COMMERCIAL DRIVERS FOR IMPROVED OCEAN FLOOR CHARTS

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Over 40% of the 800+ multibeam echosounders worldwide are used for commercial surveys. These systems, as well as towed swath bathymetric side-scan sonar systems, have special requirements when used in deep water (>500 meters water depth) since they are generally surveying in preparation for installations such as cables and pipelines that will actually lie on the seabed. Future requirements for these surveys will be more rigorous as oil and gas development goes into water depths exceeding 2,000 meters, and as telecommunications cables must be buried in deeper water, often as a requirement for installation permits. These applications require one-meter bathymetry (0.05% of water depth in 2,000 meters) and precise navigation, which can only be achieved by deep towed sonar systems and eventually, when cost-effective, by AUVs. In the near future, commercial surveys will be covering around one million square kilometers per year, acquiring data that exceed International Hydrographic Organization standards. These data are being placed into integrated GIS databases, which will replace paper charts and reports, greatly improving the access and functionality of commercial survey information.

The first multibeam echosounders were introduced for non-military use about 20 years ago. Since then the use of these systems has proliferated and the technology has improved to provide seabed maps with unprecedented accuracy and swath coverage. The purpose of this paper is to show the large number of swath bathymetry systems presently engaged in commercial surveys of the world's seafloor, to describe the types of surveys that are required for commercial purposes, and to demonstrate technological trends and mapping requirements for future surveys.

Commercial survey capacity

Although some traditional government survey activity, such as hydrographic surveys, EEZ surveys, and habitat surveys, are now being commercialized (primarily for cost effectiveness), the bulk of commercial surveys have a fundamentally different objective. Commercial surveys will generally result in some direct interaction with the seabed, such as installation of cables and pipelines, planning for safe installation of drilling platforms, control of dredging, etc. These are engineering surveys, so require careful quantitative control and are typically designed specifically for the engineering requirements of each project.

Based primarily on the compilation of Worldwide Seafloor Swath-Mapping Systems by Norman Cherkis while with the U.S. Naval Research Laboratory, and now updated by Five Ocean Consultants, we note that there are around 824 multibeam echosounders that are presently available worldwide. The utilization of these systems can be roughly categorized, as shown in Table 1.

Table 1: Multibeam usage by government and military agencies, research and educational groups, and private commercial companies

	Government	Research	Commercial	% Commercial
Shallow water	301	52	285	45 %
Medium depth	46	25	35	33 %
Deep water	29	32	19	24 %
Total	376	109	339	41 %

In addition, there are a total of 11 towed swath bathymetric side-scan systems, of which five are used entirely for commercial surveys.

Clearly many of these systems are not being utilized on a fulltime basis, but the amount of data that they are capable of collecting is staggering. Further, over 40% of the worldwide multibeams are used for commercial surveys. As might be expected, since most are used for engineering surveys, the proportion of mapping systems used for commercial surveys decreases with increasing water depth. There are less engineering surveys required in deep water.

Deep water surveys, primarily for cables

Surveys in medium depths and deep water carry the most significant technological challenges. For commercial work, these surveys are primarily for submarine cables, although there is increasing activity in the oil and gas market in deeper water for pipelines and drilling site studies. Although there is a tendency to think of deep water areas as having less relief and geologic variability, this is largely a prejudice based on the extent of our knowledge of these areas. Unless covered with undisturbed sediment, these deep areas can have very complex geomorphology, particularly along tectonic plate margins and on the steep subsea continental and island slopes. When a man-made structure is to be installed in these deep areas, the goal of the surveys must be to characterize the seabed on a scale that is important to the installation, regardless of water depth.

By a large margin the main need for medium and deep water surveys (greater than 500 meters water depth) has been for the installation of submarine telecommunication cables. By the year 2002, there has been over 839,000 kms of submarine cable installed. This is enough cable to encircle the world 21 times. Although over 50% of the total submarine cable was installed in the “boom” telecom years of 1999-2001, the industry suffered a severe downturn with only 30,000 kilometers of cable planned for installation in 2003. Market analysts expect the industry to recover from the present slump and to resume installing about 100,000 route kilometers per year after 2004.

A partial world map depicting just the cable route surveys conducted by Fugro is shown in Figure 1. This map likely includes about 30% of the total worldwide cable routes. Note that many of the cables are concentrated along great circle routes connecting the communications hubs in various parts of the world.

