Chapter 5 - Sidescan Sonar

Previous chapters in this document presented sonar as a tool for finding water depths using the time delays of acoustic echoes. Yet this is only one function of sonar and only one of the two ways sonar is employed in the SEA BEAM 2100 system. The other way in which the SEA BEAM 2100 may be used is as a *sidescan* sonar. This section provides a description of sidescan sonar—how it works and what it is used for. It includes a detailed description of the SEA BEAM 2100 sidescan sonar system including an examination of the methods used for collecting and processing data.

Understanding Sidescan Sonar

Instead of measuring the depth to the ocean bottom, a sidescan sonar reveals information about sea floor composition by taking advantage of the different sound absorbing and reflecting characteristics of different materials. Some types of material, such as metals or recently extruded volcanic rock, are very efficient at reflecting acoustic pulses. Clay and silt, on the other hand, do not reflect sound well. Strong reflectors create strong echoes, while weak reflectors create weaker echoes. Knowing these characteristics, you can use the strength of acoustic returns to examine the composition of the sea floor. Reporting the strength of echoes is essentially what a sidescan sonar is designed to do.

Combining bottom-composition information provided by a sidescan sonar with the depth information from a range-finding sonar can be a powerful tool for examining the characteristics of an ocean bottom. Figure Chapter 5 - -1 shows an example of such a combination of data types. The seafloor canyon that was mapped in bathymetry in Figure 1-1 is shown mapped in sidescan. The bathymetry map clearly shows the shape of the canyon, while the sidescan indicates that the material forming the floor of the canyon, which is highly reflective, is different from that of the canyon walls and from the surrounding sea floor.

Figure Chapter 5 - -1: Example of Sidescan Mapping

How Sidescan Sonar Works

Sidescan sonar employs much of the same hardware and processes as a conventional depth-sounding sonar. Pulses are transmitted by a transmitter using a projector (or array of projectors), and hydrophones receive echoes of those pulses from the ocean floor and pass them to a receiver system. Where sidescan sonar differs from a depth-sounding system is in the way it processes these returns.

To explain the processing of a sidescan sonar, recall the description of a simple, single-beam echo sounding system in Chapter 2, “Sonar Concepts“ (see Figure Chapter 5 - -2). To briefly review, the transmitter of the single-beam echo sounder produces an acoustic pulse, or ping, which is transferred into the water by the projector. The ping expands as a spherical wave from its source, striking the sea floor at the point closest to the projector source. The ping is then reflected in a return spherical wave, part of which is detected by the hydrophone. The receiver records the returned echo, which can be illustrated by a plot of amplitude as a function of time (see Figure Chapter 5 - -3). The time between the transmission of the ping and the reception of its echo is used to compute the range to the sea floor.

