3. METHODS

Recently, various methods have been developed for successful application at the depths of the ocean seafloor of the continental margins using not only underwater photography, but also underwater acoustic methods. For instance, to the eastern tropical part of the Pacific ocean was recently surveyed in the scope of a program for studying distribution of the ferromanganese clusters located at the seafloor basement, carried out at depths from 4400 to 5100 m with the use of a 1-5 m above the bottom of installed underwater cameras.

3.1. Modern Tools for Ocean Floor Exploration and Surveying

Systematic ocean exploration in the 20th century started on the ships, naval or merchant navies of different countries. However, the diversity of scientific tasks and the need to study completely different objects both in the water column and on the ocean floor led to the creation of the specialized geological and geophysical vessels, which were installed, as well as different equipment and tools. Generally, the ocean scientific research fleet consists of vessels of various state and departmental affiliation (Fig.5). They were designed for specialized study of the seabed relief, the biological and geological resources of the ocean, geophysical fields, multilateral study of the properties of the ocean water column and the nearby atmosphere layers. Special units of the scientific fleet are drilling vessels and drilling platforms, as well as underwater manned vehicles.

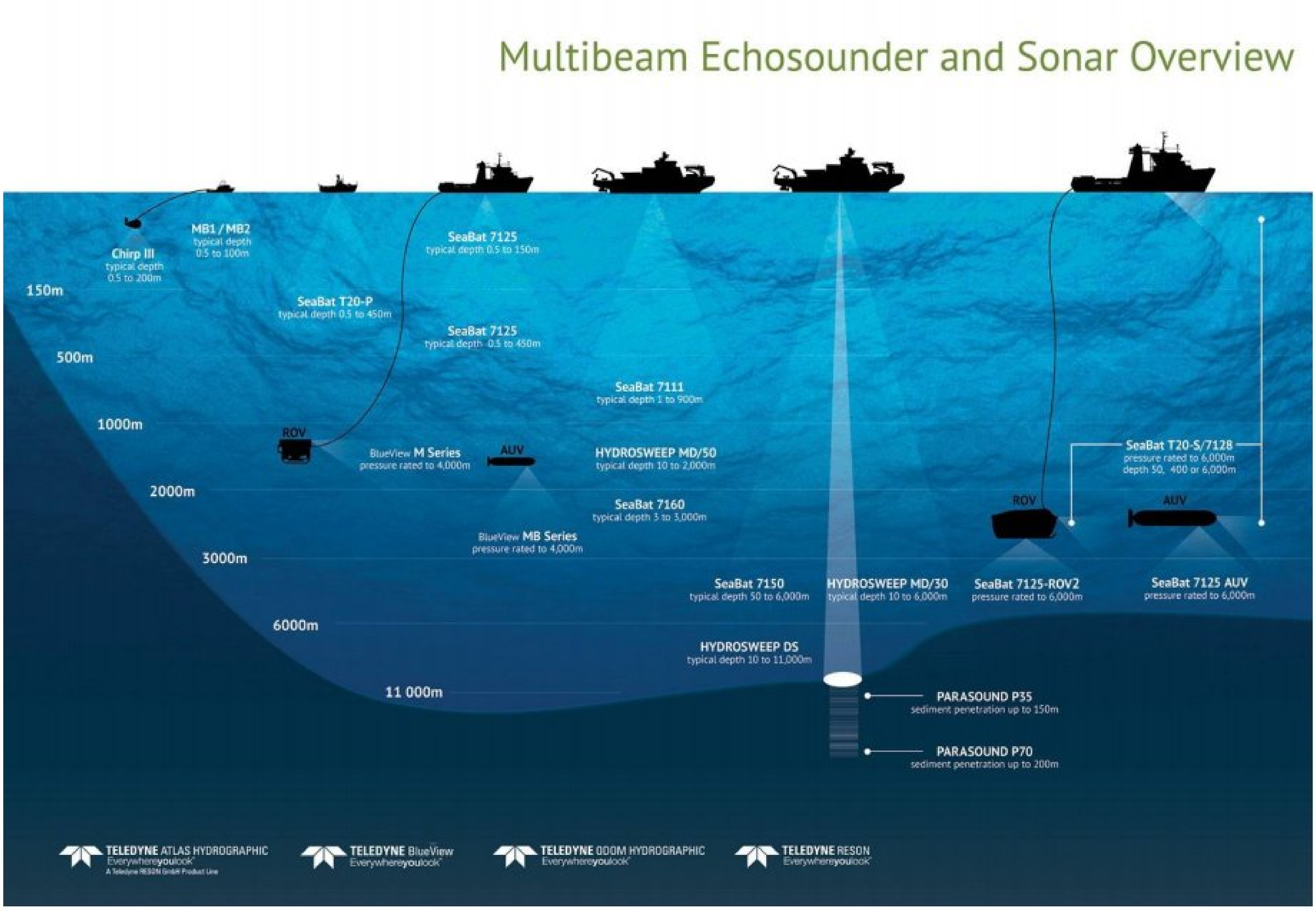

Fig. 5. Types of the echo-sounder devices. Image source: www.whitepapers.marinetechnologynews.com

3.2. Echo Sounder: history, types of sounders

The question of the depth of the ocean has long attracted humanity. To measure depth of the ocean first various tenches and a metal cable were used. These methods of measurement could not be considered as accurate and of course led to major errors, which contributed to the map errors.