Approximately 15% of the world’s oceans are in water depths of less than 2,000 meters, and about the same proportion of submarine cables lie in these water depths. To get some idea of the amount of seabed that has been surveyed to install these cables, consider that typical specifications call for mapping a swath that is 10 kilometers wide in deep water, and one kilometer wide in shallow water areas. The typical cutoff between shallow and deep water for cable installation is between 1,000 and 2,000 meters, depending upon local conditions. Thus the surveys for cable presently installed would cover over 7 million square kilometers of ocean floor. Although the survey corridors overlap in many areas, this still represents a huge region. The majority of this mapping has been specified to maintain bathymetric accuracy of better than 1% of water depth, with much higher levels of accuracy in the many medium depth areas where cable burial is contemplated.

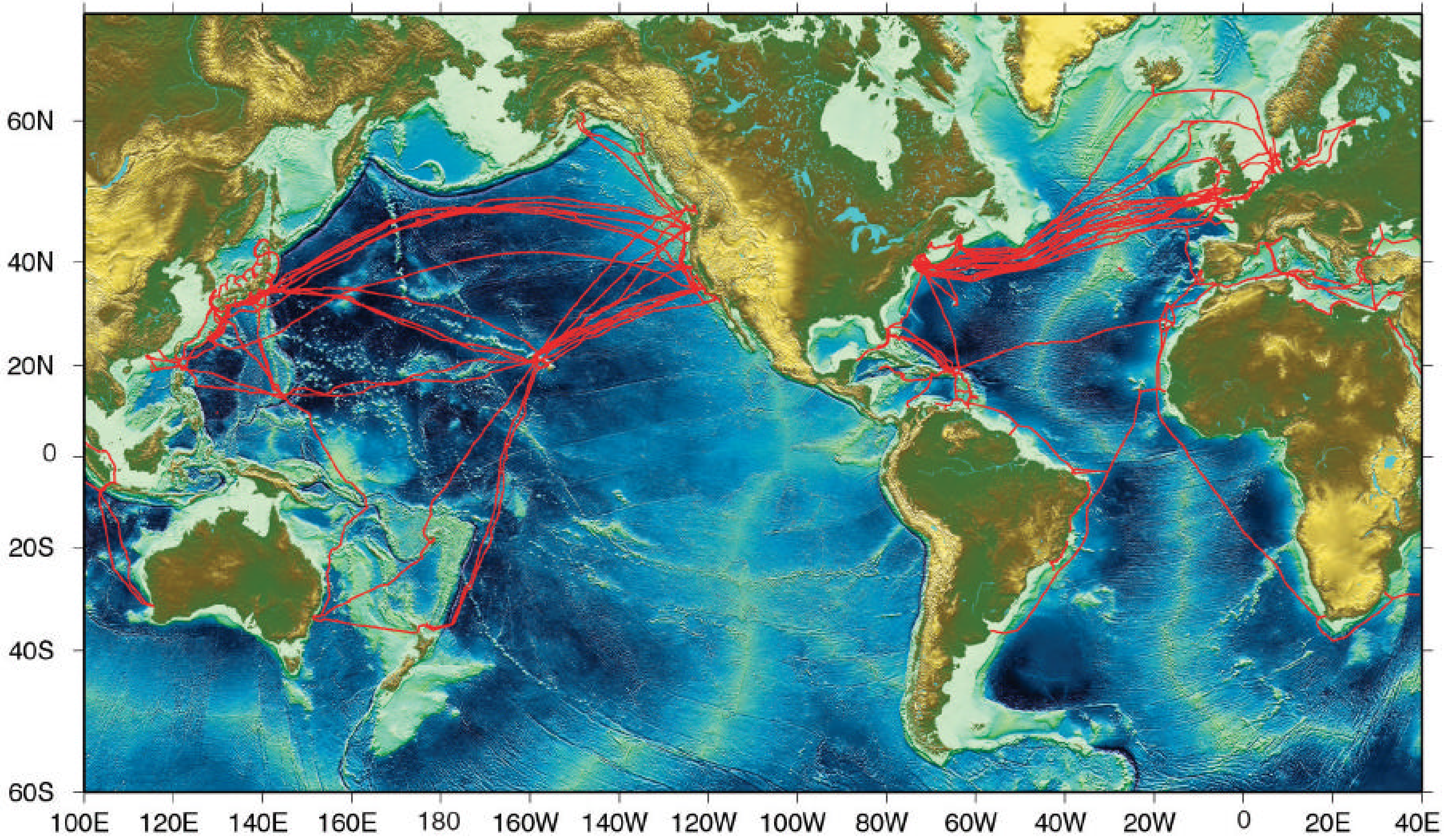


Figure 1. Submarine cable routes (in red) surveyed by Fugro

To meet predicted future cable installation requirements, we can expect that there will be on the order of one million square kilometers of seabed surveys per year in future years, requiring about 1,200 major survey vessel days per year. These surveys will all be conducted to exacting specifications requiring the best equipment available, because the cable installation companies know that the success of a cable that costs hundreds of millions of dollars is very dependent on the accuracy of a survey that costs only a small fraction of that investment.

