Six SUBBOTTOM PROFILERS

INTRODUCTION

High-resolution seismic reflection systems operating at acoustic frequencies between 1.0 and 14.0 kHz are grouped within the general category of subbottom profilers. These systems allow for continuous high-resolution seismic profile recordings of the uppermost 30 m of strata, below the sea floor.

The subbottom profiler (SBP) has long been a principal tool in the high-resolution investigation of offshore sites for the emplacement of pipelines, bottom-supported structures such as jack-up rigs, and in the exploration for shallow mineral deposits as well as numerous other applications.

HISTORICAL BACKGROUND

The *Marine Sonoprobe*, developed in the early 1950s (1), was the forerunner of present-day subbottom profiling systems. Initial development of the Marine Sonoprobe was aimed at producing a tool for the offshore investigation of recent sediments; however, the system soon found its application in the survey of pipeline routes (1). Numerous systems, which operate at frequencies between 3.5 and 7.0 kHz, are presently available under a variety of trade names.

APPLICATIONS

Subbottom profilers provide continuous seismic reflection profiles in real time at relatively high ship speeds (10–12 kts) and in all water depths, while allowing up to 30 m penetration of the sea floor (2, 3, and 4). The records obtained by these systems reveal in great detail the shallow sedimentary structure of the uppermost strata beneath the sea floor (fig. 6.1). The resolution is typically better than a half meter, depending upon the operating frequency and a variety of other factors.

Subbottom reflection data have been used extensively for pre- and postdredging operations within harbors and channels, at offshore construction sites and for selection of pipeline routes, siting of drilling platforms, in the reconnaissance of sites for the construction of artificial islands for nuclear power plants and petroleum drilling operations, and in the exploration for minerals in shallow waters such as sands and gravels. The continuous seismic subbottom profiles also allow the detection of near-surface hydrocarbon gas seeps within the water column, as shown in the profile recording of figure 6.2. When properly calibrated, SBP data may also be used for obtaining continuous bathymetric profiles.

P. K. Trabant, *Applied High-Resolution Geophysical Methods*

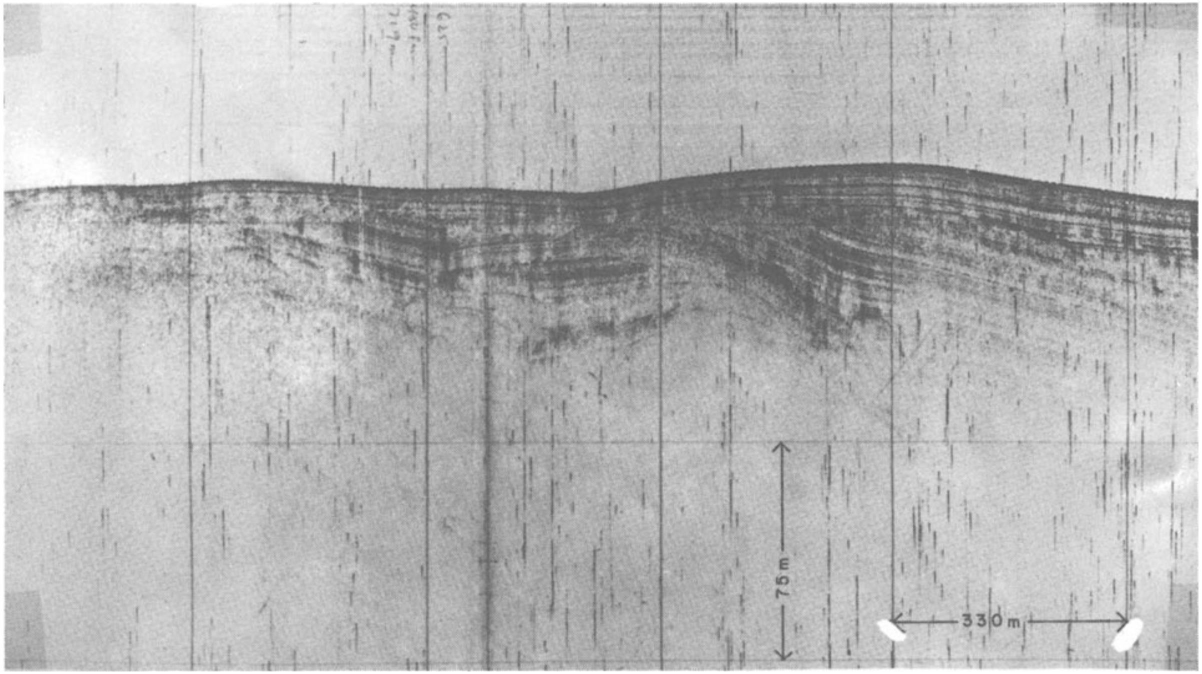

FIGURE 6.1 Typical 3.5-kHz SBP recording from the north Atlantic, water depth 2720 meters. Note unconformity and thrust folds. (Courtesy of Ferranti–O.R.E., Falmouth, Mass.)