Acoustic systems (echo sounders) appeared before the II World War. This was a revolutionary breakthrough in the practice of studying the ocean, since sounders allowed to build a continuous profile of the bottom relief along the measurement line. The principle of operation of the sounders is to send an audio signal (Fig.6), which is reflected from the acoustically rigid surface of the bottom and returns to the receiving antenna. The speed of sound in the oceans can vary from 1400 to 1550 m/s. The maximum speed is timed to the depths of 1200-1300 m. The way passes a very long distances without loss of energy. Multiplying the speed of the acoustic noise in the water by the time gives seafloor depth.

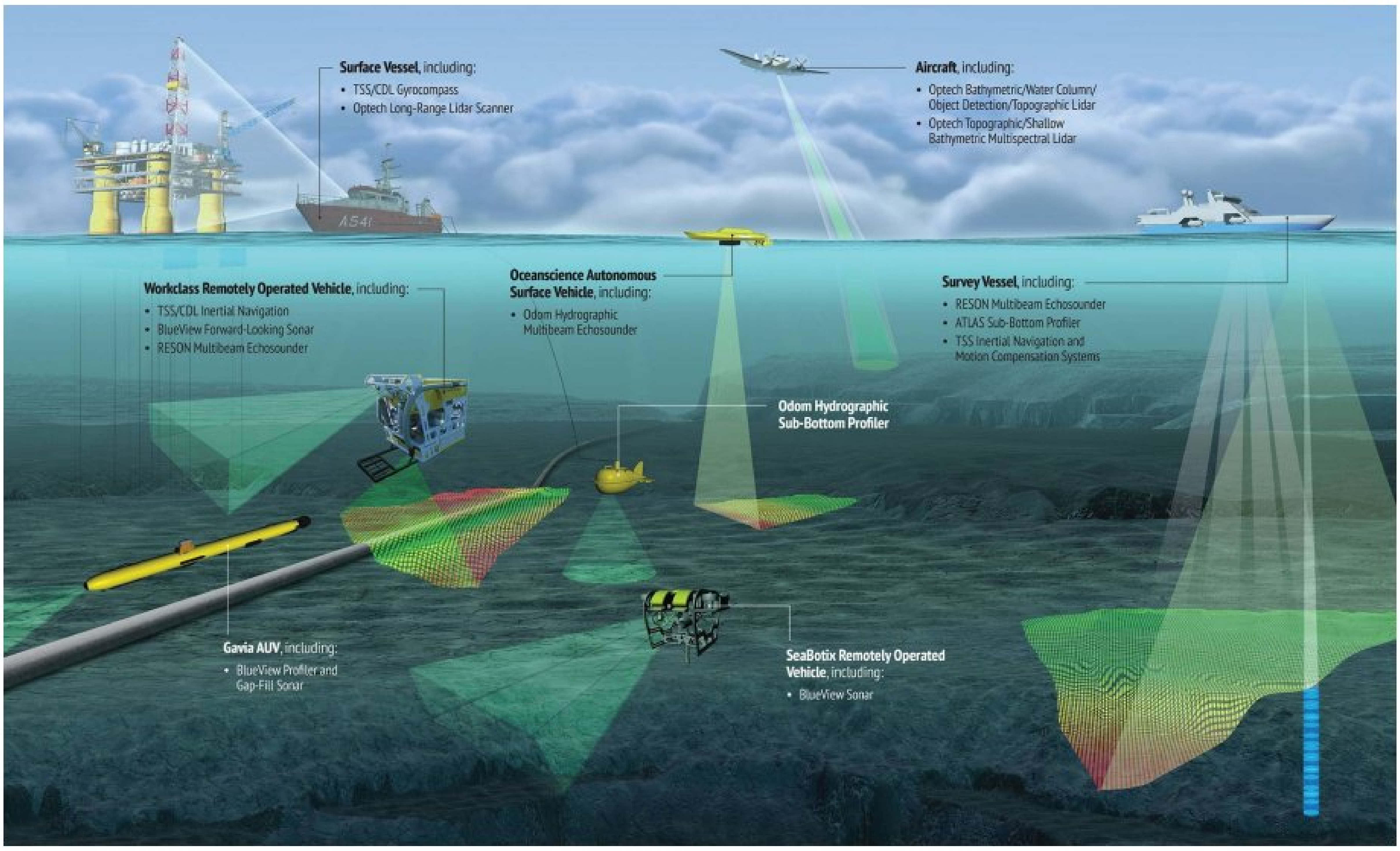

Fig. 6. Schematic construction of the multi-beam echo sounder systems. Image source: http://images.marinetechnologynews.com

The accuracy of such measurement is impacted by the water properties: temperature, salinity, and so on. The difference in the speed of the sound for depths up to 200 m reaches 3-4 m/s and for depths up to 800 m to 1-1.5 m/s. Therefore, for each specific area before taking the ocean floor depth measurements it is required to carry out special measurements that give a curve of change of speed of sound in water which allows to make the appropriate amendments.