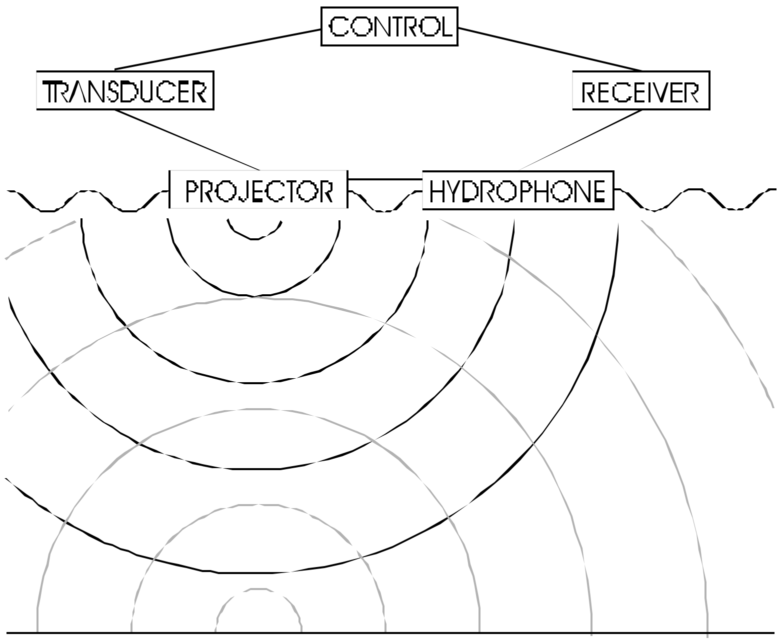

Figure Chapter 5 - -2: Single-Beam Echo Sounding System

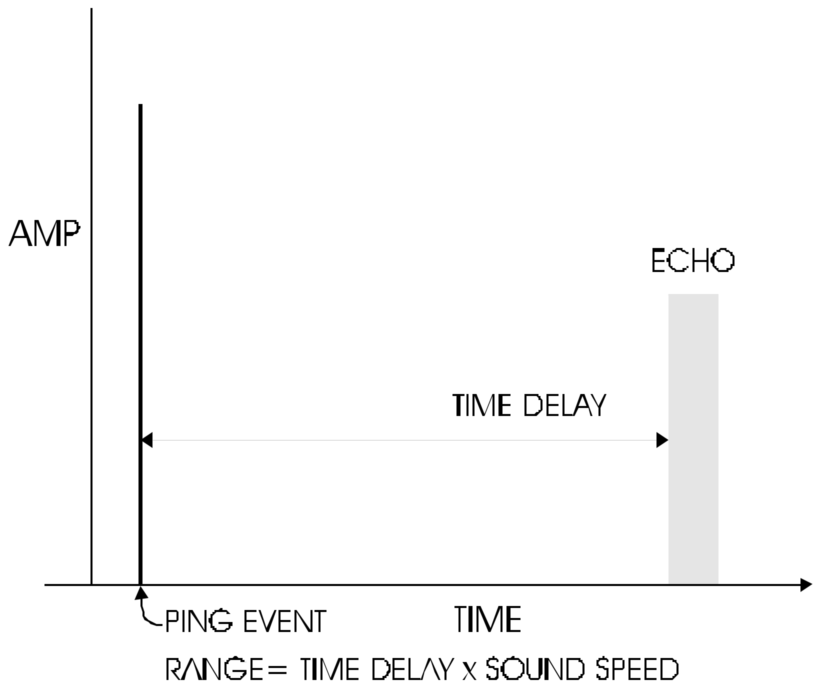

Figure Chapter 5 - -3: Plot of Amplitude as a Function of Time

This simplified picture does not consider what happens to the transmitted pulse *after* it first strikes the bottom, because a single-beam echo sounder is only interested in the time between transmission and the earliest return echo. Yet to a sidescan sonar, the first returned echo only marks when things start to get interesting. Look at what happens to the transmitted pulse as it continues its spherical propagation.

Figure Chapter 5 - -4 shows the single-beam echo sounder schematic at a time shortly after the ping first intersected with the bottom. At this time, the first return echo is on its way back to the hydrophones. But the ping is still expanding, and in our schematic is intersecting the bottom at two points. These points also create echoes. They are weaker than the first return (remember, as the spherical pulse expands and propagates, it loses power), and they occur after it does (because it took the ping longer to get to them). It is easy to see that as the pulse front continues to propagate, it will produce a continuous series of weakening echoes in time. If the receiver continues to collect these echoes, it will see a amplitude versus time sequence similar to the one pictured in Figure Chapter 5 - -5, with a strong first bottom echo followed by a declining slope of continuous returns.

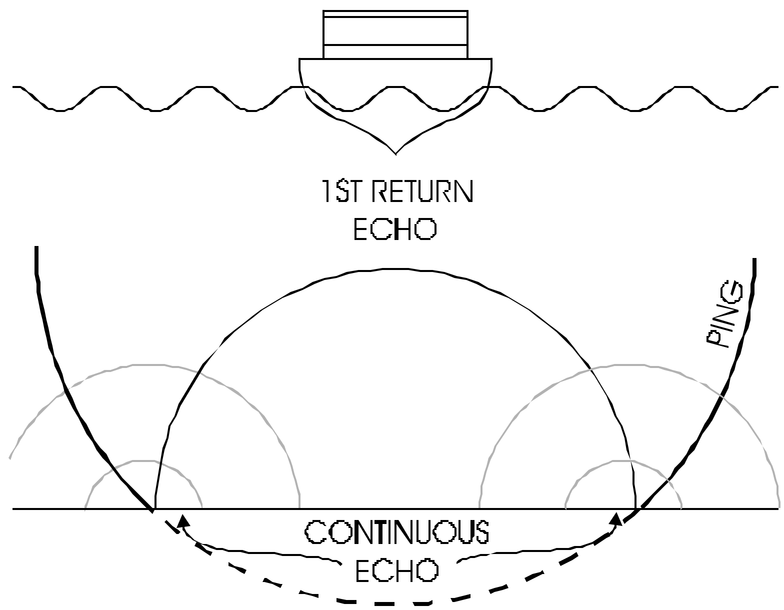

Figure Chapter 5 - -4: Single-Beam Echo Sounder Schematic

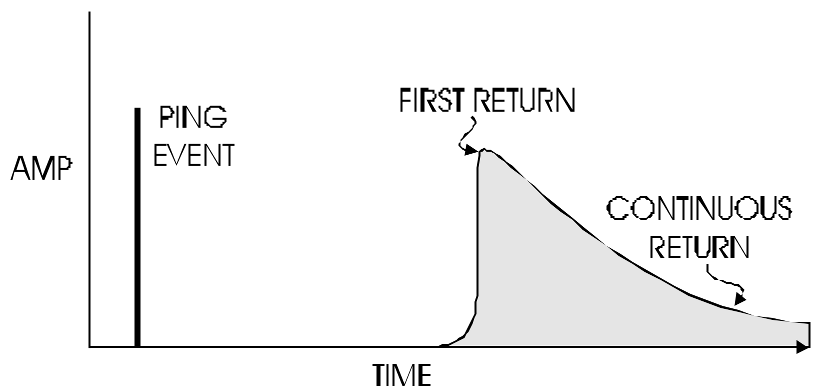

Figure Chapter 5 - -5: Amplitude Versus Time Sequence

Thus far, this discussion has ignored the characteristics of the ocean bottom. Although unstated, the assumption to this point has been that the bottom is perfectly flat and perfectly uniform. Consider now what happens when some detail is added to the ocean bottom. Figure Chapter 5 - -6 redraws the schematic (shown in Figure Chapter 5 - -4) with a spherical pulse front some time after the first bottom echo. In this case, however, a box represents detail on the bottom. This box is more efficient at reflecting acoustic energy than the surrounding uniform bottom. Because of this, the energy of its echo is slightly higher than that of the surrounding bottom, which causes a small jump in the amplitude measured by the receiver at the time of its return. An observer looking at the amplitude versus time sequence in Figure Chapter 5 - -7 would be able to discern from this jump that some discrete feature exists on the bottom.

