigation, hazard detection, finding sunken ships or aircraft, planning cable routes and even looking for fish. Some of these systems are now within the price range of the amateur mariner. This article describes how those systems evolved from a length of rope with knots in it.

Today, **bathymetric data** is obtained mostly by electronic techniques, either via acoustic systems (sonar, sound navigation ranging) or to a lesser extent, optical systems (lasers or reflected sunlight).

Seabed imaging and mapping, from shallow coastal areas to deep oceanic waters, is important for the following purposes, among others:

- navigation of vessels in shallow water.
- submarine navigation.
- knowing where to drop anchor, as the water cannot be deeper than the anchor chain is long.
- mapping the location of rocks, reefs and other marine navigational hazards.
- locating shipwrecks for historical purposes/archaeology or for hazard avoidance, salvage or recreational diving.
- searching for downed aircraft, such as Malaysia Airlines flight MH370, presumed crashed into the sea.
- placement of oil rigs and underwater cables and pipeline.
- knowing where to dredge to create or restore shipping channels.
- recovery of underwater mineral deposits.

Since the oceans cover around 71% of the Earth's surface, these mapping tasks are much more significant, and certainly more difficult than land mapping. In most areas, the ocean bottom is not visible and depth measurement is difficult.

Apart from taking accurate depth measurements, it is also important to accurately know the location of each depth reading (latitude/longitude).

This benefits enormously from the development of GPS and other satellite navigation systems. We published a detailed article on augmented GPS technology, accurate to less than a metre, in the September 2018 issue (siliconchip.com.au/Article/11222).

In nautical terminology, "sounding" means the measurement of depth by any means, using sound waves or otherwise. This could be done using a long stick, a rope or laser light. The laser airborne depth sounder (LADS) was an Australian invention, first deployed in 1977.

State-of-the-art bathymetry systems are usually based on side scan or

BATHYMETRY

multibeam sonar, using an array of transducers and powerful computers to form 3D images of the seabed or river bed under a ship, or a towed sonar array. But electronic/acoustic water depth measurements go back over 100 years and simpler methods have been in use since antiquity.

Fig.1 shows a comparison of the three most common modern sounding techniques. We'll now describe the history of sounding techniques, starting from the beginning and proceeding to the present and the latest sonar and LIDAR systems.

Historical bathymetry

Seabed mapping has been performed since ancient times. It was practised by the Ancient Egyptians, who used poles and ropes, and also the ancient Greeks and Romans, who used a rope with a weight on the end to determine depth, known as a lead line or sounding line – see Fig.2.

Such lines were the primary method of determining seabed depth right up until the 20th century, and are still used today a backup to electronic depth sounding systems (sonar).

In the 19th century, attempts were made to automate the lead line sounding process. These employed mechanisms which would indicate when the seabed had been reached.

Among these were Edward Massey's sounding machine, employed by the Royal Navy, who purchased 1750 of them in 1811. There was also Peter Burt's buoy and nipper device.

These devices were designed to work up to around 150 fathoms' depth (275m). In the late 19th century, the installation of undersea telegraph cables created a much greater demand for depth measurement.

Lord Kelvin (then Sir William Thomson) developed and patented

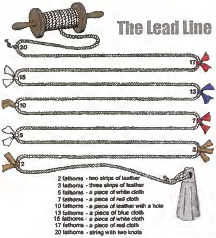


Fig.2: a lead line or sounding line showing different markers at traditional depths of 2, 3, 5, 7, 10, 13, 15, 17 and 20 fathoms. A fathom is today defined as exactly six feet or 1.8288m. Fathoms and feet are still used on US nautical charts whereas other countries use metres.

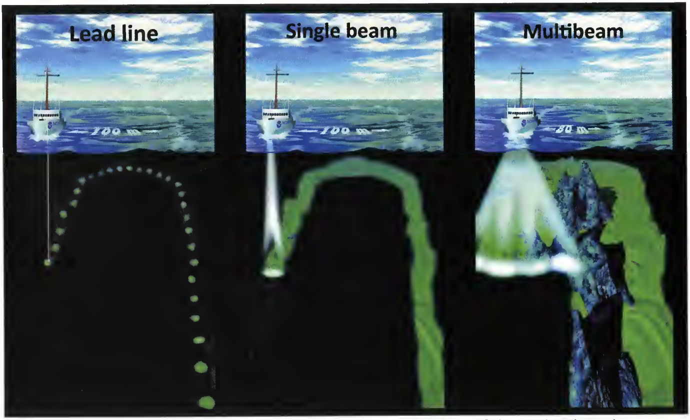
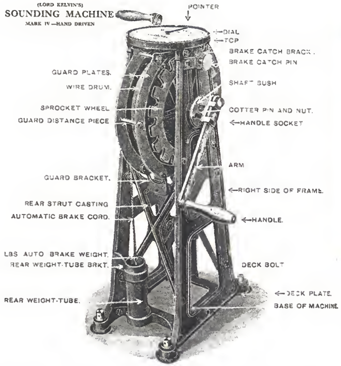