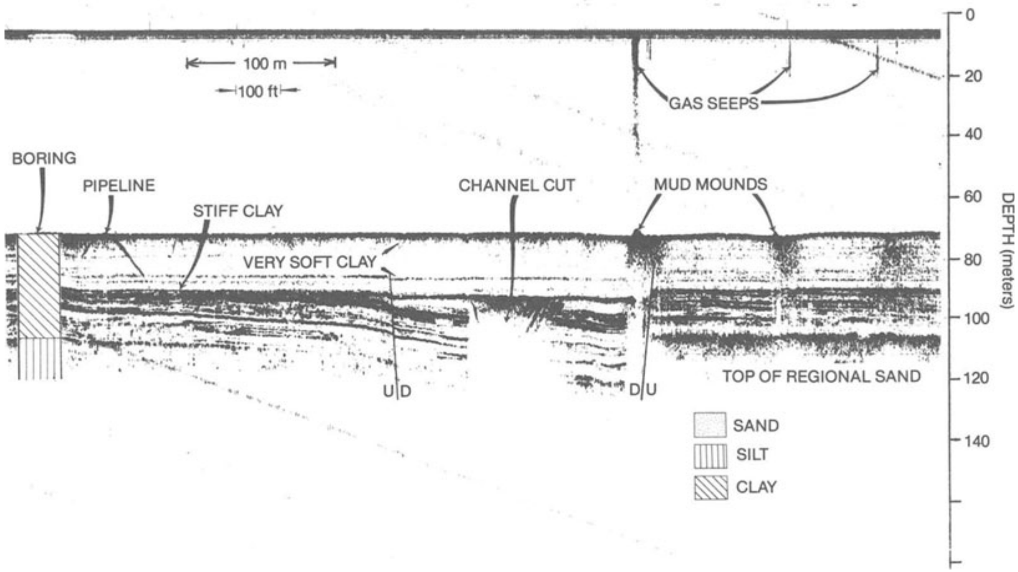

FIGURE 6.2 Subbottom profiler (3.5 kHz) record depicting: geoengineering borehole tie-in, gas seeps, pipeline, mud mounds, faults, and channel cut and fill features, Gulf of Mexico. (From Antoine and Trabant, 1976, by permission of the authors.) (8)

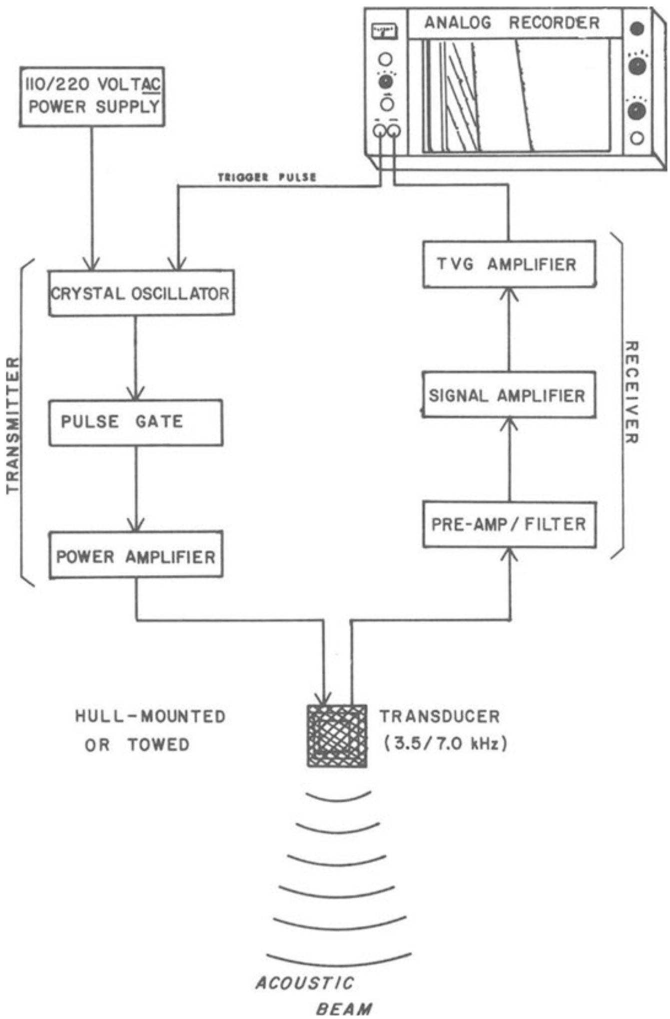

FIGURE 6.3 Electronic block-diagram of subbottom profiler system. Note that all transceiver components are usually housed within a single box. (Diagram by the author.)

PRINCIPLE OF OPERATION

The typical SBP system consists of a transceiver electronics package, a transducer (some units contain a number of transducers for greater power

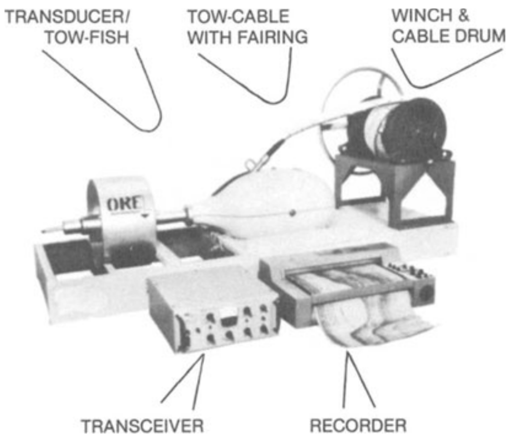

FIGURE 6.4 Typical subbottom profiler system components: transceiver, winch, transducer fish, and recorder. (Courtesy of Ferranti–O.R.E., Falmouth, Mass.)

output), and a facsimile-type recorder (figs. 6.3, 6.4). The operational circuitry and dimensions are similar to but larger than those of echo sounder systems, in order to operate at lower frequencies (1.0 to 10 kHz), and generate higher power outputs of up to 10 kW. The block diagram of figure 6.3 depicts the basic circuitry common to most systems. Compared to the echo sounder, one finds additional filtering circuitry and time varying gain circuits to boost the received signal amplitude levels with depth of penetration.

Most SBP systems are equipped with electronic circuitry to blank out the water column. While this feature produces a cleaner record, it also masks the presence of features within the water column such as gas seeps, which are of concern to the emplacement and safety of drilling structures.