Echo sounder measurements is a basic method to measure the ocean seafloor depth. It is therefore the basis for all subsequent geological, geophysical research works and theoretical developments. Many tectonic conclusions about the structure of the ocean floor depend, as mentioned above, on the idea of its relief. In turn, it is closely related to the accuracy of bathymetric maps, the creation of which is subject to the methods of depth measurements. The echo-sounder recorders allowed measurement on the ship. Development of echo-sounder devices increased the number of measurements, improved their accuracy and expanded the scope of the research. In the late 1970-s the multi-beam sonar echo-sounder was invented (Caress and Chayes, 1996.). It opened a new opportunities for detailed study and mapping of the underwater topography. The special feature of the multi-beam echo sounders consists in the fact that the not one sound beam is sent to the ocean floor but many tens (or hundreds) of beams. The fan beams diverge from the emitter along the axis of the vessel, and enable the bathymetric survey of the seafloor with a wide band (from 70% of the depth to three or more depths – i.e., at the depth of 5000 m, a band of 15,000 m can be mapped). Currently, the multi-beam echo sounders of various designs (181-rays and more) are installed worldwide on approximately 1,000 vessels.

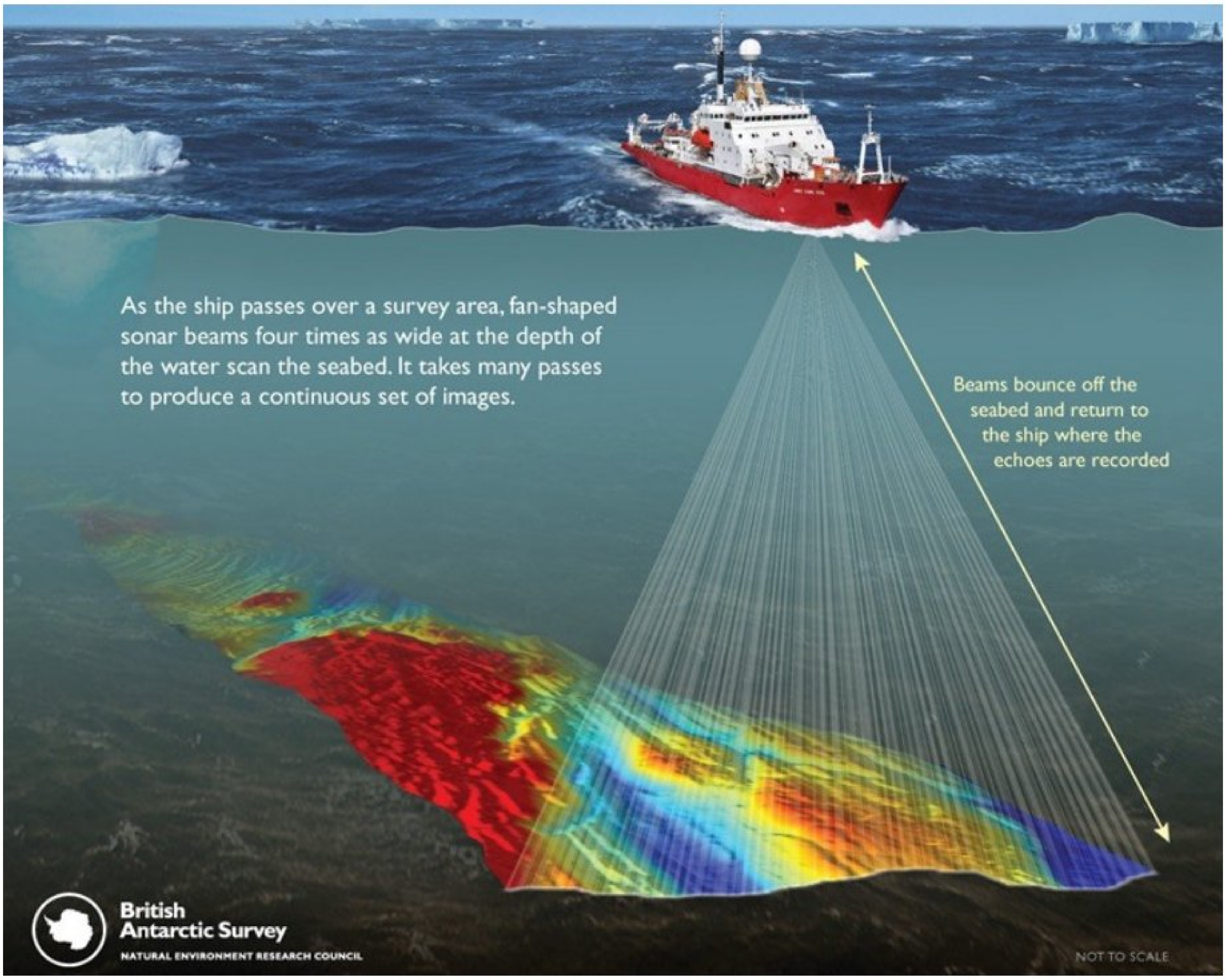

Fig. 7. Principle of the echo-sounder device functioning. Image source: British Antarctic Survey.

Example of the one of the modern modifications of sounders created in Norway in the mid-90s, which measures ocean floor depth by 81 beams (Fig. 7). The vertex angle of the radiation cone is about 120°, and the maximum width of the irradiation band is up to 3.5 depth. It is also equipped with a shallow-water echo sounder 1000, which is designed for offshore operations (average depth ca 200 m) and measures depths by 151 beams with a maximum matrix angle of up to 150° and a bandwidth of up to 7.4 depth.

Currently, the technical parameters of all modern echo sounders have been significantly improved. Schematic diagram of the multi-beam echo sounder consists of radiating and receiving antennas, subsystems radiation intake, control of onboard pitching and rolling sweeps, as well as numerous special blocks that allow to enter commands to do digital processing, to visualize bottom topography in real-time regime, etc (Fig. 8).