Future survey trends

Although we anticipate that EEZ surveys will require significant commercial resources in the near future, these surveys can be largely satisfied with existing technology. In contrast, requirements for surveys for oil and gas exploitation and for cables in deeper water are going to become rapidly more stringent.

Oil wells are now being drilled in 2,000+ meters water depth offshore Brazil and in the Gulf of Mexico, and are approaching those depths in other areas such as offshore Nigeria and Norway. These drill sites require very precise seabed surveys, and eventually deep pipelines will tie them to shore. The pipelines will require swath surveys that show seabed relief to at least one-meter accuracy.

In the cable industry, installers are facing new requirements that have largely grown out of the success of the industry and the large number of cables already installed. Many cable landings are highly congested, such as the approaches to Japan shown in Figure 2. The proliferation of cables in these areas has had several results, including:

- Fishermen are concerned, and actively protesting, installation of more cables that interfere with or restrict bottom impact fishing.
- Environmentalists are increasingly concerned about the potential impact of cables on the seabed ecostructure (although there have been no serious studies showing such damage).
- Cable installers are not able to maintain sufficient separation between routes, and adequate crossing angles, to allow for proper cable protection and maintenance.
- Engineers are finding that in many areas all the good routes have been used, so future cables will need to be installed over seabed that has characteristics that previously would have been considered unacceptably hazardous. These effects are particularly evident around Japan, where the complex island arc geology limits the areas where a cable can be installed.