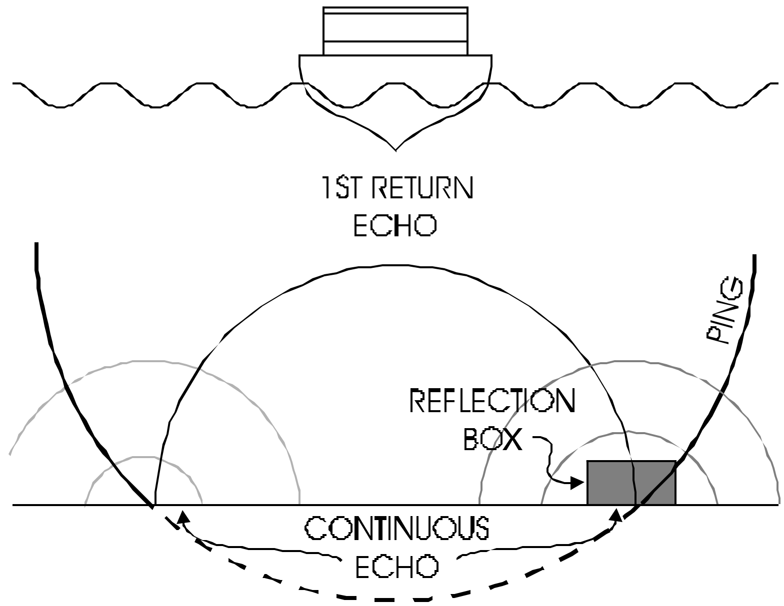

Figure Chapter 5 - -6: Schematic with a Spherical Pulse Front with a Detailed Bottom

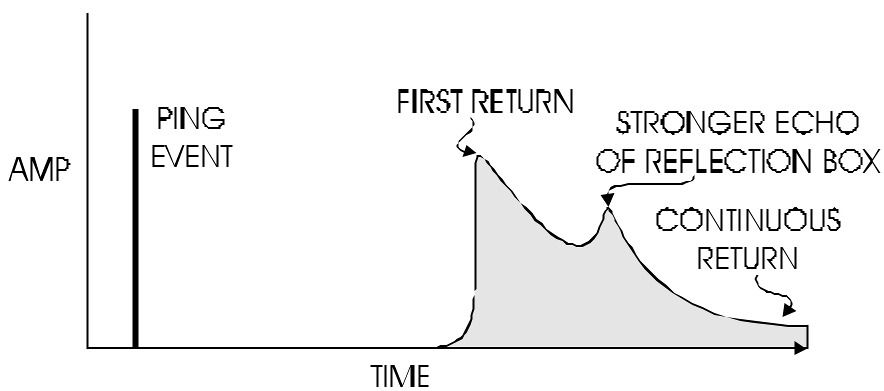

Figure Chapter 5 - -7: Amplitude Versus Time Sequence

In reality, of course, ocean bottoms can be very complex. They may be composed of many different components, all with different acoustic reflection characteristics. True amplitude versus time sequences observed by receivers are similarly complex.

A Basic Sidescan Sonar

As a practical instrument, the simplistic sidescan sonar described above is not very useful. While it provides the *times* of echoes, it does not provide their *direction*. Returning to the example presented in Figure Chapter 5 - -6 and Figure Chapter 5 - -7, the sidescan sonar detects a bottom feature (the box). From the amplitude versus time plot in Figure Chapter 5 - -7, an observer can tell there is a highly reflective feature on the bottom. From the time difference between the first echo (which is presumed to be due to the bottom directly below the sonar system) and the echo of the reflective feature, the observer can compute the range to the feature from the sonar. But remember, this is all the information the observer has.

Figure Chapter 5 - -8 shows the bottom in this example redrawn from an overhead view. The "X" marks the point on the sea floor where the ping strikes first, creating the first return echo. After striking at the "X," the spherical pulse front continues to propagate, intersecting the bottom in an expanding circle, eventually striking the bottom feature represented by the box. The observer can compute the range R between the "X" and the box, but otherwise does not know where on the ring of the expanding wave front the box is. In the real world, where sidescan sonars are used to locate objects such as rock formations or sunken vessels on the bottom, it is easy to see that this simple depth sounder amplitude information is too limited to be useful.

