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THESIS

SIDE SCAN SONAR TARGET DETECTION
IN THE
PRESENCE OF BOTTOM BACKSCATTER

by

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September 1983

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Side Scan Sonar Target Detection in the Presence of Bottom Backscatter

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ABSTRACT

The effect of bottom backscatter on target detection ranges for 100-kHz Klein and EG&G side scan sonars was investigated. Glass spheres of 16-cm diameter with measured target strengths of -24 dB were deployed in 30-m water depth, 0.7 m above sand and shale bottoms. Controlled test runs past a linear target configuration were performed. For a sand bottom, the Klein system yielded target detections at a maximum range of 150 m with 100% success. The EG&G system yielded 100% detection out to 152-m range, with detection 46% of the time at 259 m and 86% at 228 m. A shale bottom masked all target returns negating detection. Detection thresholds were estimated by comparing field results to theoretical ranges calculated from the sonar equation using applicable backscatter coefficients. The results show that it is possible to determine the geophysical and side scan system inputs sufficiently well to allow determination of the efficient spacing of survey lines in shallow water hydrographic applications of side scan sonar.

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I. INTRODUCTION

A. HYDROGRAPHIC SURVEYING

The fundamental objective of hydrography is to determine the sea floor topography and reference it geographically to known points on the surface of the earth. It is the hydrographer's responsibility to perform the task of measuring and mapping bottom features while being physically removed from the area of interest by the covering body of water. In contrast, land surveyors may directly occupy the terrain being mapped. The goal, therefore, must be attained by inference from information collected through the use of remote sensing, discrete sampling methods.

1. Conventional Hydrography

The basic approach to hydrography using conventional or "classical" methodology from a simplistic point of view is to obtain a sufficient number of depth measurements made from positions on the sea surface which satisfy an acceptable standard of coverage for a given area, and from these to determine the local trend of the sea floor so that the topography may be inferred. Data acquisition is accomplished through the use of a mobile survey platform, usually a vessel, from which hydrographers measure water depths along its path of travel with some form of echo sounder (Figure 1.1). These soundings are referenced to geographical positions by fixing the vessel's location at successive times and correlating them with the recorded depths. Vessel positions are obtained by electronic navigation systems or visual positioning techniques. The desired pattern of soundings is attained through carefully-spaced,