OPERATION

Continuous SBP records are displayed on facsimile or fiber optic type recorders such as shown in figure 6.4. Such recorders require a variety of operational control features including: trigger signal output for activating the transmitter, signal input from the receiver, sweep and keying time

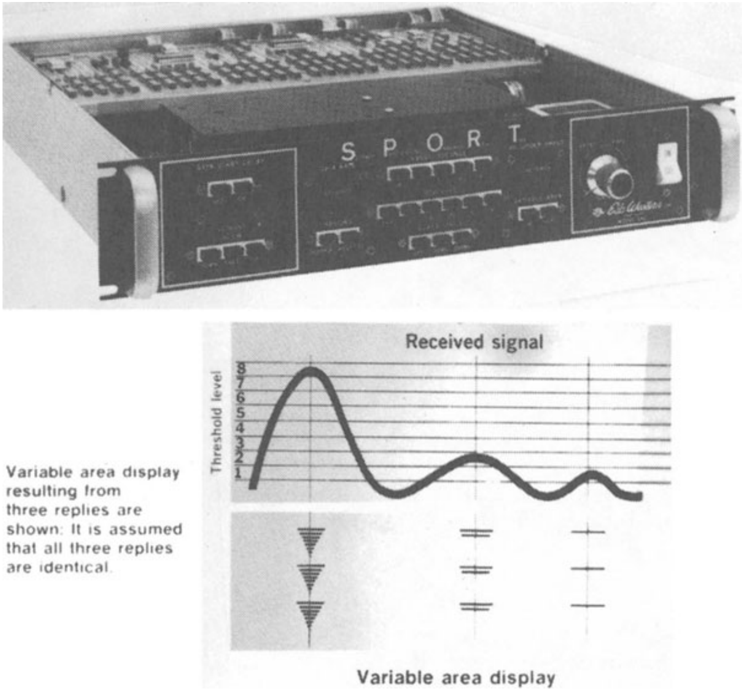

FIGURE 6.5 Real-time subbottom profiler digital processor system (SPORT). (Courtesy of Edo Western Co., Salt Lake City, Utah.)

controls, scale line settings, and delay circuits. A major requirement for a recorder is that it have a dynamic recording range, gain and sweep speeds to produce a readable record scale, and the varying gray scales associated with the seismic reflectors. The dynamic range for such analog recording systems is generally on the order of 20 to 25 dB. This range can be markedly increased, however, through the use of digital sampling and playback techniques (fig. 6.5).

DIGITAL OPERATION

Digital systems represent the future trend for most electronic instrumentation, and as such, SBP systems have witnessed this development since the mid-1970s. Conversion of the returned analog reflection data to binary bits allows for temporary storage in memory, and digital microprocessor manipulation prior to graphic display and/or recording on digital tape. Manipulations of the reflection data in this format allow the retention of virtually unlimited dynamic ranges, band pass filtering, time varying gain enhancement, and vertical stacking of adjacent traces for signal-to-noise enhancement (fig. 6.5).

Digital units are available as stand alone transceiver units, or as add-on features for existing analog systems. Digital tape recordings allow for postsurvey processing by seismic array computers for further data enhancement.

OPERATIONAL ADJUSTMENTS

The power output and receiver gain of a subbottom unit in operation needs to be balanced or adjusted to equal levels. This tuning may be performed by listening to the amplified signal with earphones, or observing the two signals on an oscilloscope.

The recordings should provide a clear indication of the first multiple, if present. The purpose of the time varying gain (TVG) circuitry is to boost the gain of the SBP record in order to compensate for signal losses of the acoustic pulse as it propagates through the water column and sea floor. The TVG adjustment should be tuned to bring in an optimum picture of the subbottom layers to a maximum depth. The onset of the TVG may be adjusted manually, to start the gain ramp increase just above the sea floor or, on some systems, placed in an automatic mode whereby the ramp starts with the first return from the sea floor.

If one desires to sample data within the water column, however, the TVG needs to be off or started at time zero. Once these basic settings are made, the acoustic response of the sea floor and underlying sediments becomes the limiting factor toward optimum reception (recording) and penetration.

The transducers required for the operational frequencies of SBP are relatively large. They are commonly mounted within fluid-filled compartments (sea chests) on the hull of the survey vessel, or towed over the side of a survey vessel, within a hydrodynamically streamlined tow body (fish) (fig. 6.4). These practices reduce noise due to water flow, bubble entrapment beneath the transducer, the roll motion of the vessel, and ship-generated noise in general.

Disadvantages of the magnetostrictive and ceramic transducers used for subbottom profilers are their limitations with respect to power output. Overdriving these transducers with excess power results in ringing both at the main operating and related (harmonic) frequencies. This problem is reduced by the use of short transmitted pulse widths and narrow band pass frequency filtering circuitry.

Cavitation is also an occasional problem with subbottom profiling units at higher power outputs (also in heavy seas for hull-mounted units) depending upon the hydrostatic pressure at the transducer. The problem is usually solved by increasing the hydrostatic head by lowering the towed units deeper in the water column (3), or providing pressure to the fluid within the sea chest for hull-mounted units (a water-filled standpipe is usually sufficient).

VARIABLE FREQUENCY UNITS

To date, subbottom profilers have operated in a monofrequency mode, employing a short pulse width at a fixed frequency (i.e., 1 ms pulse at 7 kHz). A number of units are in the process of development, however, which would transmit a longer signal burst containing either several frequencies or consist in a sweep through a portion of the applicable frequency spectrum (5).

Similar developments took place during the 1950s for the development of the Vibroseis (trademark of Continental Oil Company) technique for the exploration of hydrocarbons (6). While the original Vibroseis system used much lower frequencies on the order of 8 to 80 Hz, serious efforts are being made with the higher frequencies employed by the SBP technique. The CHIRP sonar (5) thus employs a pseudorandomly generated signal between 1 and 5 kHz, with individual frequency signal lengths of a few cycles, for a total tone burst length (pulse width) of about 100 ms at 5 kW power output.