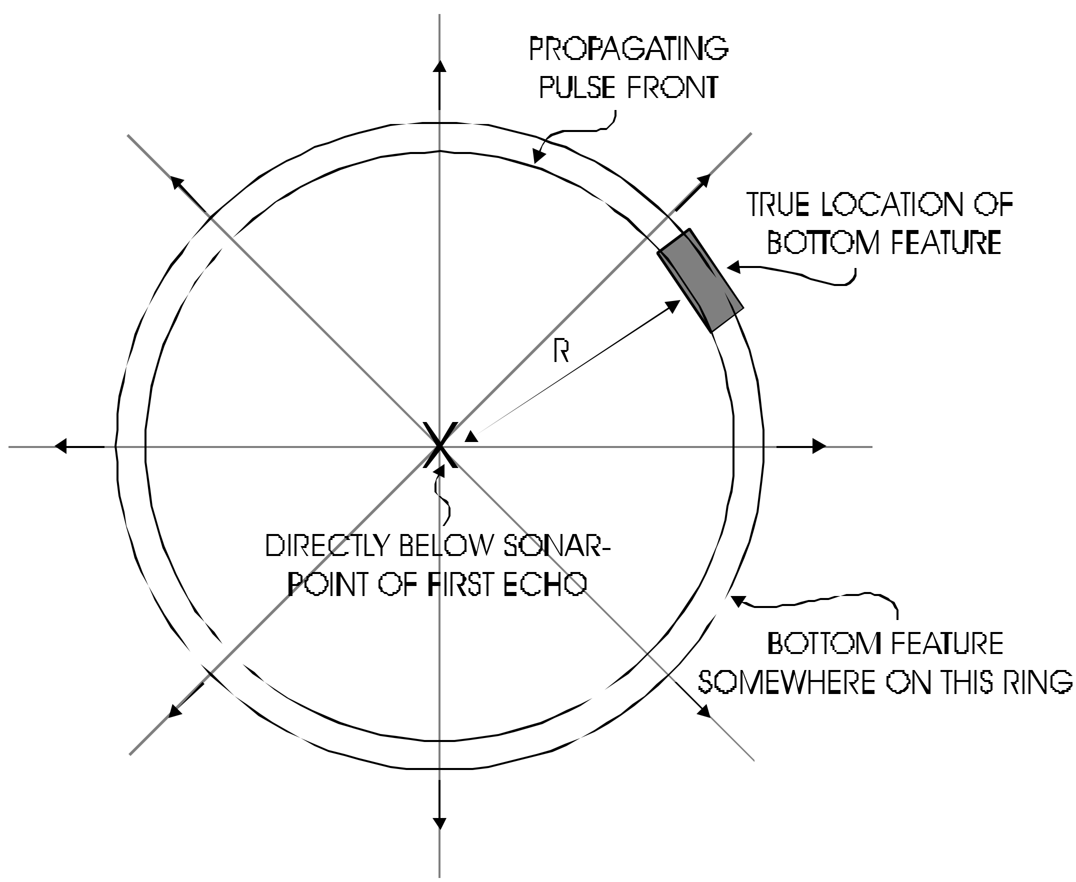

Figure Chapter 5 - -8: An Overhead View of the Bottom

Most sidescan sonars deal with this problem by introducing some *directivity* to their projected pulses, and, to some degree, their receivers. This is done by using a *line array* of projectors to send pulses. The long axis of the line array is oriented parallel to the direction of travel of the sonar survey vessel (often the arrays are towed behind the ship). Recall from the discussion of Beam Forming in Chapter 3 that a line array of projectors sends a circular pulse that expands in a plane perpendicular to the long axis of the array. Figure Chapter 5 - -9 shows a survey vessel towing a line array, and the propagation of circular pulses from that array. These pulses first strike the bottom directly below the sonar system, and then their intersection with the sea floor travels away from the array in either direction. Echoes are returned first from the bottom directly below the array, followed by echoes from points farther and farther away along a line perpendicular to the array axis and the survey ship' s track.