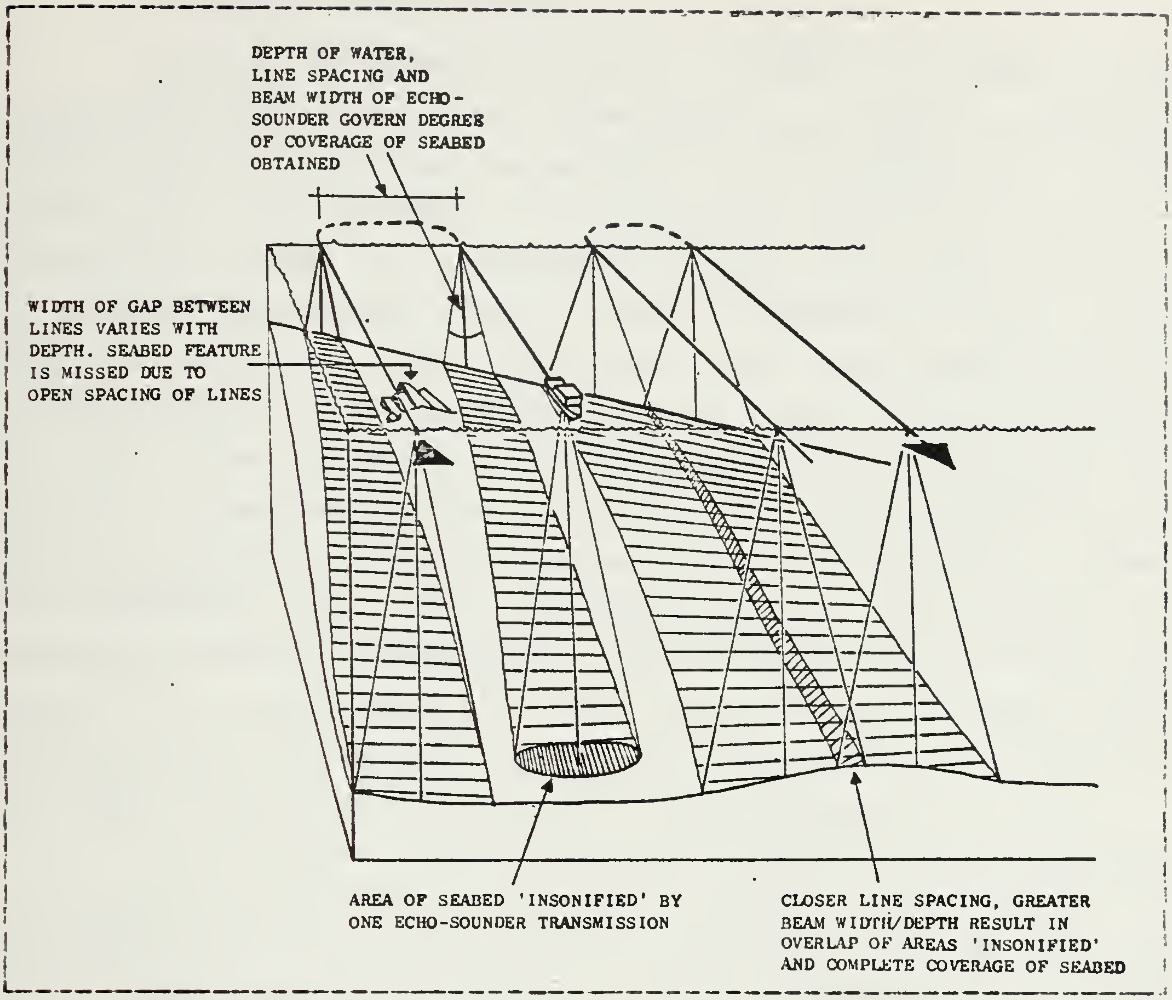

Figure 1.1 Conventional Echo Sounder [Ingham,1979].

essentially-parallel, survey lines and a sufficient number of crosscheck lines. Thus, profiles of the bottom along the survey vessel's track are acquired. Ultimately, at the conclusion of the data processing, representative soundings and depth contours are displayed in chart form.

There are numerous and more sophisticated means of acquiring and processing hydrographic survey data than have been mentioned in this brief discussion. Complementing these various techniques is a wide variety of advanced hardware, such as the multi-beam, or array echo sounder, which introduce additional complexity and cost.

2. Inherent Difficulties

As may be deduced from this simple overview, data acquisition, storage, and processing constitute an enormous task, which is a time-consuming, labor-intensive, costly operation. Compounding the requirements of this straightforward approach, the hydrographer frequently faces the task of running additional survey lines to confirm bottom topography in areas for which the data arouse his suspicion of a missed between-line, anomalously-shoal depth. Note in Figure 1.1 the caveat concerning the gap and a missed feature. The areas in question may be indicated by depths inconsistent with the general trend of the surrounding soundings. These discrepancies call for an increase in the density of sounding lines to satisfy any reservations the surveyor may have as to the specific shape and extent of the bottom feature and to determine the area's "least depth", which is of legal and practical interest to the mariner.

In the case of verifying or disproving the existence of obstructions on the bottom, most notably shipwrecks, the obstacles must be located and a least depth must be obtained to a high degree of accuracy. This requirement is most often accomplished through the technique of wire-sweep surveys. This method leaves practically nothing to chance in the determination of a least depth, contrary to methods incorporating the conventional echo sounder. However, wire-sweep surveys do not reveal anything about the contour of the obstacle. Obstacles such as ship masts or stacks, vertically standing pipes or stanchions, or various bits of scattered debris that constitute a poor sonar reflector to the overhead, vertically-scanning echo sounder, may escape detection. Their absence in the survey records could one day prove to be anything but insignificant.