The advantages of such multifrequency pulses are that they combine sufficient frequency variability to penetrate most bottoms to optimum depths, without operating separate equipment, while increasing the signal-to-noise ratio. The returned signal must be processed, however, or cross-correlated with the transmitted pulse either in real time, or during postsurvey data processing. This processing must be performed in order to decode the complex returned multiplexed signal, and obtain the optimum resolution or picture of the subsea strata. This latter process

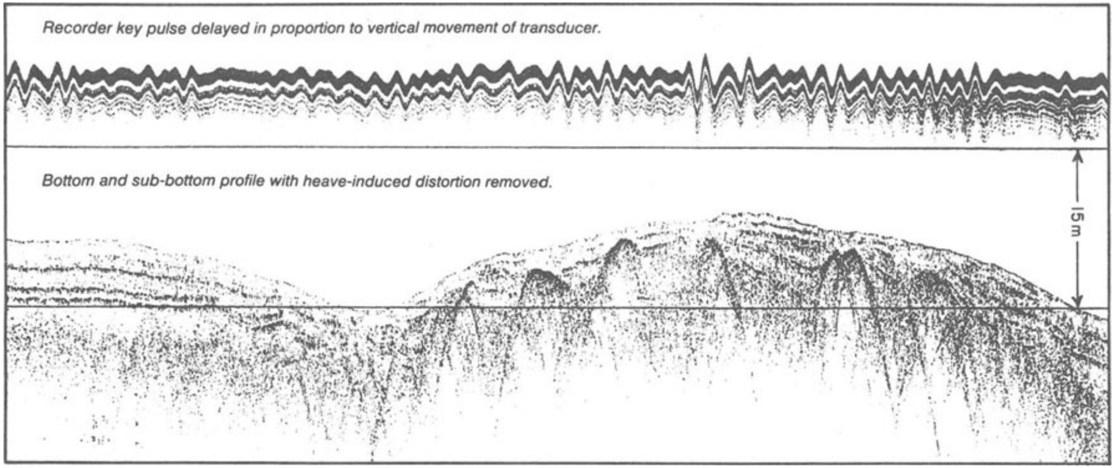

FIGURE 6.6 Subbottom profiler recording (3.5 kHz), illustrating the removal of heave-induced distortion, from Gulf of Mexico. (Courtesy of Ferranti–O.R.E., Falmouth, Mass.)

FIGURE 6.7 Heave (ship's motion) compensator processor and accelerometer. (Courtesy of Edo Western Co., Salt Lake City, Utah.)

may be done with ease in real time with the advent of programmable microprocessor systems, and promises great technical advantages within the near future.

HEAVE COMPENSATORS

Several methods have been devised toward removing the effect of survey vessel motion on subbottom profiler recordings. The distortions created by this movement frequently obscure the subbottom reflectors (fig. 6.6), rendering interpretation difficult. The motion of a survey vessel may be cancelled by input from motion sensors (accelerometers, fig. 6.7) or by simply filtering the incoming data with respect to time (swell filtering), and applying a smoothing function relative to the sea floor. This latter technique is relatively simple and produces good results, as shown by the seismic recording of figure 6.6.

DEEP-TOW SYSTEMS

Subbottom profilers have also been successfully operated as part of deep-tow systems. The units are mounted in a tow fish on a cable towed at considerable depth in order to reduce the effects inherent to deep water surveys. These effects include: amplitude loss due to spherical signal spreading, and the effects of side echoes caused by the wide transmission beam (fig. 6.8).

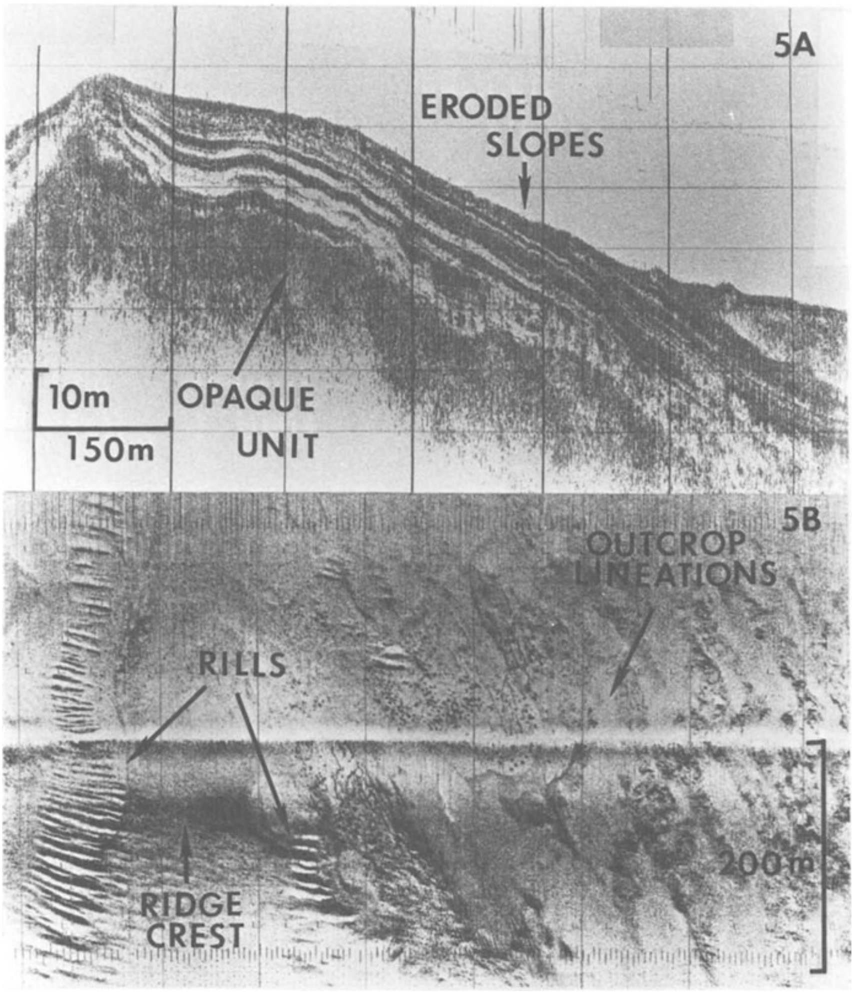

FIGURE 6.8 Matched deep-tow subbottom profile and side scan sonar record (swath width 400 m) of eroded submarine channel ridge flanks, water depth 2650 m, Mississippi Fan, Gulf of Mexico. (From Prior et al. 1983, by permission of the author.) (10)

As deep water operations beyond the shelf break become more common, the use of such deep-tow units is necessary to obtain meaningful high-resolution reflection data.