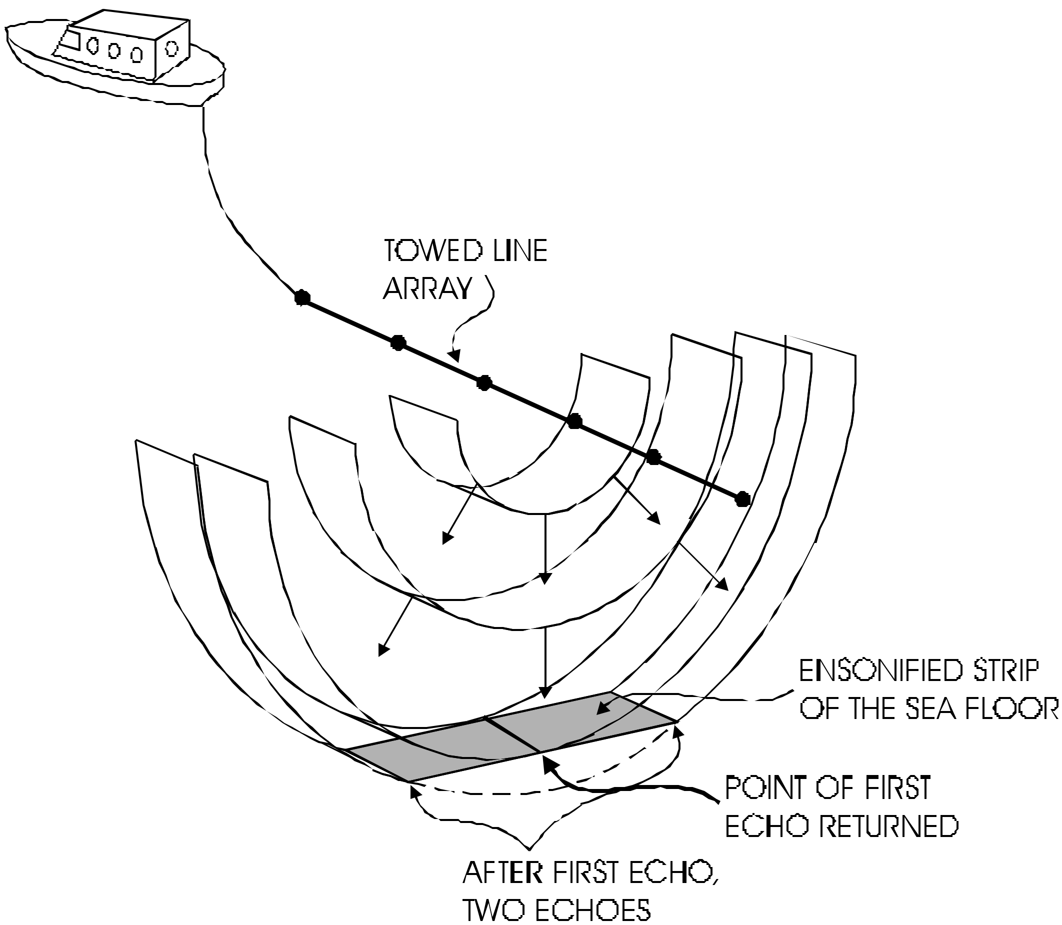

Figure Chapter 5 - -9: Survey Vessel Towing a Line Array

Sidescan sonars can receive the echoes from the bottom using two hydrophones, each set up to receive the returns from one side of the ship's survey track. In reality, instead of one projector and two hydrophone arrays, two line arrays are used as transducers. One transmits a fan beam towards the port side and then listens to its returns, and the other does the same on the starboard side. To understand the reason for this arrangement refer again to Figure Chapter 5 - -9. When a pulse front first strikes the bottom below the survey vessel, an echo returns from only the one point of intersection. Later, however, the pulse front intersects the bottom at two points, one on each side of the ship. The echoes from these two points would occur simultaneously, and a single hydrophone system would have no way of distinguishing between them. If, however, two separate hydrophones each record the echoes from only one side of the ship, there would be no such confusion. The name *sidescan* is used for historical reasons—because these sonars were originally built to be sensitive to echo returns from bottom locations on either *side* of a survey ship, instead of directly below as was the case for a traditional single-beam depth-sounder. With the advent of multibeam sonars such as the SEA BEAM 2100, which map both depth and sidescan across a swath of the bottom, the distinction inherent in this name has become less meaningful.

In practice, sidescan sonars tend to mount both the line array and hydrophones on a *towfish*, a device that is towed in the water somewhat below the surface behind a survey vessel. As the survey vessel travels, the towfish transmits and listens to the echoes of a series of pulses (see Figure Chapter 5 - -10). The echoes of each pulse are used to build up an amplitude versus time plot (or *trace*) for each side of the vessel (see Figure Chapter 5 - -11). To adjust for the decline in the strength of echoes due to attenuation, a time-varying gain is applied to the amplitude values so that sea floor features with similar reflectivities have similar amplitudes. Eventually the noise inherent in the system (which remains constant) becomes comparable to the amplitude of the echo, and the amplified trace becomes dominated by noise. Recording of each trace is usually cut off before this occurs so that the next ping can be transmitted.

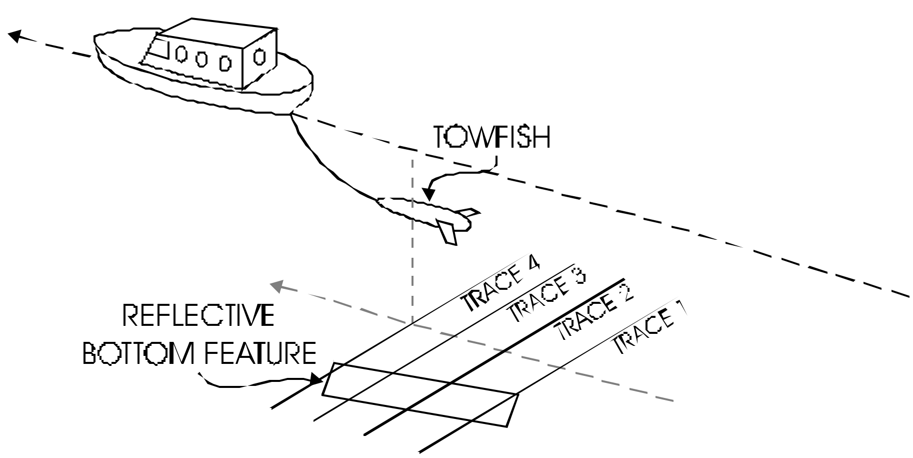

Figure Chapter 5 - -10: A Sidescan Sonar Measuring a Featured Ocean Floor with Four Pings

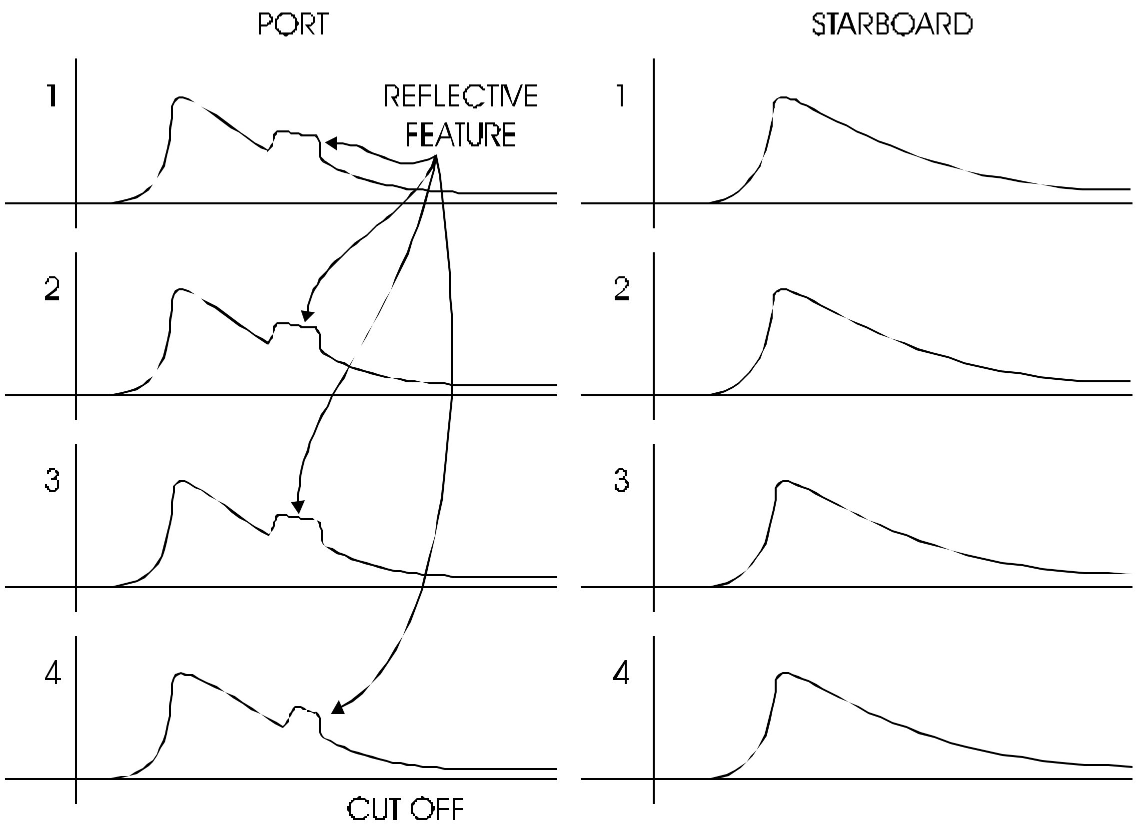

Figure Chapter 5 - -11: Amplitude Versus Time Plot for the Four Pings in Figure Chapter 5 - -10