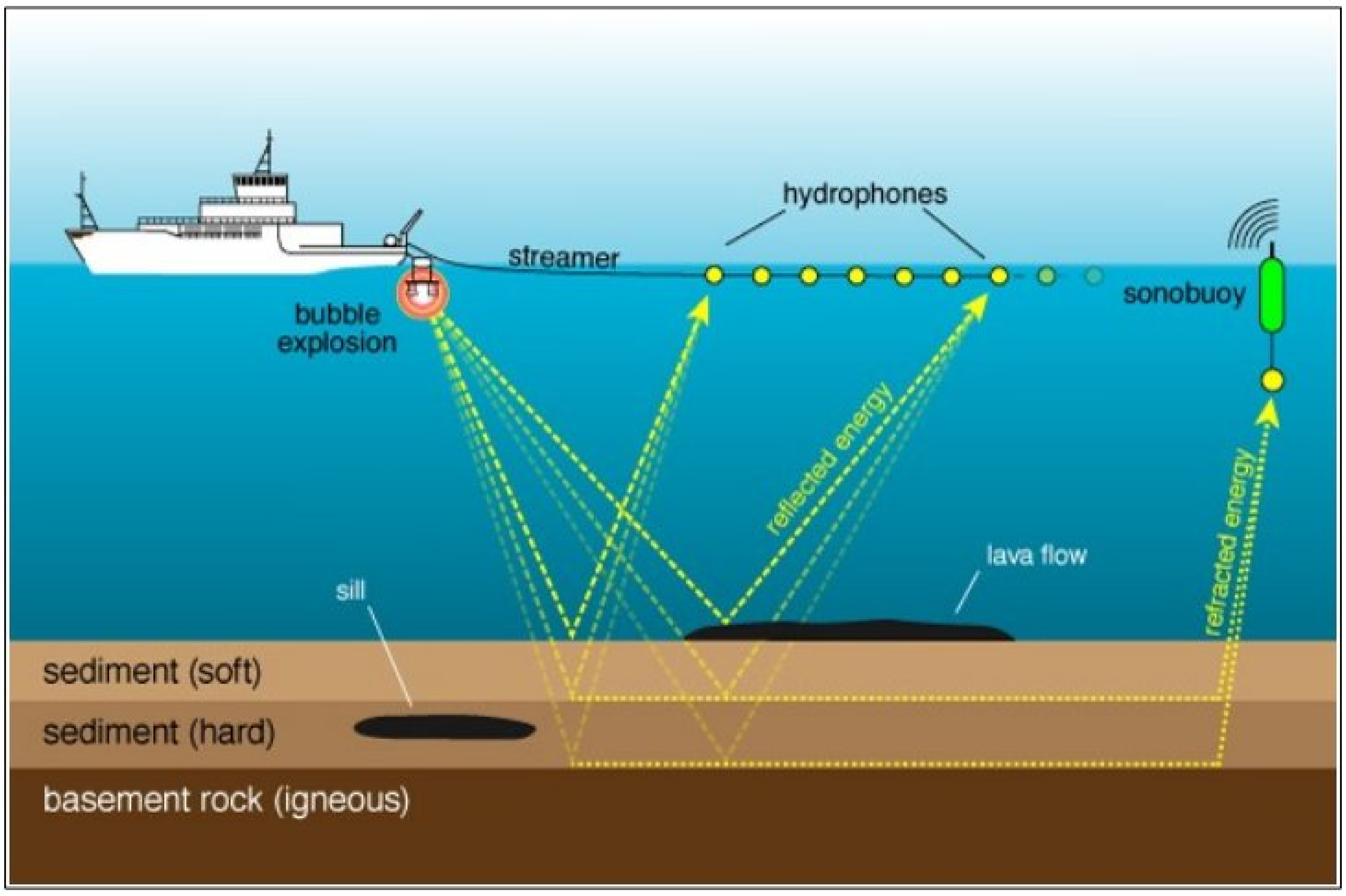

Fig.8. Measurements of various types of the seafloor sediments. Image source: http://www3.kutztown.edu/JOCMS2011/methods.html

Thus, in the period from 1840 to 1970, from the first depth measurement carried out by John Ross to the formation of a new theory of global tectonics, there are four change periods of "equipment":

1. in 1870, the rope line was replaced by a metal cable,
2. in 1922 an echo sounder appeared,
3. in 1922 an echo sounder appeared depth sounder-recorder,
4. in the late 1970s a multi-beam echo sounder. The latter marks a qualitatively new stage of measuring the depths.
5. at present, we are in the stage of accumulating detailed information on the depths of the ocean, which can be generalized in the first half of the 21st century, which may lead to a new geodynamic understanding of the structure of the ocean floor.

3.3. Seismic methods in the ocean floor exploration

Seismic methods in the ocean floor exploration are the most important ones to study the structure of the sedimentary cover of ocean or its deeper horizons (structure, velocity characteristics, etc). Depending on the frequency of the radiation, the depth of the penetration energy into the sedimentary cover or deeper horizons may change. High-frequency single-channel (continuous seismic profiling) multi-channel methods, as well as deep seismic sounding can be distinguished by the frequency of radiation. The principle of the seismic method is based on the penetration of the energy (for example, issued by the compressed air, electric discharge, etc), into the water column and then into the rock. After reflection of the signal from the sedimental horizons, the reflected signal goes back to the ship and is received by the special antenna (the seismic streamer). The received data is accumulated digitally on a seismic station. Further processing is completed on the computer stations by a variety of software programs that filter out the acoustic noises and store useful information about the structure of the earth's crust. There are many modifications of the equipment (such as bottom stations, radio beacons, etc.).