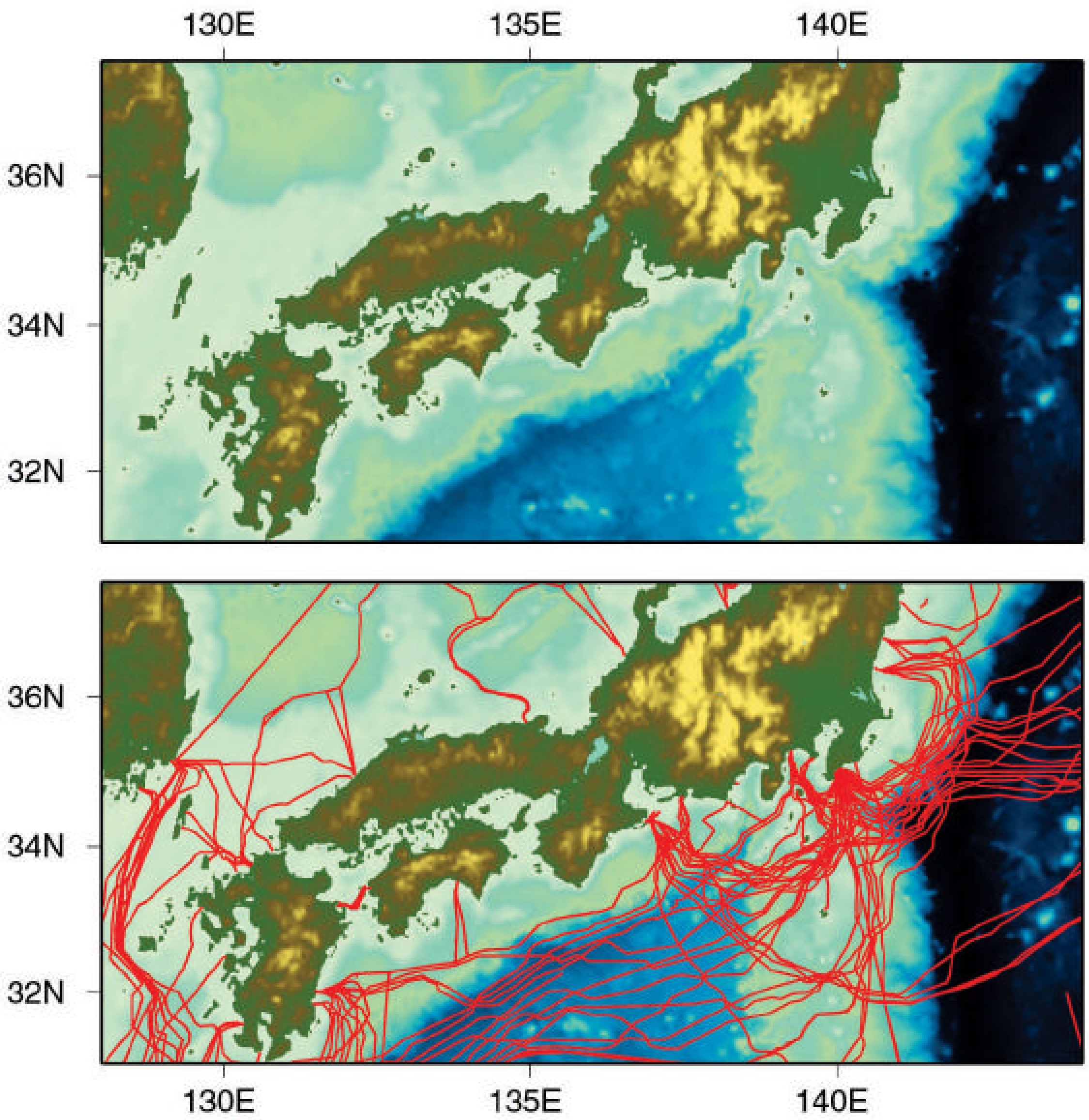


Figure 2. Cable system landings in Japan. Note the severe congestion offshore communication hubs, which is exacerbated by the complex seafloor geology and these volcanic islands.

In response to the concerns of environmentalists, fishermen, and other users of the seafloor, permitting authorities in many areas, particularly in the USA, are insisting that submarine cables must be buried to a prescribed subbottom depth as a requirement for obtaining installation permits. This guarantee of cable burial, as opposed to the “best effort” to bury as was common in the past, requires more exact survey down to the maximum burial depth. The required depth of burial is typically from shore to as little as 1,000 meters water depth, and to as much as 2,500 meters water depth where there are significant deep fisheries.

Cable burial is generally accomplished using a cable plow, which is dragged along the seafloor, scooping out a narrow trench that is as little as 70 centimeters to as much as 10 meters deep. The cable is fed through the plow into the trench. The plow has a footprint of just a few meters where it rides along the seafloor on skids, wheels, or tracks. The plow must drag slowly and smoothly across the bottom to accomplish the cable burial. An unexpected obstruction, or even a slope on the order of >15º for a few meters, can cause the plow to lose bottom contact and leave the cable exposed. Even worse, an extreme event will cause the plow to tumble on the bottom, aborting the cable installation and often causing damage to the cable. Successful burial requires a proper burial assessment survey (BAS) to provide appropriate data for a cable engineer to plan the operation.

The first requirement for an adequate BAS is a high-resolution geophysical survey, including swath bathymetry and side-scan imagery. This will generally be followed by seabed testing using physical probes (cores, cone penetrometer testing, etc.) and, where needed, bottom contact geophysical tests such as electrical resistivity profiles and/or refraction seismic profiles. All of this requires, however, very high-resolution bathymetry – typically to a relative accuracy on the order of one meter. By relative accuracy we mean that the absolute depth of the seafloor is not the most important factor. It is, however, essential that relief on the seabed is known to better than a meter, and that the location of features on the seafloor is at least as accurate as necessary to plan any installation or maintenance activity.