Each trace is converted into a series of gray shades on a plotting device. The shade of gray is determined by the amplitude (white corresponding to high amplitude, black to low amplitude, or vice-versa). The port and starboard traces are plotted next to and facing each other so that the ship' s track is at the center of the picture, and subsequent pairs of traces are plotted in series to build up a "picture" of the bottom (see Figure Chapter 5 - -12).

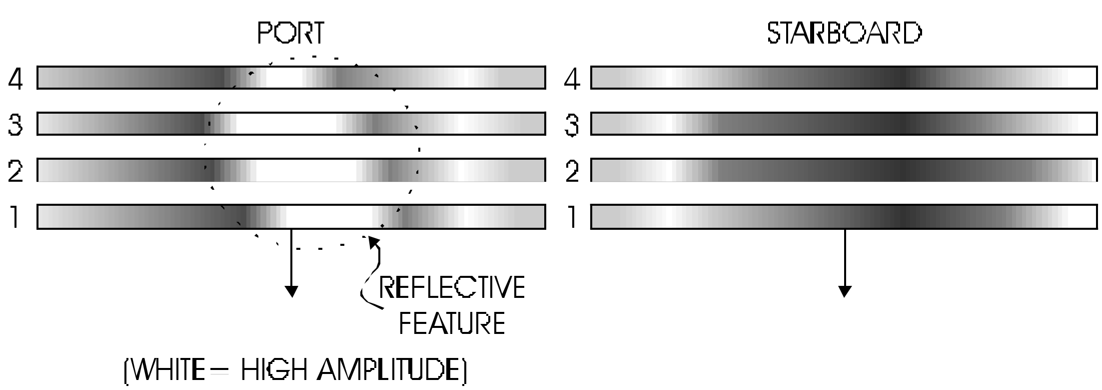

Figure Chapter 5 - -12: Port and Starboard Traces Plotted in Series

Figure Chapter 5 - -13 shows a sample of sidescan data from a SEA BEAM 2100 survey. In the figure, the survey vessel has traveled from the upper left to the lower right, and dark gray shades represent higher amplitude echoes.

Several hundred sidescan swaths, showing both port and starboard, are represented by the many parallel gray lines that cross the ship' s track. The noisy dark area across the middle is directly below the ship' s track. Clearly visible on the starboard (lower) side of the ship' s track are two dark lines, which are the sidescan echoes of undersea pipelines.

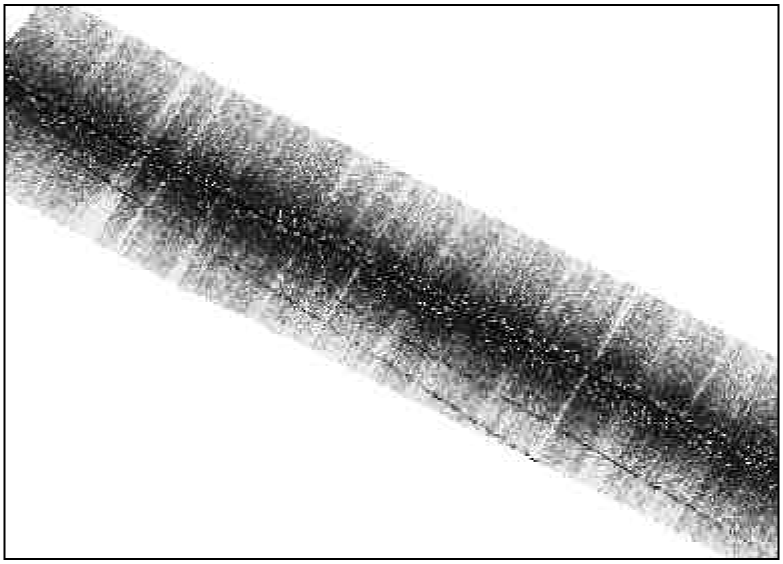

Figure Chapter 5 - -13: Undersea Pipelines Detected Using Sidescan Sonar

Limitations of Traditional Sidescan Sonar

In the above treatment of sidescan sonar, note that all of the examples deal with a flat ocean floor. In reality the ocean floor is far from flat, which introduces uncertainties in the interpretation of sidescan data. Recall that the only information a traditional sidescan sonar provides is a series of echo amplitudes as a function of time. The directivity of the sonar indicates which direction these echoes were coming from. But an observer cannot really be sure of the exact location of the sources of these echoes.

This problem is illustrated in Figure Chapter 5 - -14, which shows only one half of a traditional two-hydrophone sidescan sonar. In this case, the sonar is surveying over an area that has a sharply sloped bottom. The first place the circular pulse fronts strike the bottom is not directly below the survey vessel, but at a point on the sloped bottom well off to the side. This is the point that will cause the earliest amplitude on the amplitude versus time trace (see Figure Chapter 5 - -15). The point directly below the sonar will cause an echo at a slightly later time. At this same time, two points on the slope will be causing an echo. Because they occur at the same time, the echoes of these three widely separated points will be confused on the trace. It is clear that by looking at only the amplitude versus time trace in this example, an observer would not have an accurate picture of the sea floor. Because of this problem, traditional sidescan sonars are really only useful for flat or near-flat bottoms, or when used in combination with bathymetry information.