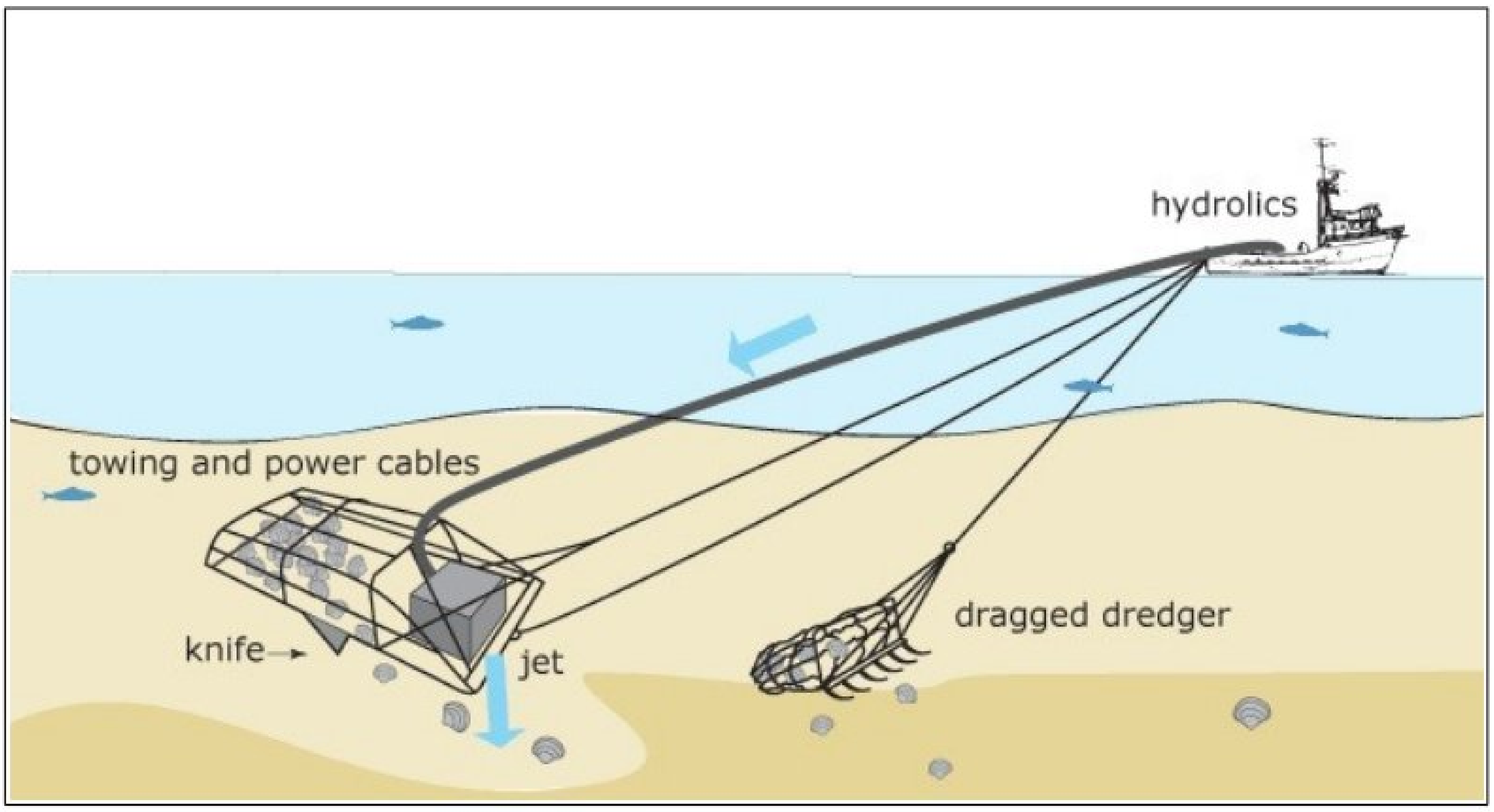

Fig. 9. Principle of ocean floor dredging. Image source: http://www.montereyfish.com

Research facilities are widely used towed devices above the bottom (for example, a set of equipment designed to study gravimetric, magnetic fields, together with a lateral-view sonar, profiling and other geological and geophysical equipment. Special immersible robot is mixed over the ocean floor at an altitude of 300-400 m. The side-scan sonars are designed to study the morphology of the bottom, identify faults in the oil pipelines, search for sunken objects (e.g. ships) of almost any size with a high degree of resolution. The principle of their operation is based on irradiation of the bottom surface with a frequency of about 6.5 kHz.

3.4. Ocean Floor Sampling: Dredging and Drilling

3.4.1. Ocean Floor Dredging

Testing of bottom rocks through the rocks extraction from the ocean floor is being used by use of various tools such as tubes, dredges, pipes, trawls, scoops, etc. Tube testing is primarily intended to study the upper (up to 50 m) layers of the sedimentary cover pressed by its own weight. The tube penetrates at a high speed to the ocean bottom and takes a column of the seafloor sediments into the hollow part of the instrument (Fig.9). In some cases even the bedrock may be taken as well. Although a complete section of oceanic crust has not yet been drilled, geologists have several pieces of evidence that help them understand the ocean floor. The some of them are the samples recovered from the ocean floor by dredging and drilling. Dredging is an underwater rock excavation. It is one of the main methods that allows to take samples of the bedrock from any depths. Dredging can be carried out at depths from 20 to 6000 m.

Fig.10. Ocean floor dredging using one pipe. Image source:
https://pikabu.ru/story/dnouglubitelnyie_suda__dredgers_5528271