Fig.1: three different sounding methods in use today. A lead line or sounding line, used since ancient times, gives spot measurements; a single beam sonar is capable of giving continuous measurements although some still give spot measurements; multibeam sonar can scan a wide area in one pass and can quickly build up a seabed map. Laser systems such as LADS give similar results to multibeam sonar.



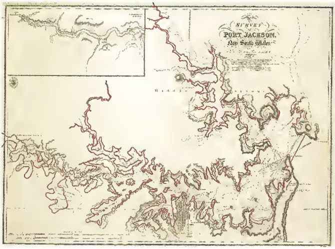


Fig.4 (above): a depth map of Port Jackson (Sydney) made using sounding lines from Roe's 1822 survey. Note how the soundings appear as tracks indicating the path of the vessel.

Fig.3 (left): one version of Lord Kelvin's mechanical sounding machine.

his device in 1876, shown in Fig.3. It featured piano wire and a hand-cranked or motorised drum for winding. There was a dial on the drum to indicated the length of line let out. This device and later versions of it were in use with the Royal Navy until the 1960s.

Using a sounding line, maps were made by periodically measuring the depth while at sea and mapping those depths in relation to landmarks (if in coastal areas) or through latitude and longitude measurements taken with a chronometer or sextant if at sea – see Fig.4.

Use of sound waves

Sounding lines are impractical for very deep water due to the amount of line that has to be reeled out. The survey vessel usually has to be stationary but the line can be swept away by currents, and it is sometimes difficult to tell when the bottom has been reached. It's a very slow method, even when it's feasible.

For these reasons, alternative means were sought to measure depth and these were developed in the early 20th century.

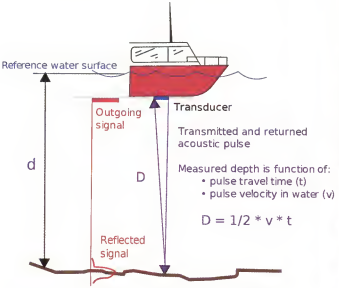


Fig.5 (above): the basic principle of echo-sounding.

Fig.6 (right): the Fessenden Oscillator transducer, initially used for detecting nearby icebergs and later for making depth measurements.

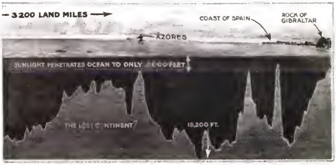


Fig.7: the ocean floor between Newport, Rhode Island (USA) and Gibraltar, as determined by the USS Stewart in 1922. This survey used the Hayes Sonic Depth Finder and found what was thought at the time to be the lost continent of Atlantis. From Popular Science, May 1923.

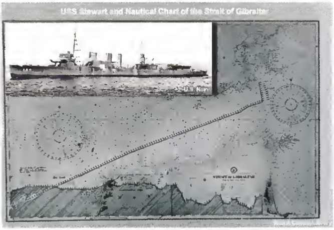


Fig.8: a map of the soundings taken by the USS Stewart across the Strait of Gibraltar in 1922.

The use of sound to detect objects in the water was first recognised by Leonardo da Vinci in 1490. He is said to have placed his ear to a tube which was immersed in water and listened for distant vessels.

The fact that sound waves travel at a known velocity in water and are reflected from solid surfaces such as the seabed is the basis upon which echo sounding and sonar were later developed.

The basic principle of echo sounding to determine depth is that an acoustic pulse is emitted from the device and it travels through the water column at a predictable speed. It strikes the seabed and is reflected to a receiver (microphone). At a basic level, the depth of the water is then computed by taking half of the return time for the pulse and multiplying by the speed of sound in water.

For example, if a pulse took 0.8 seconds to return and the speed of sound in water was 1500m/s, the water depth would be 0.8s x 1500m/s ÷ 2 = 600 metres.