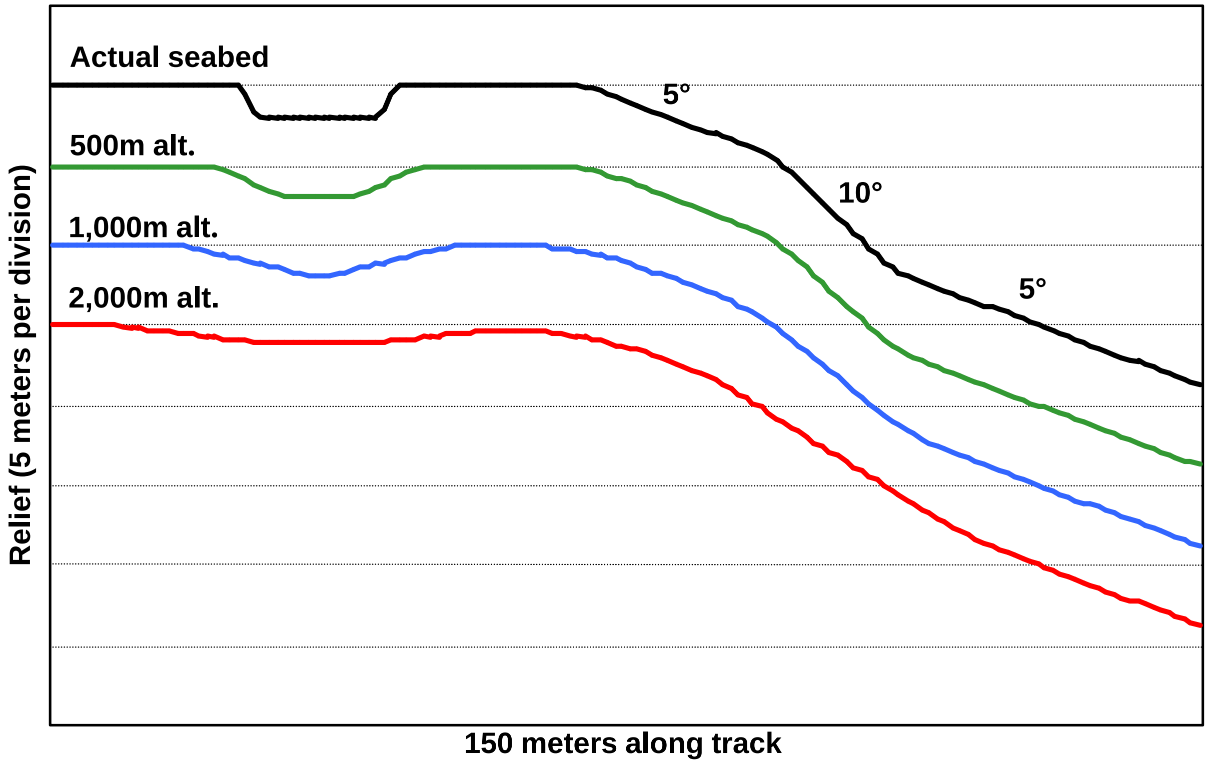
In practice, this means that solid one-meter contour data is needed to the depth of burial. In 2,000 meters water depth, this is +/- 0.05% of water depth. Furthermore, to define the shape of the seabed there should be a grid cell size of actual soundings that is not greater than one meter. This level of precision cannot be accomplished by mapping instruments near the sea surface. It must be accomplished by well-navigated sonars that are relatively close to the seabed.

The most economical way to get high-resolution surveys in deep water has been to use a deep-towed swathmapping system. Some multibeam echosounders have been adapted to this purpose. The most widespread application for cable route surveys, however, has been the 100 kHz vector side-scan system used by FSSI. These systems use a pair of side-scan sonar arrays on each side of the towfish to measure the vertical angle of every reflector from the seabed. The reflection angle and range is then used to calculate the depth and position of the reflector based on towfish depth, location, and attitude. Initially, 2,048 pixels, each with a reflection intensity and an x,y,z position, are calculated for each ping. The sounding data are then processed into lesser number of individual soundings depending on the charting specifications. For a high-resolution survey, this might be 500 soundings across a 500-meter swath, or similar data density across narrower swath widths. When towed at an altitude above the seafloor of 100 to 175 meters, such a system provides the one-meter contour bathymetry data as needed for cable BAS and pipeline surveys.

The effect of mapping close to the seafloor is illustrated in Figure 3. Panel A shows a representative bathymetric profile (black) over about 150 meters of seafloor. The profile covers a 2-meter depression that might be a 20-meter-wide pockmark, than has a short 10° slope in the middle of a long 5° slope. If we assume that we are measuring this slope with an excellent one-degree echo sounder, the curves illustrate how the seabed features are muted as we move to an altitude of 500 meters (green), then 1,000 meters (blue), and finally 1,000 meters (red) above the bottom. The pockmark and steeper slope, which would be a hazard to a plow operation, are almost immeasurable from the surface in deep water.

Panel B of Figure 3 shows the same effect, this time as a plot of slope, or gradient of the bottom, as measured from increasing altitude.