Dredging is a process that involves the aquatic excavation of water beds to remove sediments, pollutants, shellfish and other materials. A dredge is a machine that scoops or suctions rocks from the bottom of ocean (Fig.10). The methods and machinery used in dredging vary widely. The equipment set includes: a deep-water winch, a cable, a system for fastening the dredge and the actual dredge. A drag is a metal sampler with a triangular, rectangular or circular cross section intended to hold the rock (Fig.11). Dragging operation includes: identification of the sampling object, launching the vessel to that point, draining the dredge, actually dredging (detaching the rock from the substrate), and lifting the sample onboard (Fig.12).

The total dredging time depends on the depth of the bottom, weather conditions. It can increase dramatically in the emergency cases or abnormal situations (e.g., difficult hooks). Most dredging is done by ships that tow a dredge along the ocean floor. The hitch used by dredging is a clamping of the dredge on the ocean floor, which works as an anchor. The dredging time at depths of ca 5000 m is about 5 hours. The weight of the raised rocks can reach 100s of kg. One of the most important mechanisms for winding of the cable is a deep-water winch.

Fig.11. Ocean floor dredging using two pipes. Image source: https://pikabu.ru/story/dnouglubitelnyie_suda__dredgers_5528271

On the modern scientific research vessels usually 10-20 ton hydraulic (sometimes electric) winches are used for dredging works. The drum of these mechanisms can take up to 10 km and more cable. A cable with a diameter of about 20 mm is used in French expeditions, while a whole length cable, made up of individual pieces with steps decreasing the diameter of about 2 mm (resembles an antenna in the radio) is used on Russian vessels. This cable provides good cushioning and safety during the hooks. The weather conditions fit for dredging can vary from the total calm in the equatorial zone to the storm conditions (wind up to 25 m/s) of the Antarctic area. As for depth, dredging in the Pacific Ocean, was carried out at the depths of more than 7,000 m.