In practice, sound velocity can vary slightly in water due to differences in salinity, temperature and depth. These effects can and usually are taken into account. In general, a 1°C increase in temperature results in a 4m/s increase in the speed of sound, an increase in depth of 100m results in an increase of 1.7m/s and an increase of one part per thousand of salinity results in an increase of 1m/s.

Note that temperature usually decreases with depth, causing the speed of sound to decrease, but at the same time the speed increases with depth (or pressure). The combination of the two effects can result in a sound velocity profile that decreases in the first few hundred metres, then increases at greater depth.

Early echo-sounding devices

The earliest acoustic depth measuring devices were known as echo ranging devices or fathometers. Today it is known as sonar ("SOund Navigation And Ranging"). These devices used a single acoustic 'beam' to measure the seabed depth and as a consequence, can only measure the depth directly beneath a vessel, just like the lead line (see Fig.5).

In 1912, Canadian Reginald Fessenden developed the first electronic or electromechanical acoustic echo ranging device (Fig.6). It used a mechanical oscillator that was similar in design to a voice coil loudspeaker. It could

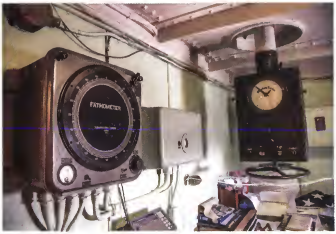


Fig.9: the Dorsey Fathometer as installed on the SS John W. Brown, a US Liberty Ship during World War II.

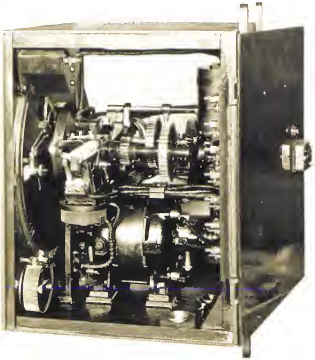


Fig.10: an internal view of the head unit of a Dorsey Fathometer from the 1925 operator's manual. Note the electromechanical nature of the componentry. There were also other electronics boxes.

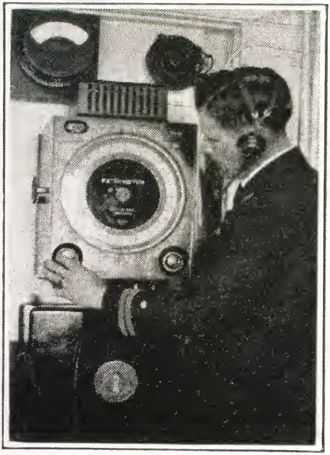


Fig.11: the Dorsey Fathometer in use, 1931.

Open source seafloor mapping software

Open source software called MB-System is available, which can processes sonar data to create seabed maps. It supports most commercial data formats. The system operates on the Poseidon Linux distribution or macOS.

Readers could create their own seabed maps from publicly available data or perhaps with their own data, if they have a boat with an echo sounder. You can download it from siliconchip.com.au/link/aanx or see videos on their YouTube channel at www.youtube.com/user/MBSystem1993

generate a sound wave and then it could be immediately reconfigured as a type of microphone, to listen for echos.

This system was first tested in Boston Harbor, then in 1914 off Newfoundland, Canada (the RMS Titanic had recently sunk in that area). The machine was shown to have had an ability to detect icebergs out to about 3km, although it could not determine their bearing due to the long wavelength used and the small size of the transducer compared to the wavelength.

In this mode of operation, the device relied on the propagation of waves horizontally through the water, but it was incidentally noticed that there would sometimes be an echo which was not associated with any iceberg. These were from a vertical wave reflecting off the seabed. This was the impetus behind the idea to use the device for depth sounding.

The device was also shown to be capable of use for underwater telephony. The machine operated at 540Hz and later models operated at 1000Hz and 3000Hz, and were used up until and during World War 2, for detecting vessels and