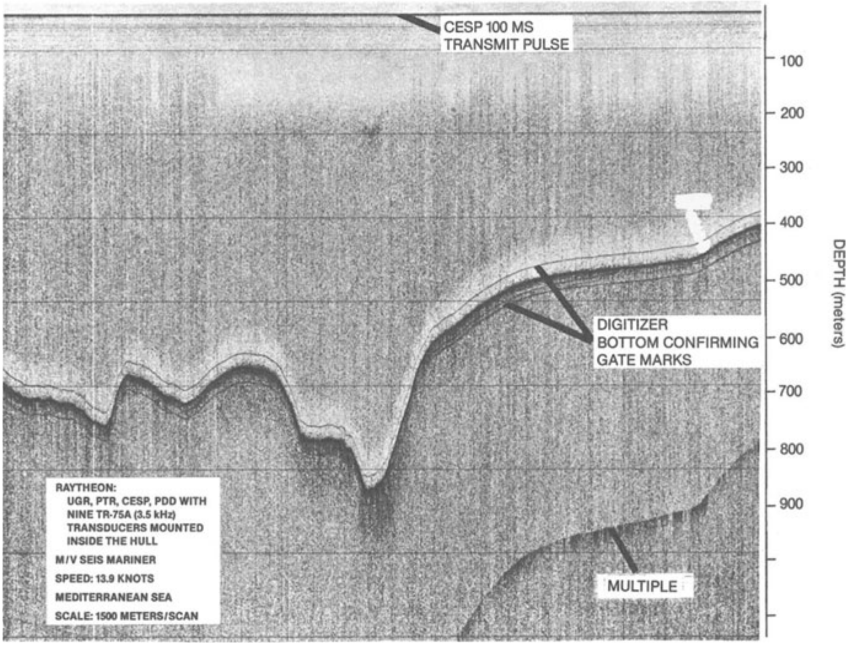

FIGURE 6.9 Subbottom profiler (3.5 kHz) recording, utilizing a signal-correlation processor (CESSP), of acoustically "hard" bottom, Mediterranean Sea. (Courtesy of Raytheon Co., Portsmouth, R. I.)

RESOLUTION

The resolution of recorded subbottom profiles is frequency dependent, as explained in chapter 2. Ideally it should be on the order of 10 cm for 3.5 kHz operation and 5 cm at 7.0 kHz (quarter wavelength at 1500 msec). However, observation has shown the resolving power to be significantly less, perhaps on the order of 1/3 to 1/2 of the wavelength at best (14 to 20 cm for operations at 3.5 kHz). Many variables are involved in the generation of reflectors, particularly the acoustic impedance of the subsea strata.

Correlations of subbottom profiles with shallow borings and core data reveal that very thin layers, such as scattered shell fragments and sand lenses, can produce strong acoustic reflections, while thick layers of

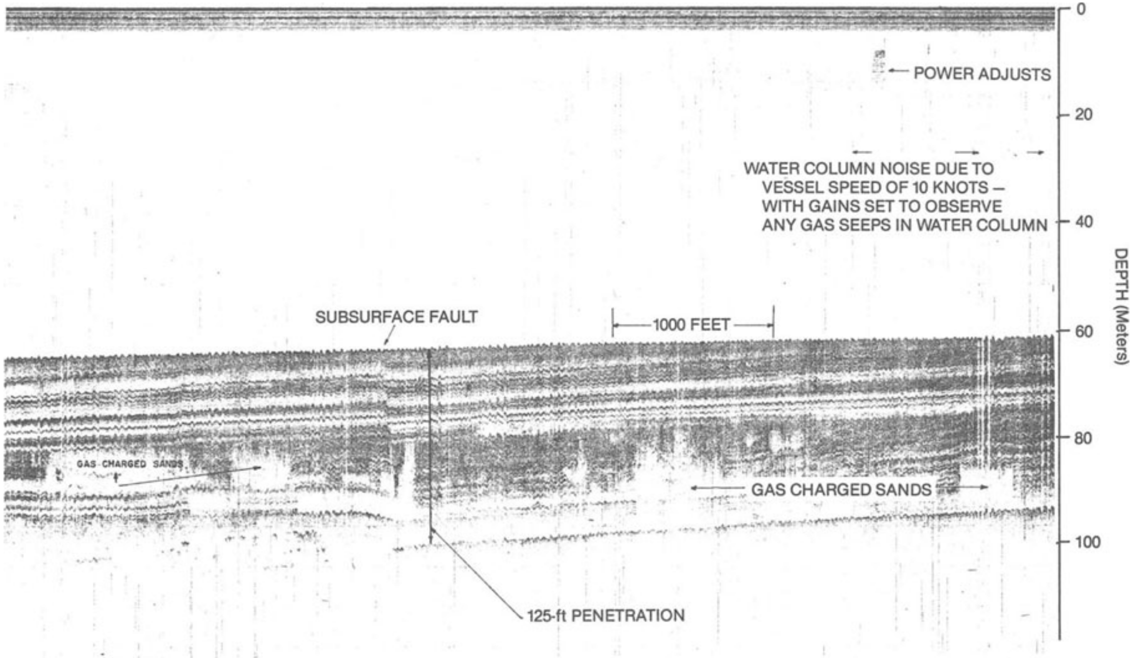

FIGURE 6.10 Subbottom profiler (3.5 kHz) record over acoustically "soft" sediments, displaying over 40 meters' penetration, Gulf of Mexico. (Courtesy of Edo Western Co., Salt Lake City, Utah.)