3.4.2. Ocean Floor Drilling

Tiny fossils in the core sample can explain what the ocean environment was like at different points in time, and at different spots around the globe. Deep ocean drilling started in April 1957 in the USA, when self-declared eclectic group of leading scientists gathered in California in Scripps Institution of Oceanography (USA) for the drilling. On drill ships, the sediment and rock cores are brought up from the bottom through the inside of the drill pipe sections (Fig.13). Once on the deck of the ship, they are split in half. One half is studied in the ship's laboratories. The other is stored in special repositories, often called core libraries.

Fig. 12. Unloading of sample material during dredging process.

Drilling in the water areas is carried out to achieve both research and practical tasks. Drilling mechanisms can be placed on the ships, platforms of various designs, as well as on artificial islands. After the first drilling attempt in 1957, drilling developed further, and in 1968, the United States began drilling the first deep-sea well in the Gulf of Mexico on an American vessel Glomar Challenger, specially designed for research purposes. Glomar Challenger is a deep sea research and scientific drilling vessel for oceanography and marine geology studies. This event was the start of an outstanding project of the 20th century which can probably be compared with space exploration. From this time onward, geologists began to receive direct data about the structure and composition of the seafloor sediments.

3.5. Unmanned underwater vehicles (UUV)

Unmanned underwater vehicles (UUV), sometimes known as underwater drones, are any vehicles that are able to operate underwater without a human occupant. The UUV are used to solve the problem of fundamental science and purely practical tasks (inspection of underwater parts of engineering structures, pipelines, etc.).

In the deep ocean, they are used to test the rocks of the bottom, direct observations of the geological structure, collection of information about the pelagic world, benthos or the properties of the aquatic environment. Using UUV apparatus a breakdown of the oceanic crust on the transverse ridge in the Atlantic ocean discovered. Underwater manned vehicles widely used to study active and inactive hydrothermal fields. The UUV vehicles may be divided into two categories, remotely operated underwater vehicles (ROVs), which are controlled by a remote human operator, and autonomous underwater vehicles (AUVs), which operate independently of direct human input. The latter category would constitute a kind of robot.

Fig.13. Ocean Floor Drilling Platform. Image source: www.myship.com

3.6. Satellite Navigation, Altimetry and GPS Positioning for the Ocean Floor Research

Navigation (determining the position of the vessel in the ocean) is considered to be the most important goal of ensuring the safety of navigation and conducting any kind of geological and geophysical research. Currently, the main method of the determining the location of the vessel is a global system of satellite navigation and GPS positioning. A large number of satellites enable to locate vessels, including submarines, up to meters away, regardless of the location of the work area.

The study of the ocean floor is possible not only through vessels, but by means of satellites from space. Systematic measurement of the surface height (altimetry) of the world ocean water level by the satellite radar at an altitude of about 800 km with an accuracy of several meters, proved that water level depends on the topography of the ocean floor and density of the underlying rocks. In other words, the positive forms of relief attract the water body increasing the height of its surface, and *vice versa*. The figurative concept of "world ocean level" is not permanent, and the differences in the height of the water surface can be more than a hundred meters. Analysis of the ocean altimetric data enabled to create a mathematical model of the relief of the entire oceans, the so-called predicted topography with a high degree of reliability. Satellite data were compared with real echo sounder measurements and extrapolated to unexplored regions.