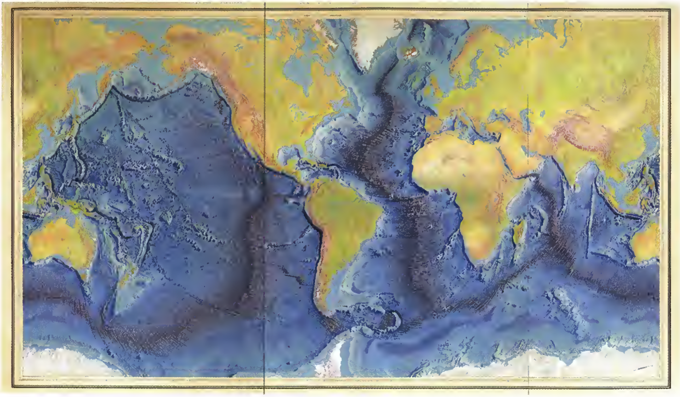


Fig.12: a hand-painted map by landscape artist Heinrich C. Berann, based on the 1950s and 1960s sounding work of Bruce C. Heezen and Marie Tharp. It shows a continuous rift valley along the Mid-Atlantic Ridge along with similar structures in the Indian Ocean, Arabian Sea, Red Sea and the Gulf of Aden. Their discovery led to the acceptance of the theory of plate tectonics and continental drift. (US Library of Congress control number 2010586277)

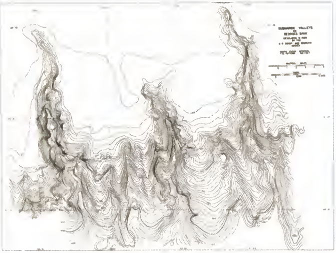


Fig.13: topological map from the US Coast and Geodetic Survey (C&GS; the predecessor of today's NOAA), showing one of the first comprehensive surveys of the continental slope of the USA. It was produced in 1932 with the most advanced echo sounding and radio acoustic ranging navigation systems available at the time. Radio acoustic ranging involved detonating an explosive charge near the ship and listening for the arrival of sound waves at remote locations, recording their time of arrival and reporting it back to the ship by radio.

mines. No examples are known to exist today.

Fessenden won the 1929 Scientific American Gold Medal for his achievement. A detailed description of the device that was written in 1914 can be seen at siliconchip.com.au/link/aanw

In 1916 and 1917, Frenchman Paul Langevin and Russian Constantin Chilowsky received US patents for ultrasonic submarine detectors, one of which used an electrostatic "singing condensor" transducer and the other used piezoelectric quartz crystals.

In 1916, British Lord Rutherford and Robert Boyle were also working on the use of piezoelectric quartz crystals in transducers to detect submarines. Following this, in 1919 and 1920 the French performed sounding surveys using their prototype device, then in 1922, surveyed a telegraph cable route from Marseilles to Philippeville, Algeria. This was the first claimed practical use of echo sounding.

Fig.14: a river survey using single beam sonar readings to determine the depth profile of a river where other methods would be unsuitable (Source: Ayers Associates).

Also in 1922, American Dr Harvey Hayes tested his Sonic Depth Finder on a US Navy ship. It used a Fessenden Oscillator and was said to be the first device capable of deep water sounding.

On one of its first tests on the USS Stewart, the ship sailed from Providence, Rhode Island to Gibraltar in nine days, during which 900 soundings were taken between 9-3200 fathoms depth (16-5850m) – see Figs.7&8.

The soundings were even taken while the vessel was

Fig.15 (above): an image of a steamship wreck in the Gulf of Finland, 33m deep, made with a StarFish sonar.

Fig.16 (right): the compact, portable StarFish 452F sonar kit. The towed body or towfish is yellow and 38cm long. The resulting data is displayed on a PC. It has a range of up to 100m on each side; larger systems have greater range and performance. This system is available online for US $6637, excluding GST and delivery costs. It operates at 450kHz. Full-size towfish are 1-2m long.

Fig.17: an image of a World War 2 era PB4Y bomber in 53m of water in Lake Washington, USA made with StarFish side scan sonar.

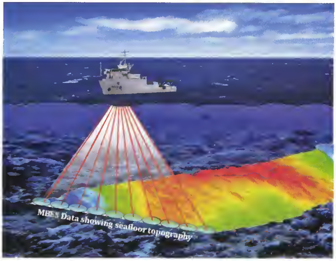


Fig.18: multibeam echo sounding uses narrow beams. This shows the sort of topography which can be generated. (Source: NOAA Photo Library, Image ID: fis01334)

cruising at 23 knots. That voyage was an enormous success, with many undersea topography discoveries made and, in a time before highly accurate means of navigation such as GPS, US Navy officials said they expected to be able to navigate across the oceans using such soundings to observe undersea topography.

The Sonic Depth Finder was operated by adjusting the interval between when the signal being transmitted and the echo of the previous signal being received. When a transmitted signal and a received signal coincided, that corresponded to a calibrated dial position indicating the depth.