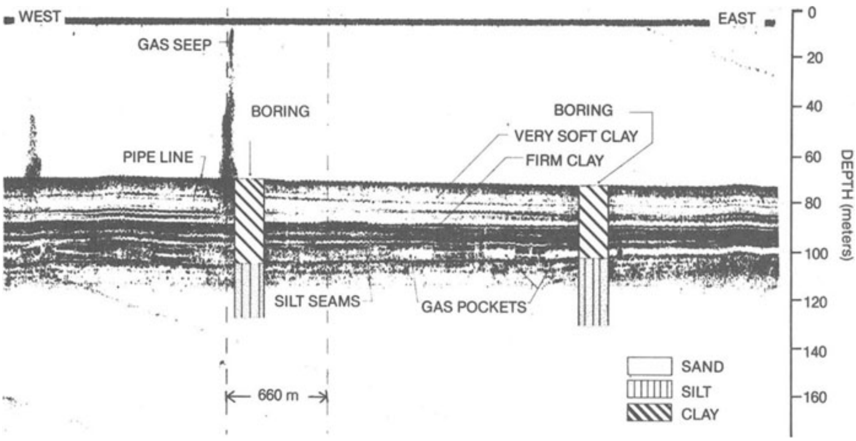

FIGURE 6.11 Example of correlation between subbottom profiler record (3.5 kHz) and geoengineering borehole data, Gulf of Mexico. (From Antoine and Trabant 1976, by permission of the authors.)

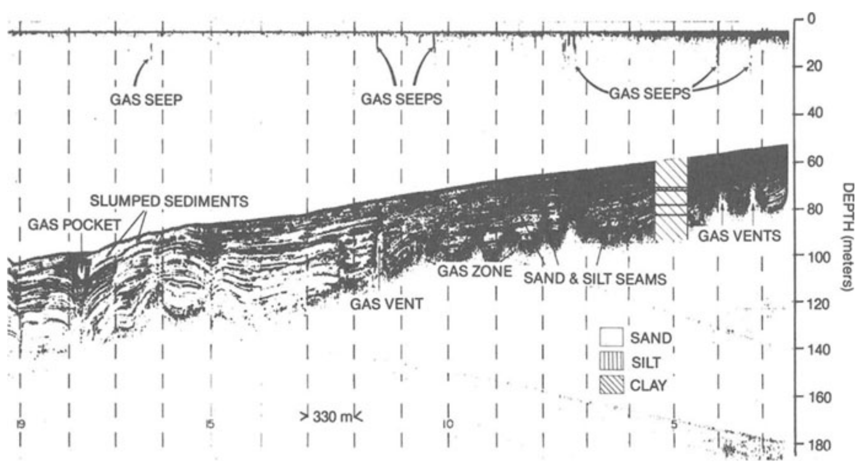

FIGURE 6.12 Subbottom profiler record (3.5 kHz) showing geoengineering borehole data, gas seeps, gas pockets and slumps, Mississippi River Delta, Gulf of Mexico. (From Antoine and Trabant 1976, by permission of the authors.)

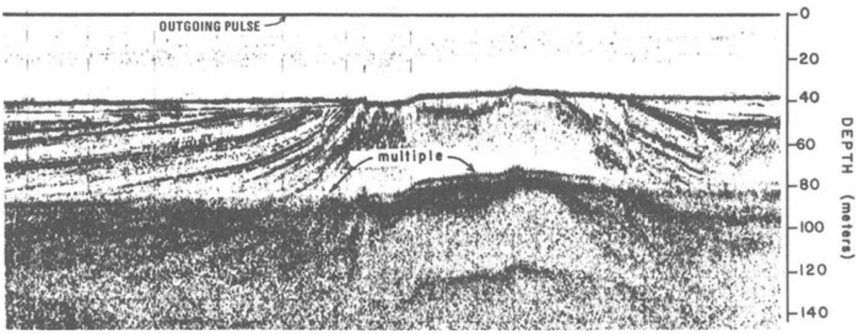

FIGURE 6.13 Example of multiple interference on a subbottom (3.5 kHz) profiler recording, Gulf of Mexico. (Courtesy of Raytheon Company, Portsmouth, R. I.)

relatively different sediment composition may not produce reflections at all. Thus, the composition, physical properties, and microfabric of submarine sediments are important factors, in addition to the recording technique and scale, which will affect the final recorded resolution obtained by a subbottom profiling system.

Penetration of the sea floor, on the other hand, is dependent upon a number of factors, including the operational frequency as well as the sea-floor sediment composition. Examples of these effects are shown on the subbottom profiles of figures 6.9 and 6.10.

INTERPRETATION

Determining the subsea geology from subbottom seismic records, while appearing straightforward at first, is subject to pitfalls that can produce erroneous results. The acoustic reflection characteristics of the sediments, their velocities, and raypaths that result in the seismic profiles, should be well understood before making an interpretation.

Knowledge of the local geology and availability of ground truth in the form of core or boring samples, are invaluable aids in this process. The detailed correlation with engineering borehole data provides an unambiguous interpretation, as illustrated by the profile of figure 6.11.