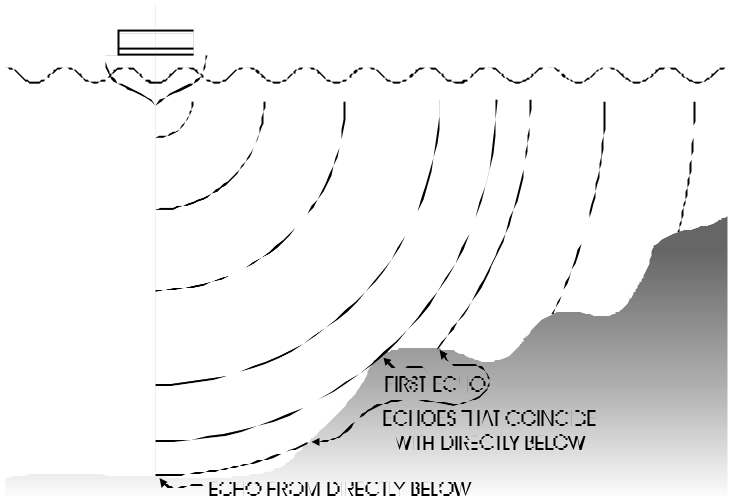

Figure Chapter 5 - -14: Half of a Two-Hydrophone Sidescan Sonar

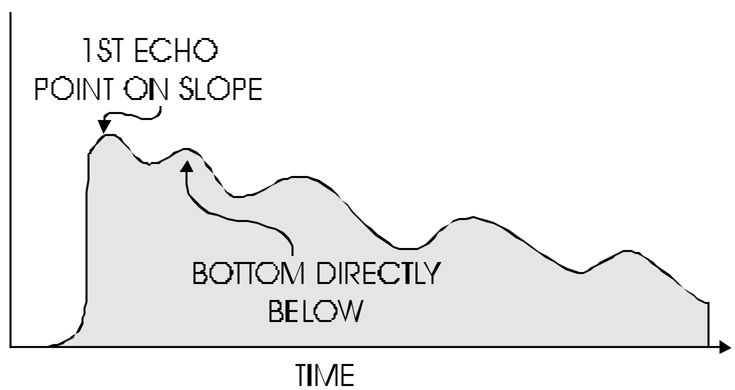

Figure Chapter 5 - -15: Amplitude versus Time Plot for the Situation Depicted in Figure Chapter 5 - -14

The SEA BEAM 2100 Sidescan Sonar

While primarily designed as a depth-sounding instrument, the SEA BEAM 2100 simultaneously provides sidescan data of the ocean bottom. This sidescan data measures roughly the same swath area covered by the depth information, but with considerably better resolution. Where the depth measurements are limited in their resolution to 151 beams of roughly 1°-widths, the sidescan divides the swath width into 2000 pixels of data. Unlike traditional sidescan sonars that use a flat-bottom assumption to find the location of objects on the ocean floor, the SEA BEAM 2100 sidescan information is *co-located* with the measured depths, so an observer can tell not only the amplitude of a return as in conventional sidescan but also *where it is* on the bottom. This co-located data allows bottom features to be examined in terms of their geometry, shown by the depth information and their composition as indicated by their sidescan returns.

To maximize the sidescan capabilities of the SEA BEAM 2100, you need to understand the processes used to collect it. This section gives a brief overview of the steps of sidescan data collection performed by the sonar, with particular emphasis on where and when sidescan returns can be influenced by user intervention.

Producing Sidescan Data With the SEA BEAM 2100

The SEA BEAM 2100 sidescan sonar uses the same hardware as the depth-sounding sonar. In fact, it uses the same pings and much of the same processing. Only fairly late in the data processing do the procedures for measuring bathymetry and generating sidescan imagery diverge. This arrangement allows the SEA BEAM 2100 to produce both types of data without much more computation than would be required for each individually.

As described in previous chapters, the projectors in the SEA BEAM 2100 system are arranged in a line array, similar to a traditional sidescan sonar. The projector array is aligned with the direction of travel of the survey vessel, although rather than being towed, it is mounted on the ship' s hull. This array ensonifies a strip of the bottom perpendicular to the survey vessel' s track. Instead of using line arrays for both transmission and reception in traditional sidescan sonar, the SEA BEAM 2100 has an array of hydrophones (between 48 and 80, depending on the installation), mounted athwartship—at right angles to the projector array. The data from the hydrophones is processed to extract both amplitude and angle information. While this processing is a complex procedure, it can be understood as a series of fairly straight-forward steps.

Many of the steps in the procedure are the same as those required for bathymetry measurement. Specifically, the processing required for Beam Forming and Beam Steering, High-Resolution Angle Estimation and Adjusting Final Angles for Roll is identical for both types of measurements. These processes are all described in detail in earlier chapters (Beam Forming and Beam Steering in Chapter 3, and Angle Estimation and Roll Compensation in Chapter 4). To briefly review:

- Beam Forming and Beam Steering – The amplitude and phase information from all of the elements in the hydrophone array are passed through an FFT to obtain amplitudes detected by several steered beams (the number of beams depends on the installation).
- High-Resolution Angle Estimation – The measurements of all beams in each time interval are collected into a time slice. Within each time slice, the response pattern of the beam is used to precisely determine the angle to specific echo events that occur in that time slice.
- Adjusting Final Angle for Roll – The angles measured in the above item are adjusted to the changing angle of the hydrophone array, yielding the true angles to echoes on the sea floor.