Despite the overall success of the USS Stewart voyage, the instrument relied on operator skill to a significant degree and had inherent limitations. So it was not regarded as suitable for precision surveys. This led to the development of a new device, considered to be the first practical echo sounding machine. It was called the Dorsey Fathometer, invented by American Herbert Dorsey in 1923.

One advantage of this device compared to others is that a ship could take soundings at full speed. One model of the device could measure depth between 8 and 3000 fathoms (15-5500m). See Fig.9, Fig.10 and Fig.11.

It was said to have an accuracy of 7.6cm (three inches), but it's unlikely that this could be achieved in reality due to variations in sound velocity through the water and so on. The display consisted of a spinning neon light which would flash at the point on the dial corresponding to the measured depth.

Early sonar devices were too large to put on smaller vessels, which were needed for harbour work, so up until the 1940s, lead lines were still used for such survey work. Eventually, the sonar equipment became small enough that it could be installed on smaller vessels.

Along with improvements in the electronics came improvements in their transducers. The operating frequency was increased beyond the audible range, into the ultrasonic region, and transmitters and receivers shifted from electromechanical to piezoelectric devices. Improvements in recording also enabled continuous measurement of depth, rather than just periodic spot measurements.

During this period, many discoveries were made about underwater geological structures, such as the mid-Atlantic Ridge, seamounts and many other geological features, especially after WWII. Before this, the seabed was thought to be mostly dull and featureless.

These discoveries, mostly during the late 1950s and early 1960s, helped lead to the development of the theory of plate tectonics, which states that the continents are on geological "plates" that drift due to motions between the plate boundaries (see Fig.12). It is now accepted as fact.

Modern echo sounding technology

In modern echo-sounding or sonar, there are three main categories: single beam, side scan and multibeam.

Fig.19: a Kongsberg multibeam echo sounder mounted on survey vessel. Note the partially visible person at bottom right for an idea of its size.

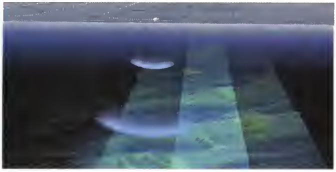
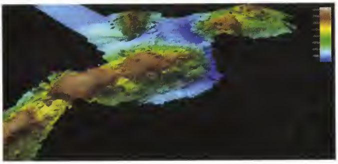
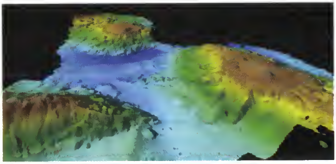


Fig.20: a typical survey pattern for multibeam sonar. The paths overlap on purpose, to give improved confidence in the data. (Courtesy: Geoscience Australia)





Figs.21: multibeam maps of seamount chain discovered by the CSIRO in 2018, 400km east of Tasmania. The seamounts rise about 3000m above the seabed, which is 5000m deep. These are important areas of biodiversity.

Single beam sonar is the traditional type and is a proven, relatively inexpensive technology. Such devices are usually mounted on the hull of a vessel. They give depth information from a single 'spot' beneath a vessel but no information is given as to what is off to the side. They are commonly used for navigation purposes.

Single beam sonar can also be used for mapping and has the advantage of lower cost, less data to deal with and the ability to be used in shallow and otherwise inaccessible waters such as rivers, where multibeam sonar is not practical. But it gives much less complete information than other methods (see Fig.14).

Sound waves generated by a single beam sonar system are typically at 12-500kHz and the approximate sound beam width (shaped like a cone) is 10-30°, depending on the transducer used.

A frequency of 200kHz is typical for depths under 100m, and since higher frequency sound is attenuated over shorter distances, 20-33kHz is typical in deeper water. Lower frequencies are also better in turbulent water.

Additional processing performed on single beam sonar data may include taking into account the vessel attitude (roll, heave, pitch and yaw), tides and speed of sound in the water at the location. The spatial resolution of mapping data obtained with single beam sonar depends on factors such as the survey route and depth of water.

Side scan sonar

Unlike single beam sonar which transmits acoustic energy downwards, side scan sonar transmits acoustic energy to the side. It does this (usually) from a towed underwater "pod" known as a towfish (Fig.16).

A fan-shaped beam is emitted from both sides of the towfish. Rather than just receiving one return signal from one spot after a pulse, like single beam sonar, many return echos are received from multiple distances off to each side after each ping.

The main purpose of side scan sonar is to produce images of the seabed, rather than mapping data. Images are generated based upon the amount of reflected sound energy as a function of time on one axis and the distance the towfish has travelled on the other axis (effectively, the next set of ping data).