A. Bathymetry Profile



B. Slope Profile

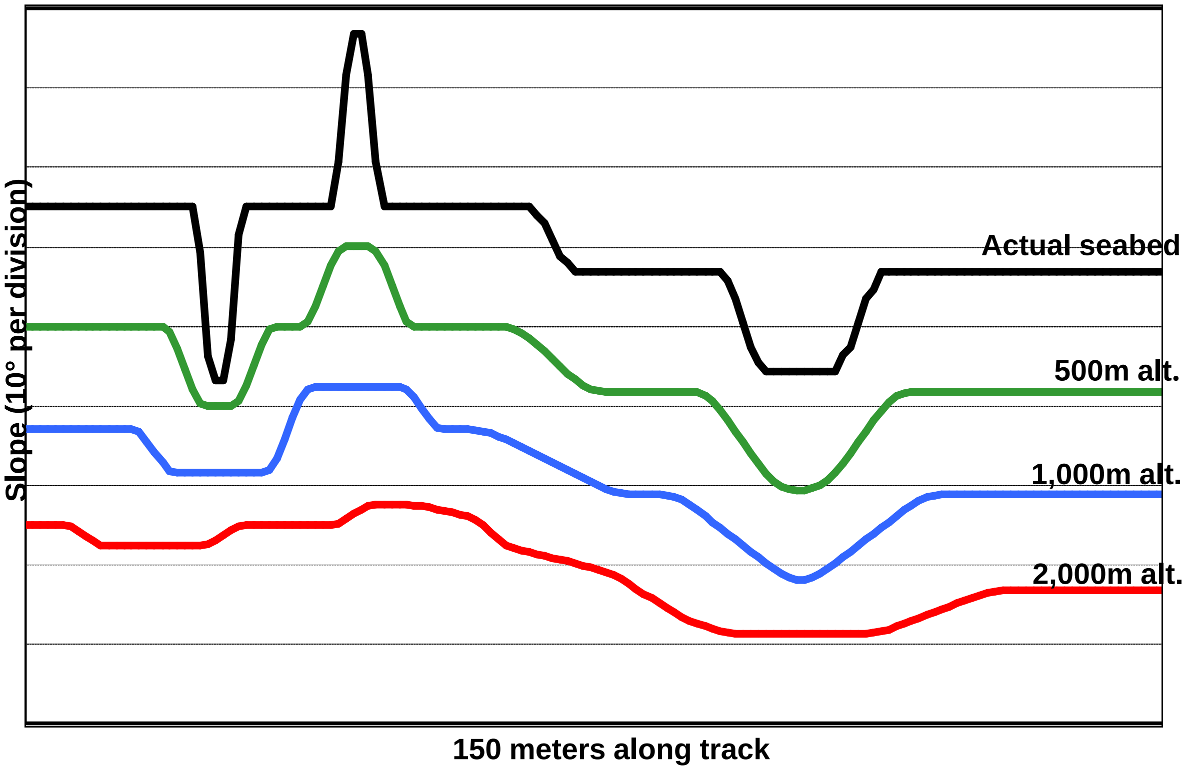


Figure 3. Loss of resolution with altitude above seafloor (vertical exaggeration = 2.5:1)

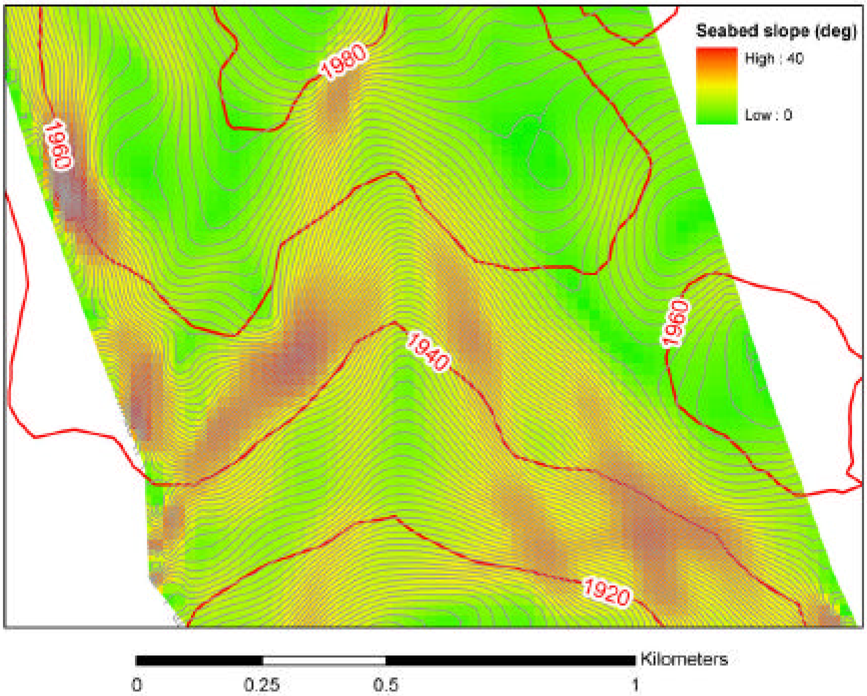


Figure 4. High-resolution bathymetry and seafloor gradients based on deep tow data show steep slopes that are muted in bathymetry measured from the surface (red contours).

Figure 4 is a small segment of a cable route survey offshore Oregon, USA, in 1,920 meters to 1,980 meters water depth. The area was first mapped from the surface using a Sys09 swath bathymetric side-scan sonar (red contours), then mapped using a Sys100D from an altitude of about 175 meters above the seafloor. The deep tow data are shown at a one-meter contour interval, and slopes were calculated based on the high-resolution bathymetry. The seabed is clearly irregular based on the surface-measured bathymetry, but there is no indication of local steep slopes. The high-resolution deep tow data, on the other hand, maps local slopes exceeding 30°.