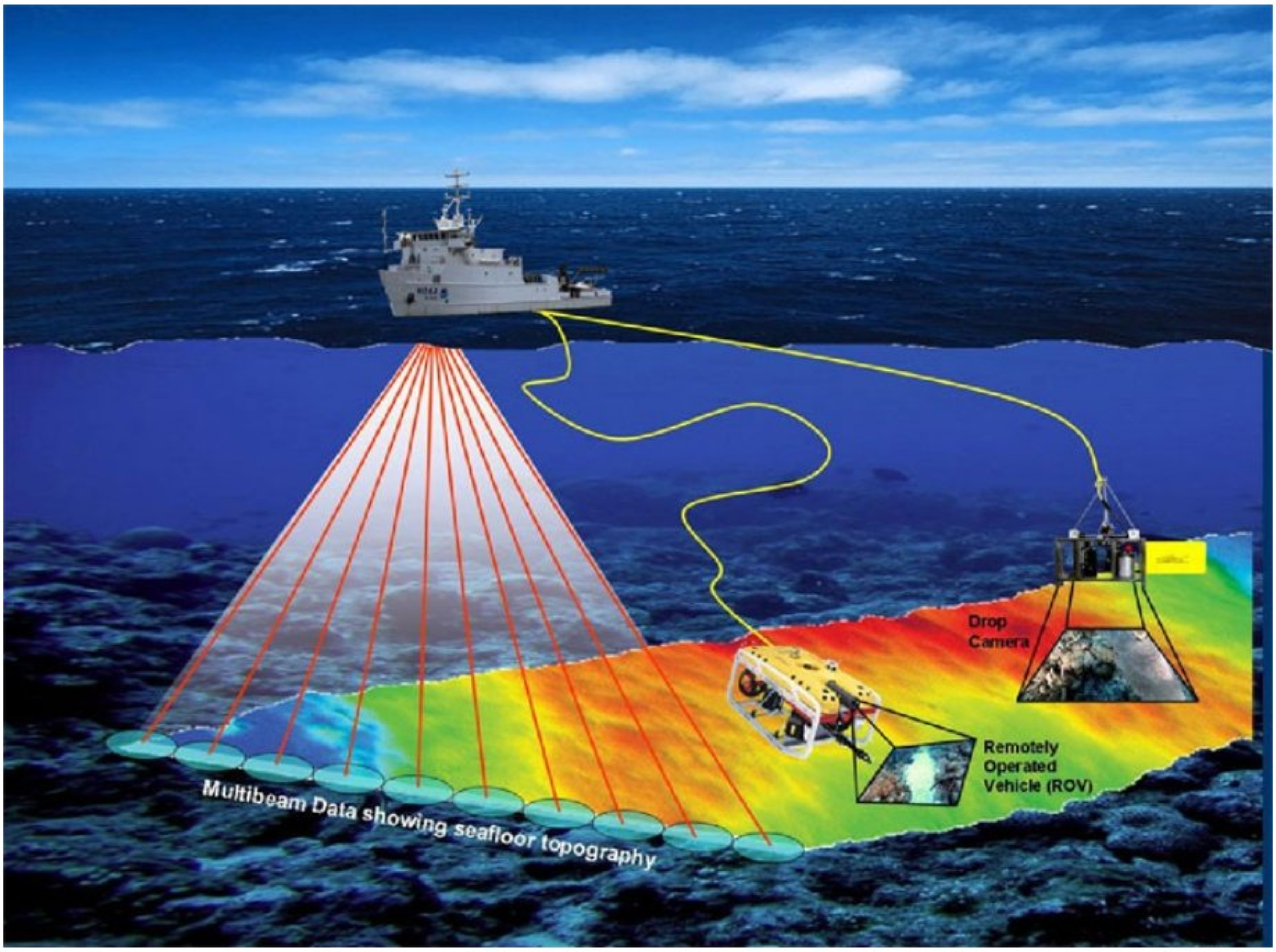

Fig.14. Illustration of multibeam sonar and various bottom type identification camera systems.
Image source: https://sanctuaries.noaa.gov

The accuracy of the predicted topography enabled to plan marine expedition paths (choose areas, tracks), to make major theoretical generalizations. However, it should be emphasized that it cannot completely replace the echo-sounder *in-situ* surveying.

3.7. Principles of the ocean floor survey multi-beam mapping

Maps are an important tool that people use to find their way around and to familiarize themselves with their surroundings. Scientists map the seafloor for a similar reason: to know what can be found on the sea floor. Sea floor maps can help boaters located these types of habitat. Nowadays, mapping of the seafloor should be conducted using a multi-beam sonar system. This system consists of a transducer and a receiver mounted on the bottom of the ship.

Due to the multi-beam echo-sounder precise surveying the main features of the study of the seafloor in recent years is represented by a complex detailed geological and geophysical surveys (Fig.14). For decades, the study of the structure of the ocean floor was conducted along the ship by route measurement. Large distances between the ticks did not allow to correlate data with a high degree of reliability. As a result of the recent research progress, all types of oceanic morphostructures of the World Ocean were detected and discovered. Large forms of underwater relief (such as mid-oceanic ridges, uplands, plateaus, gutters, fault zones, etc.) were discovered as well as smaller ones, such as separate mountains, underwater canals. The details of the study significantly improved after the organization of work on landfills – limited areas within which parallel tacks are located at the distances of 2-5 miles.

The use of multi-beam echo sounders resulted in full (or almost complete) coverage of the world Ocean floor mapping. A survey of the bottom at the current level should include a set of such equipment as a multi-beam echo sounder, profiler, magnetometer, gravimeter, side-scan sonar, and continuous seismic profiling. Studies of landforms are usually accompanied by the station research (collecting various geophysical data).As the ship follows a planned straight line over the area to be mapped, the transducers sends multiple sound pulses to the sea floor. These pulses are sent in many directions at one time. When the pulses hit the sea floor, they will reflect back to the ship and be detected by the receiver. The multibeam system then calculates the angle, the time it took for the pulses to travel, the ship's orientation to the water to determine the depth of the seafloor at that spot. Once the data pulses return and are analyzed by the computer, topography maps of the seafloor can be created. To "ground-truth" the mapping data divers or remotely operated vehicles (ROVs) are used to verify the data collected on board the ship.