The returned data is analysed and processed to produce a picture-like image (see Figs.15 & 17). The seabed and objects on it, such as ship or aircraft wrecks or obstructions, can be imaged well. However, this type of system is not so suitable for accurate depth data. No image is produced in the central part of a side scan image, which is between the two side beams.

Man-made objects, typically containing metal which reflects sound energy well, show up brightly on the image. Sound frequencies in the range of 100-500kHz are typically used. One such device of note is GLORIA (Geological LOng Range Inclined Asdic) which is an extremely long-range system that can scan the seabed 22km out to each side, and has a ping rate of twice per minute.

Multibeam sonar

Multibeam (swathe) sonar is similar to side scan sonar but the data is processed differently. Whereas side-scan sonar images are produced primarily based on the strength of the echos, with multibeam sonar, the travel time of the echos is measured instead. This type of sonar is mostly used for mapping (see Figs.18-22).

A multibeam sonar system transmits a broad, fan-shaped pulse of sound energy like a side scan sonar, but "beamforming" is used for transmitting and receiving the data,

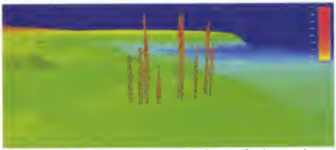


Fig.22: multibeam sonar is not only for producing static images such as of the seabed. It can also image dynamic phenomena such as methane gas seeping from the seabed in the Gulf of Mexico. (Source: NOAA, Image ID: fish2946, NOAA's Fisheries Collection 2010)

Fig.23: the 208 x 244 x 759mm EdgeTech 6205s hybrid multibeam and side scan sonar instrument. It operates at 230, 550, 850 and 1600kHz and has a range of 250m at the lowest frequency and 35m at the highest, used for side scan. For multibeam work at 230kHz, it has a swathe width of 400m.

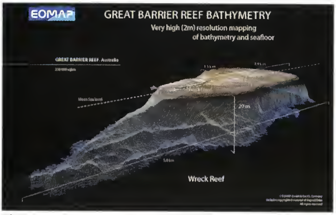


Fig.24: satellite-derived bathymetry image of an island in the Great Barrier Reef. (Courtesy EOMAP)

yielding narrow slices of around 1°. There are therefore a large number of independent beams in a multibeam sonar and for each one, there is a known angle and return time.

Knowing the speed of sound in the water being surveyed and the angle of the received beam, it is then possible to determine the depth and range of the object that the signal bounced off, and thus a map of the seabed can be created. Data has to be adjusted for heave, pitch, roll, yaw and speed of the survey vessel or towfish.

Different frequencies are used. Higher frequencies give improved image resolution but less range while lower frequencies give less resolution but a greater range. The optimal mix of frequencies is chosen for each situation, to give the best results.

The discovery of beamforming

The concept of beamforming was invented by Australian radio astronomer Bernard Mills, who used an array of antennas (two rows of 250 half-dipole elements) that, by adjusting the phasing of the elements, could produce a pencil-like beam which could be steered across the sky.

The telescope was built in 1954 at Badgery's Creek, near Sydney. The Mills Cross beamforming technique (as it became known) was used by American U2 spy planes for radar mapping over the Soviet Union between 1956 and 1960.

After a U2 was shot down in 1960, engineers at General Instrument Corporation, who made the U2 radar, looked for other uses for the technology.

The principles used were just as valid for acoustic energy as for radio energy, so they decided to use it to produce the first multibeam sonar.

This was then adopted by the US Navy and tested in 1963, with a system known as SASS or Sonar Array Sounding System. It operated at 12kHz and had 61 1° beams.

This system was classified (ie, secret) then and even today, some of the bathymetric data produced by it remains classified or is released in a smoothed or lower-resolution format.

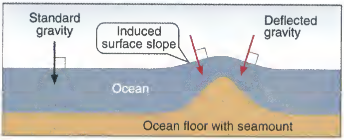


Fig.25: underwater structures cause the sea level to change. This can be measured with satellites. A seamount might be a few kilometres high and produce a bump in the sea level of a few metres, which is in the detectable range.