Deep-towed bathymetric sonars are limited, however, by the accuracy of their navigation. They provide an excellent characterization of the seafloor, but without great care the real-world position of the data can be poor. The position of these towed sonars is presently almost always controlled by some form of acoustic ranging. The simplest technique uses an ultra-short baseline (USBL) array of hydrophones on the surface vessel to measure the direction and range of a signal sent from the deep-tow. These systems provide a position that is accurate to about 1% of the slant range to the towfish, so in 1,000 meters water depth (where the slant range can be expected to be about 2,500 meters), the towfish position is accurate to about +/- 25 meters. The USBL technique rarely works at longer ranges.

FSSI is developing an “inverted short baseline” (ISBL) acoustic position system that works with an array of hydrophones mounted on the towfish that actually measures the position of the surface vessel relative to the towfish. This technique has the advantage of operation in the stable and quiet environment at depth, so operates at ranges out to about 5,000 meters (where the towfish can be at least 2,000 meters deep). The accuracy of this location system is, however, also only about 1% of slant range.

For many cable surveys, the position of plow is not known any better than USBL or ISBL position accuracies, so in practice the uncertainty of all the navigation means that hazards must be avoided by a wide margin.

For deeper surveys where position accuracy is essential, we currently have a choice of either using a second vessel equipped with a USBL as a chase boat that will track the towfish from above it (thus minimizing the range to the towfish), or of deploying seafloor transponders to configure a long baseline (LBL) navigation grid on the bottom. The LBL navigation grid provides the most accuracy, but is very expensive and impractical for long and skinny survey patterns such as for cables and pipelines. The LBL would, however, be practical for small block surveys such as mapping a complex deep water drill site. The chase boat is generally used for very deep pipeline and cable surveys.

In the future, we expect to improve towfish navigation by using an inertial navigation system in deep towed sonar systems.

The commercial survey industry is now bringing special-built AUVs into service for high-resolution seabed surveys. These systems can safely survey even closer to the seafloor than a towed system, so have inherently better swathmapping resolution and accuracy compared to a towed system. Most AUVs are also already equipped with sophisticated inertial navigation systems in order to provide excellent navigation. Unfortunately, current AUV systems (mother vessel and AUV) cost at least twice as much per day as a well equipped conventional survey vessel equipped with a deep tow swathmapping system – even including a chase boat for improved navigation. For small oil and gas block surveys, the AUV operation can make up for much of the additional cost because it can turn quickly, while a deep tow system will often spend more time making long turns than actually surveying inside the block area. For long and skinny surveys, however, the towed array can survey faster than the AUV, making the cost differential even greater. AUV operations are going to have to become much less expensive before they are practical for most cable or pipeline applications.

When most of the technical problems still associated with AUVs are resolved (particularly with propulsion systems), and when the huge development costs of these systems have been amortized, an AUV survey system should not be much more expensive than a deep towed mapping system. The AUVs could also be operated from less expensive vessels. There is little doubt that in the long term, when the cost issues are resolved, AUVs will be economical for all surveys, including cable routes, and will replace towed systems.

Data integration and visualization

Commercial surveyors are currently revolutionizing they way that they handle data. A typical major intercontinental cable route survey will result in hundreds of charts and many volumes of survey reports. Handling and storing all this paper is very inefficient. If there are multiple surveys in the same area, the resultant charts and reports are usually stored in different places and are rarely cross-referenced. Furthermore, if there are different sets of charts for a single cable system, such as early planning charts, survey charts, installation charts, and maintenance/repair charts – these data are often never integrated.

We are now working to provide all data from commercial surveys in an integrated digital format using a geographical information system (GIS). The GIS database will include existing information about an area, including regional geology, existing or planned seabed structures such as cables and pipelines, oceanographic and meteorological conditions, known hazards such as shipwrecks, geographical boundaries, aerial photographs of adjacent land areas, etc. Text reports, photographs, and other data will be referenced to the GIS and can be accessed via hotlinks.