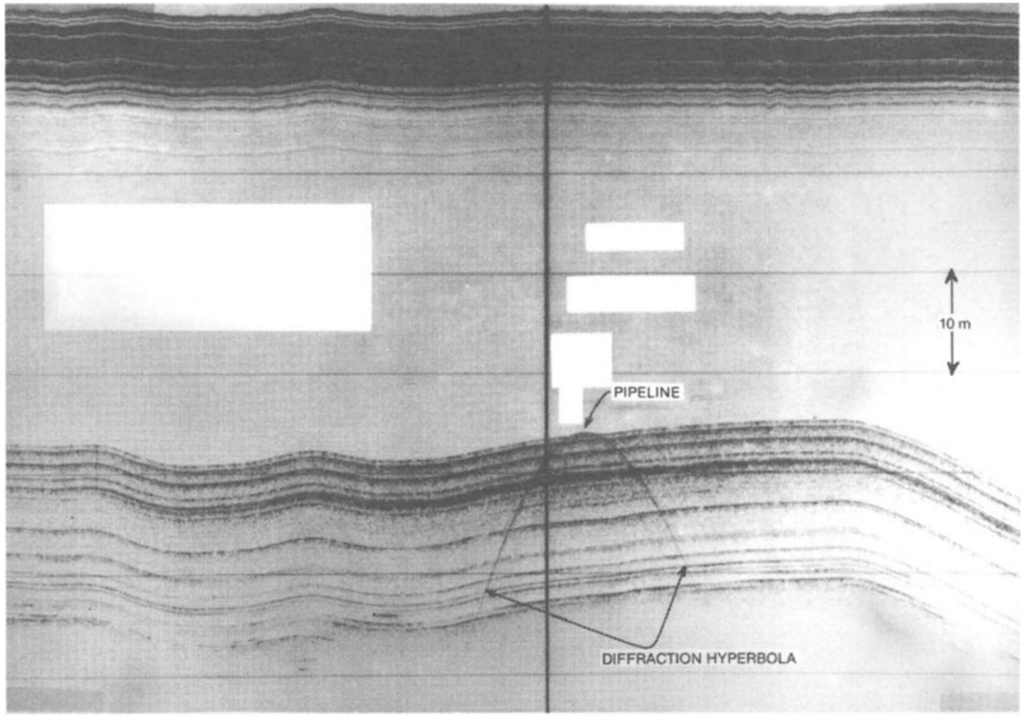

FIGURE 6.14 Subbottom profiler (14 kHz) record, over 30.5 cm (12 in) pipeline in Gulf of Mexico. (Courtesy of Ferranti–O.R.E., Falmouth, Mass.)

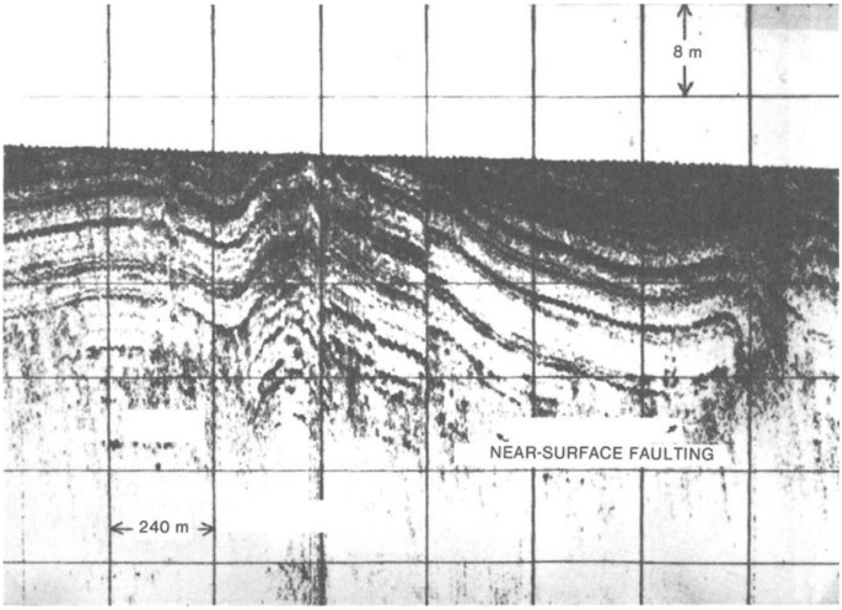

FIGURE 6.15 Subbottom profiler (3.5 kHz) recording showing "active" faulting, and a surface angular-unconformity, Gulf of Mexico. (Courtesy of Fairfield Industries, Houston, Tex.)

Acoustically hard bottoms composed of sand, limestone, or the presence of gas-bearing sediments, may not permit penetration, and hence seismic reflections, as shown in figure 6.9. The use of lower frequencies (chaps. 7–9) may alleviate this problem, while reducing the resolution.

Soft clays, on the other hand, usually allow excellent penetration of the sea floor. Subbottom profilers are commonly referred to as *mud penetrometers* in Europe (7). The seismic profile of figure 6.12 displays that ideal penetration within soft deltaic sediments.

Interference by multiples (chap. 2) within shallow waters frequently limits interpretation to the depth of the first multiple. Strata underlying the first multiple may be masked, as shown by the profile of figure 6.13.

Subbottom seismic profilers are sometimes excellent for locating pipelines and determining their depth of burial (fig. 6.14). The deter-

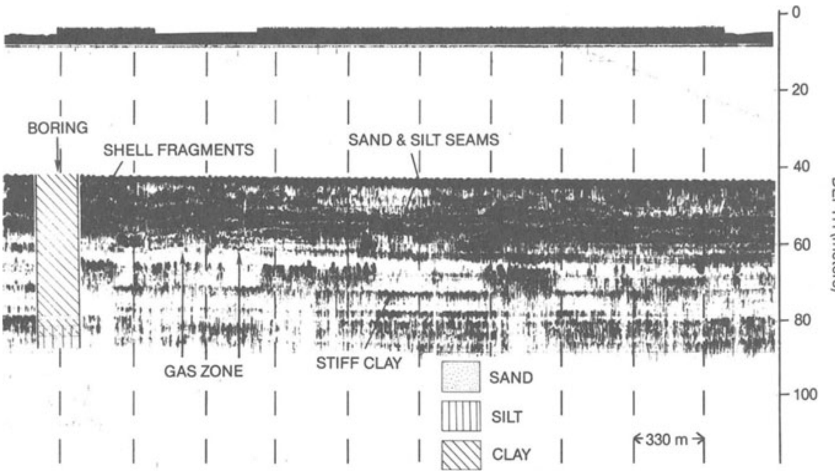

FIGURE 6.16 Subbottom profiler (3.5 kHz) record showing correlation with geoengineering borehole data, and presence of shallow gas-bearing strata. (From Antoine and Trabant 1976, by permission of the authors.)

mination of the orientation and displacement of near-surface faults (fig. 6.15) is relatively simple. The vertical exaggeration of the recordings, however, must be taken into account when establishing dips and slopes.