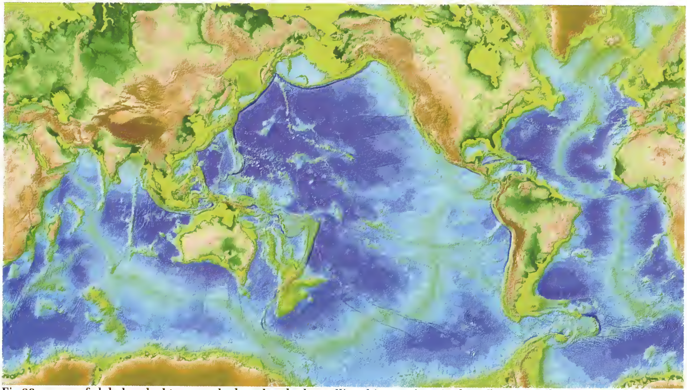


Fig.26: a map of global seabed topography based on both satellite altimetry (gravity-based) and ship-based depth soundings, from the US Government agency NOAA. The gravity data is used where sparse ship-based depth readings are unavailable.

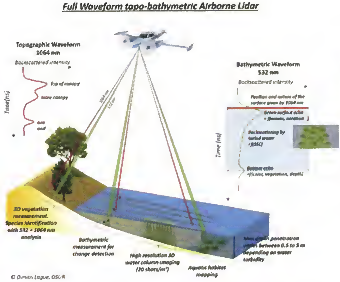


Fig.27: the general scheme for one particular implementation of airborne LIDAR. This image shows its use for both bathymetric and land topographic imaging and the expected return waveforms for the laser pulses. An infrared beam (1064nm) is reflected from the surface of the water while the green beam (532nm) is reflected from the seabed. (Courtesy: Dimitri Lague, Université de Rennes)

Fig.28: the LADS equipment. (Courtesy: RAN)

At about the same time as SASS, a Narrow Beam Echo Sounder (NBES) intended for non-military use was produced which had 16 beams of 2-2/3°.

The NBES technology became what is now known as the SeaBeam Classic, which was the first commercial multibeam sonar system and was installed on Australia's survey vessel HMAS Cook in 1977.

In modern multibeam systems, the transducers can either be attached to the vessel (Fig.19) or be in the form of a towfish or remotely operated vehicle.

Note that while we said that multibeam sonar systems work based on the echo delay rather than strength, it is also possible to determine and process the echo strength to determine how reflective each particular object on the bottom is, giving a more detailed (eg, false coloured) map – see Fig.22.

Most modern multibeam systems can also produce backscattered images as for side scan sonar, but the images produced are not as good as a dedicated side scan system. This is because a multibeam system will produce one backscatter data point per beam, whereas a dedicated side scan system will produce essentially a continuous series of values and therefore the result has a much higher resolution.

It is therefore important to choose the appropriate instrument for the information that is required. Some systems are hybrids and combine side scan imaging systems with multibeam bathymetric systems. (See Fig.23).

Satellite bathymetry

Satellite-derived bathymetry or satellite optical bathymetry uses optical sensors on satellites to detect sunlight reflected from the seabed to determine depth. Mathematical algorithms are used to calculate depth depending upon such factors as the wavelengths of light reflected and the amount of each wavelength, seabed types and reflectance of the seabed (see Fig.24).

These systems typically use specific "registration" points of known depth and properties for calibration. The depth capability of the system depends on the turbidity of the water. In very turbid water, it might be 0-5m, in moderately turbid water it might be 10-25m and in clear waters, it might be 25-35m.

Horizontal accuracy is similar to the resolution of the satellite imaging sensor, which is typically 2-5m, depending on the sensor, and depth accuracy is around 10-20% of the actual depth. A similar technique can also be used from aircraft.

The search for MH370

Australia was extensively involved in the search for missing Malaysian Airlines flight MH370, and this was discussed in the Silicon Chip article of September 2015 on Autonomous Underwater Vehicles (AUVs) - see siliconchip.com.au/Article/9002

The search involved the acquisition of high-resolution side scan and multibeam sonar images of remote parts of the southern Indian Ocean which had never before been imaged. The search was in two phases.

Phase 1 used multibeam sonar mounted on a vessel to map the ocean floor, since only low-resolution satellite gravity measurements were available.

Phase 2 involved lowering a "towfish" from the search vessel thousands of metres, to within 100m of the seabed, where it produced photograph-like side scan and multibeam sonar images up to 1km on either side.

The search was one of the largest marine surveys ever and involved the collection of 278,000km^2 of bathymetric data and 710,000km^2 of data overall.

The data was released to the public on 28th June 2018. The imagery revealed unknown shipwrecks, whale bones and geological features.