A map showing some of the data included in a typical GIS database is shown as Figure 5. The figure includes various regional bathymetric compilations in shades of blue, cable route survey bathymetry in orange, various hazards and boundaries, etc. The included data can all be accessed, manipulated, and plotted independently

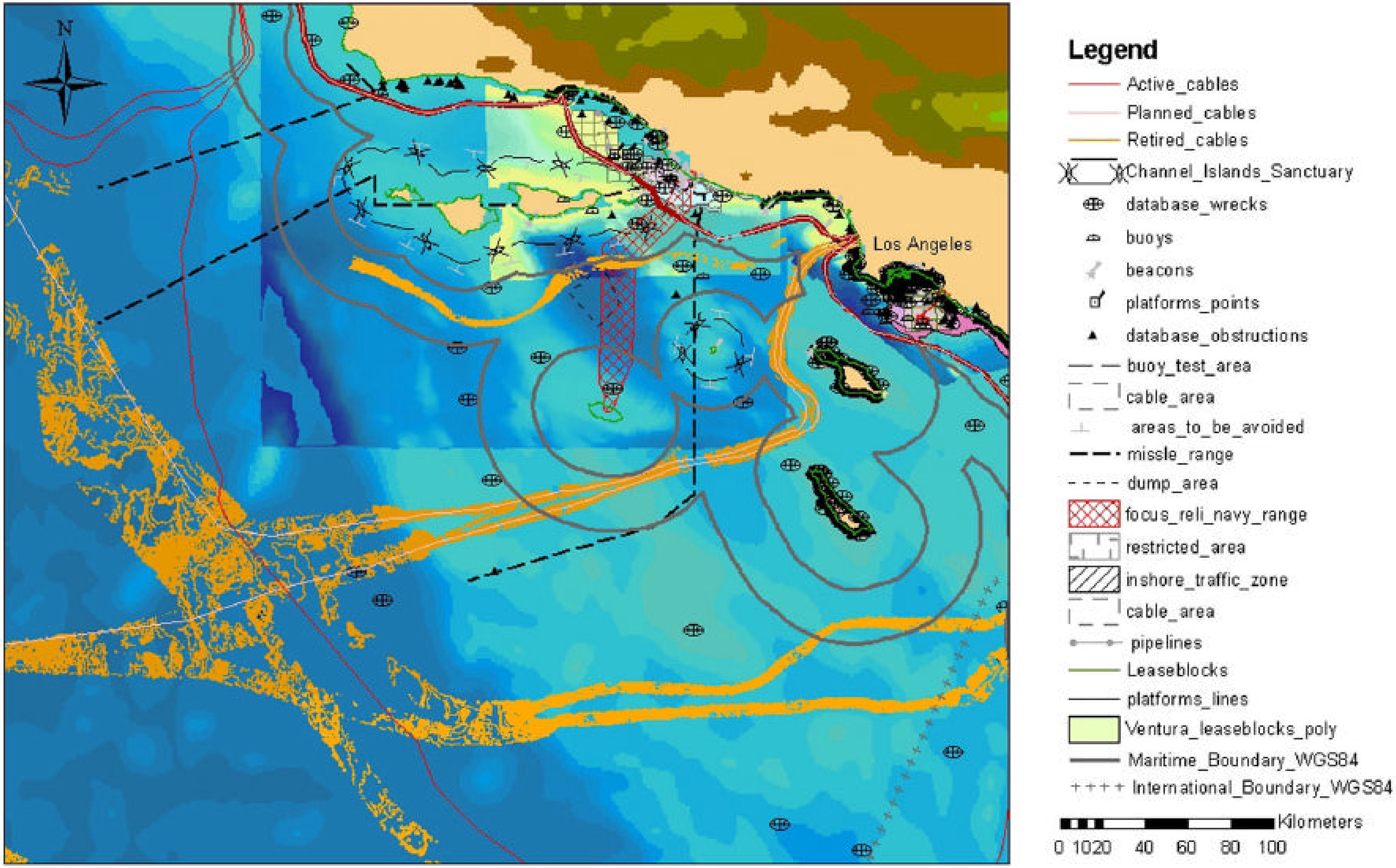


Figure 5. Data included in a GIS database offshore Southern California

We also plan to establish GIS databases for various congested cable landings, so that data acquired from many sources can be integrated. The database will be protected so that various users can have access to different portions of the database at different levels. Where appropriate, approved users will be able to perform calculations and measurements on the data, so that it can be used interactively for design and engineering purposes. All these functions are accessible over the Internet.

In the near future traditional paper reports and charts will be completely replaced by digital products that can be easily stored, organized, and accessed. This will also make it much more practical for data that are collected for commercial purposes to be made available to approved users in research and/or government agencies. Considering that we anticipate over a million square kilometers of high quality swath survey data being acquired every year just for the cable industry alone, the organization and accessibility of these data are very important.

Don Hussong graduated from Princeton University with a degree in Geological Engineering in 1964, and received a Ph.D. in Solid Earth Geophysics from the University of Hawaii in 1972. He left the University as a Professor of Marine Geophysics to found Fugro Seafloor Surveys in 1985, and has been President of FSSI since then. Now located in Seattle, the company became part of the Fugro Group in 1996.