The degree of activity or movement of faults may also be assessed from SBP profiles according to the amount of near-surface displacement and lack of recent surface sediment cover (fig. 6.15).

The presence of shallow gas-bearing sediments is indicated on SBP records by strong reflections, with underlying wipe-out zones as shown in figure 6.16, and abrupt lateral changes in subbottom reflection characteristics. These lateral changes in subbottom character produce the so-called battleship formations (8), and the presence of shallow gas is occasionally indicated by gas seeps in the water column as well as mud volcanoes (9) or pock marks (mounds and depressions) on the sea floor.

Relict features such as infilled river beds, stream channels, and canyons are easily identified on subbottom profile records, as revealed by the cut and fill strata of figure 6.17. Such features are usually the result of glacio-eustatic (worldwide) fluctuations in sea level, associated with the waxing and waning of continental ice sheets during the Pleistocene Epoch. The effect of these transgressive/regressive cycles was to alternately expose

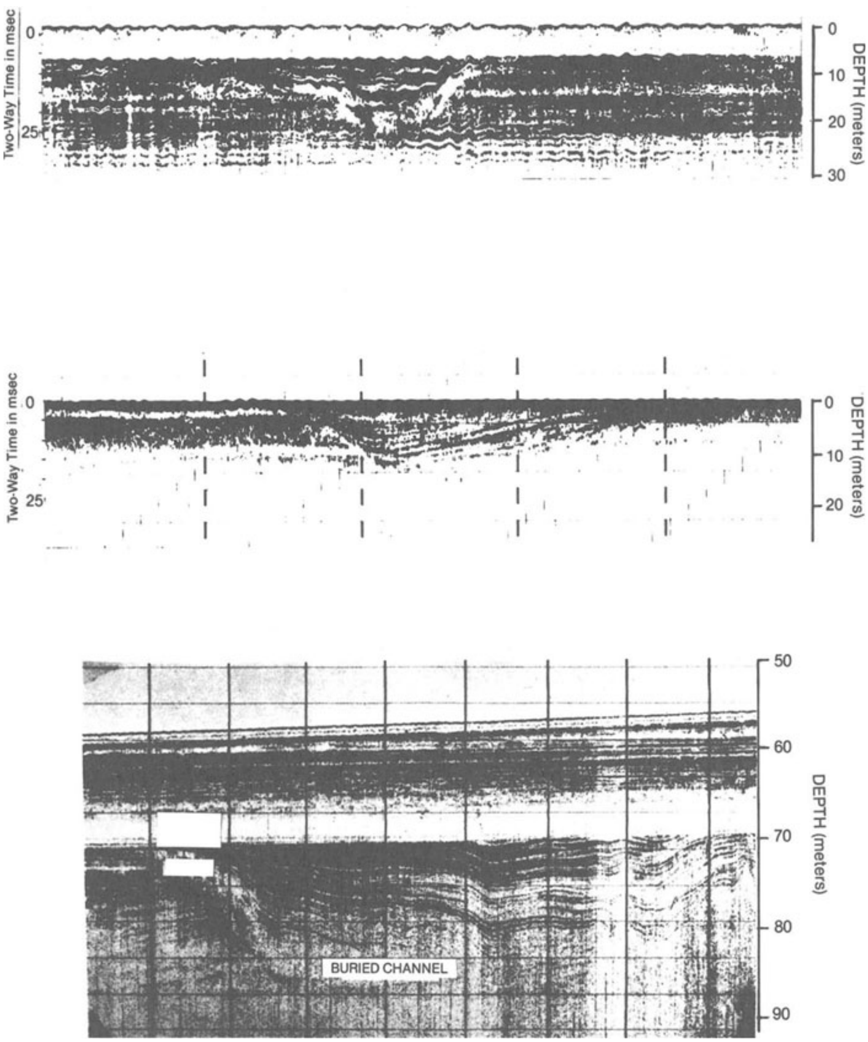

FIGURE 6.17 Subbottom profiles (3.5 kHz) depicting relict infilled river channels, or "cut and fill" features. (Courtesy of Fairfield Industries, Houston, Tex.)

and inundate areas of the present continental shelf to depths on the order of 150 m below present sea level. The curve in figure 6.18 depicts the relative changes in sea level since the last major glaciation.

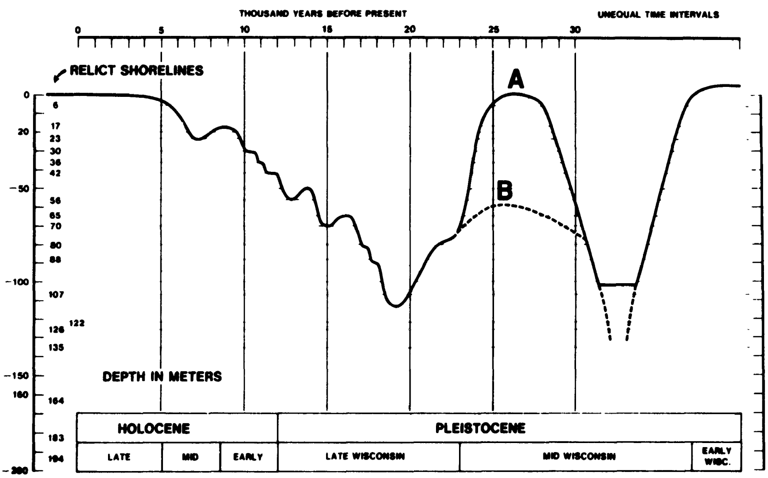

FIGURE 6.18 Curve of relative change in sea level for the northern Gulf of Mexico. Curve derived from various sources. (Courtesy of Coastal Environments, Inc., Baton Rouge, La.)

In summary, the subbottom profiler provides a most important tool in the conduct of HRG surveys, as it establishes the geology and shallow seismic stratigraphy immediately beneath the sea floor.