Although the remains of MH370 were never found, the extensive data set is of scientific value and of general interest, so there was at least some return on the many millions of dollars spent on the search, even though the aircraft was unfortunately not found.

A very interesting interactive "story map" showing the data and features of interest has been placed on the web at siliconchip.com.au/link/aany

You can download Phase 1 data from siliconchip.com.au/link/aanz and Phase 2 data from siliconchip.com.au/link/aao0

Fig.29: the aircraft used to carry LADS, a de Havilland Dash 8-202. (Courtesy: RAN)

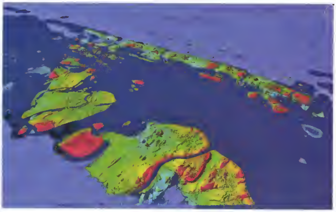


Fig.30: typical LADS survey data. (Courtesy: RAN)

Another form of satellite bathymetry, satellite radar altimetry, relies on the fact that structures beneath the ocean alter the gravitational pull over that area and cause changes in the ocean surface level, which can be measured by satellites using radar.

This results in a low-resolution map of an area showing general features such as underwater mountains and mountain ranges. See Figs. 25 & 26.

Laser Airborne Depth Sounder (LADS) and LIDAR

Lasers can be used from aircraft to determine seabed depth and such systems are generally known as LIDAR (LIght Detection And Ranging) – see Fig.27. Australia was a pioneer in developing this technology and has a system known as LADS (see Figs.28-30).

Australia has a vast ocean area within its territorial waters and a huge area of search and rescue responsibility (53 million km^2, or 10% of the earth's surface) and many of these waters (such as reef areas) are hard to map due to their relative inaccessibility and lack of existing charts.

Some of the charts used until recent times (the 1970s) were actually made by Captain Cook!

There was therefore an urgent need to develop a system that could remotely measure ocean depths, and this was produced by the then Defence Science and Technology Organisation (DSTO) which started feasibility trials of the LADS system in 1977.

An aircraft flies over an area of interest and an onboard laser system emits two beams (originating from a single laser), one of which is reflected off the ocean surface and the other is reflected from the seabed. The relative distances from the aircraft are computed and the depth of the seabed below the sea surface can therefore be determined.

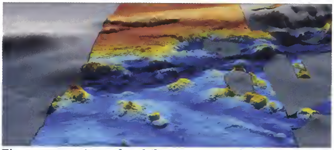


Fig.31: comparison of multibeam sonar and satellite data imagery around an area known as Broken Ridge showing new multibeam sonar mapping data in colour, compared with older, much lower satellite resolution data in monochrome. (Source: Geoscience Australia)

The laser used is a Neodymium:Yttrium-Aluminum-Garnet (Nd:YAG) laser which typically emits in the infrared. The beam also goes through a frequency doubler to produce a green beam. The infrared beam is reflected off the ocean surface and the green beam is reflected from the seabed. The beam has a pulse repetition rate of 990Hz.

The system can measure depths of 0-80m and measure surface topography (land) from 0-50m in height. The aircraft flies at an altitude of 1200-3000 feet (360-915m) at a speed of 140-200 knots (260-370km/h). The beam (swath) width is 114-598m; for standard surveys, it is 193m. Data points are between 2-6m apart across the beam.

The aircraft can go on sorties of up to seven hours, which it does about 140 times per year. Note that this system is suitable only for relatively shallow waters (ie, up to 80m deep); other sounding systems are used elsewhere.

The Royal Australian Navy, in conjunction with Fugro LADS Corporation and other subcontractors, operates the LADS system from Cairns airport and the data that is collected is sent to the Australian Hydrographic Office in Wollongong for processing.

Mapping under the seabed

In our article on A Home-Grown Aussie Supercomputer in the November 2018 issue, we described how Downunder Geosystems uses their supercomputers to process the data from huge arrays of hydrophones – up to 10,000 in a single survey (siliconchip.com.au/Article/11300).

Unlike the sonar systems described above, they do not use transducers to produce sound waves. Because they are mapping the area under the seabed, they need powerful soundwaves to penetrate the rock strata.

So a large underwater air cannon is used to generate the initial sound waves.

Some of these pass through the seabed and reflect off layers below, including oil and gas deposits, and are reflected up to the surface where they are picked up by the towed hydrophone arrays and recorded for later processing.

The vast amount of data and complex reflections mean that it takes days of processing by a huge supercomputer to turn the resulting data into a 3D map of the area under the seabed. This is ideal for determining where to drill for oil and gas. SC