BDI bathymetry and sidescan processing essentially share the result of these three procedures. Emerging from them is a list of time slices, each with amplitudes and direction angles for a number of echo events (called hits). At this point, the Bathymetry and Sidescan processing diverge.

Mapping Sidescan Values for 2000 Pixel Resolution

The final stage of sidescan data processing is mapping the detected echoes to build an image of the sea floor. In detecting the echoes of a specific ping, the SEA BEAM 2100 monitors the particular set of sequential time slices that generally range between when the first (nearest) and last (farthest) bottom echoes are expected. This range is controlled by the SEA BEAM 2100 operator through the Start and Stop Gates settings (see Chapter 9 of the *SEA BEAM 2100 Operator's Manual* for information about the theory and operation of the Start and Stop Gates settings).

Recall that the sidescan process collects the echoes from a swath of the sea floor that is oriented perpendicular to the path of a survey vessel. For each bottom swath, the SEA BEAM 2100 sidescan data is mapped into an array of 2000 pixel locations. This array contains the amplitudes of echoes from the sea floor. The physical size represented by these 2000 pixels is determined by the value of *sidescan pixel size*, which is set by the SEA BEAM 2100 operator (see Chapter 10 of the *SEA BEAM 2100 Operator's Manual* for information on setting sidescan pixel size). For instance, if the sidescan pixel size is set to 2 meters per pixel, the 2000-pixel sidescan swath is 4000 meters wide. In all cases the mapped swath is centered directly below the path of the survey vessel.

The echoes from all relevant time slices are added to the sidescan swath array. The echo angles are converted to physical locations on the bottom based on sound velocity. These are then mapped into the pixels in the sidescan swath array (see Figure Chapter 5 - -16). Amplitudes of echoes that fall within the physical limits of the 2000 pixel swath are retained; all others are discarded. At the conclusion of the process, some pixels will have no echoes recorded in them, some will have one, and others will have many. Pixels that have one echo are assigned the amplitude of that echo. If a pixel has more than one echo, the average of the amplitudes is used. Pixels with no reported echoes are assigned a value interpolated from neighboring pixels.

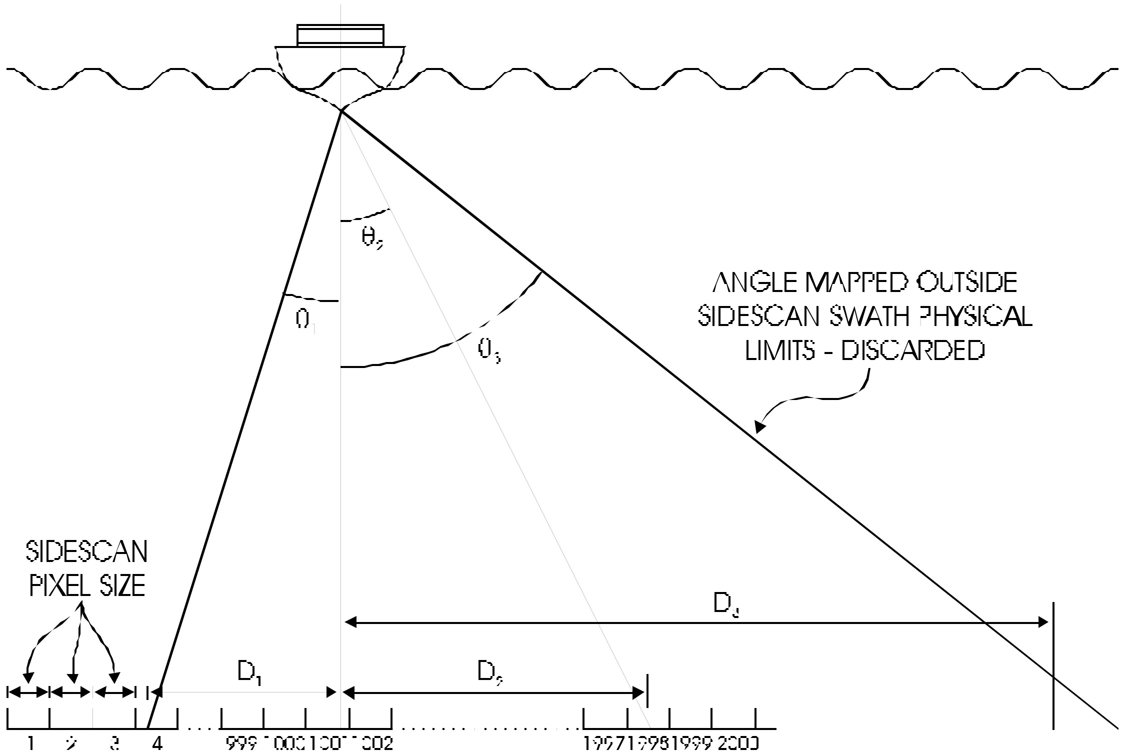

Figure Chapter 5 - -16: Mapping Hits in the Sidescan Array

The 2000 amplitude values that result from this process are recorded in the sidescan sonar record.

Display of Sidescan Data

The SEA BEAM 2100 displays the 2000 pixels of sidescan data as gray scales on both the operator control station screen and a thermal graphic recorder. To accomplish this, the amplitude values of the sidescan data are converted to gray scales.

The amplitude values are first converted to dB power units using the following conversion formula:

Power (dB) = 20.0 x log10 (Amplitude)

The conversion of power to gray scale is governed by the SEA BEAM 2100 operator through the values of *gray scale minimum* and *gray scale maximum*. See Chapter 10 of the *SEA BEAM 2100 Operator's Manual* for information on setting these values.