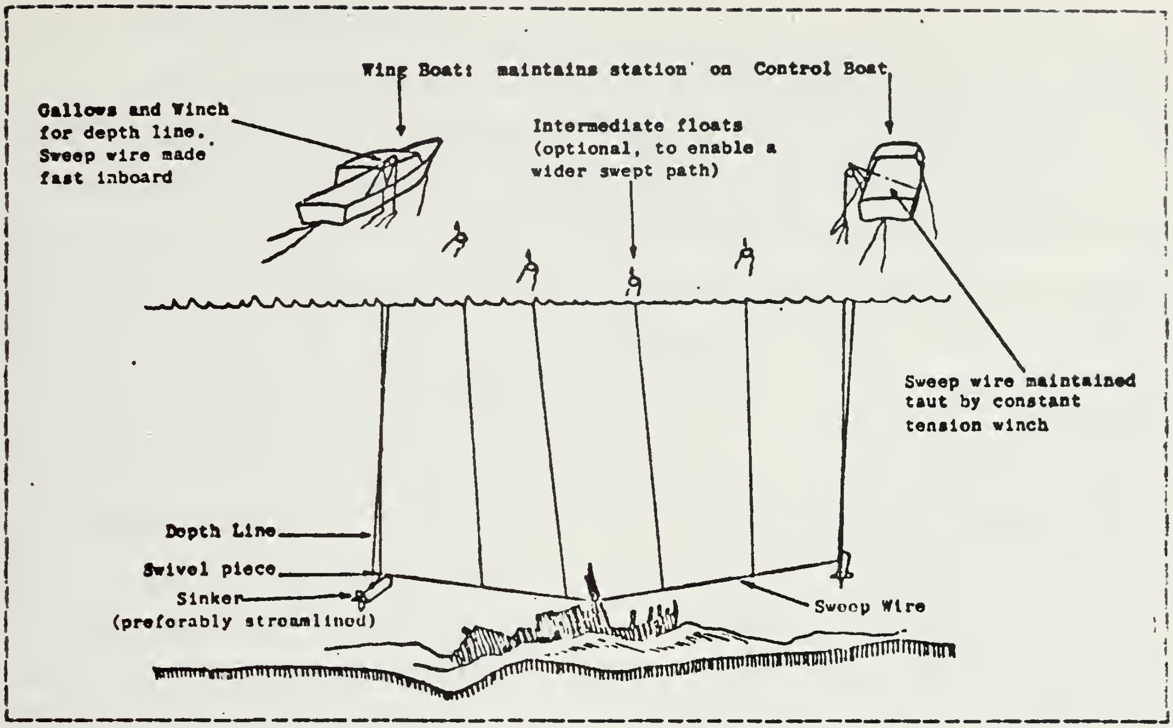

Figure 1.2 Two-Ship Wire Sweep [Ingham, 1979].

A wire-sweep survey is usually a two-vessel operation (Figure 1.2), although a single-vessel sweep may be conducted at the expense of a severely limited width of the area swept per run. In practice, a thin wire is suspended at a known water depth between two vessels and is towed horizontally over the survey area. Many successive runs at various wire depths are required before the hydrographer is able to state without doubt the least depth, or at least a cleared depth at the precise location of the obstruction. Although an effective method for yielding a desired result, it bears a high price tag with respect to time and effort leading one to question its cost-effectiveness, particularly in searching for the anomalous feature.

3. <u>An Alternative</u>

At the conclusion of data acquisition within a specified portion of a survey area, the hydrographer has collected as much depth information as reasonable diligence will allow. It is at this time that the art of inference of the physical dimensions of the sea floor comes into play. The inference is usually manifested in the form of depth contours depicted throughout the region. Whether this task is performed by hand or by machine, it inevitably remains somewhat subjective due to the inability to obtain a depth for every point on the bottom. This unavoidable consequence is a result of the obvious limitations presented by the spacing of sounding lines and the charts on which the information is presented. As a result, it's entirely possible that a significant feature may be disastrously omitted, or even added as the consequence of a false echo.

Considering the foregoing scenario, the advent of side-looking, or side scan sonar, offers an obvious remedy to this dangerous error source in hydrographic surveys. This towed, dual-channel sonar takes the form of a hydrodynamically stabilized "fish" that scans on either side of its path at a typical operating frequency of 100 kHz. An acoustic beam, of the order of 40° vertical beamwidth and inclined below the horizontal, is employed to provide a continuous, large swath of coverage. Operating ranges will vary significantly depending on the water temperature and salinity. An effective range of 1,750 m may be expected in fresh water in contrast to 380 m in sea water [Denbigh & Flemming, 1982]. Additionally, a narrow horizontal beamwidth of approximately 1° enables detailed resolution in the direction of travel. A real time, graphic display of sea floor images that approaches the likeness of an aerial photograph is generated at a dual-channel recorder aboard the towing vessel.

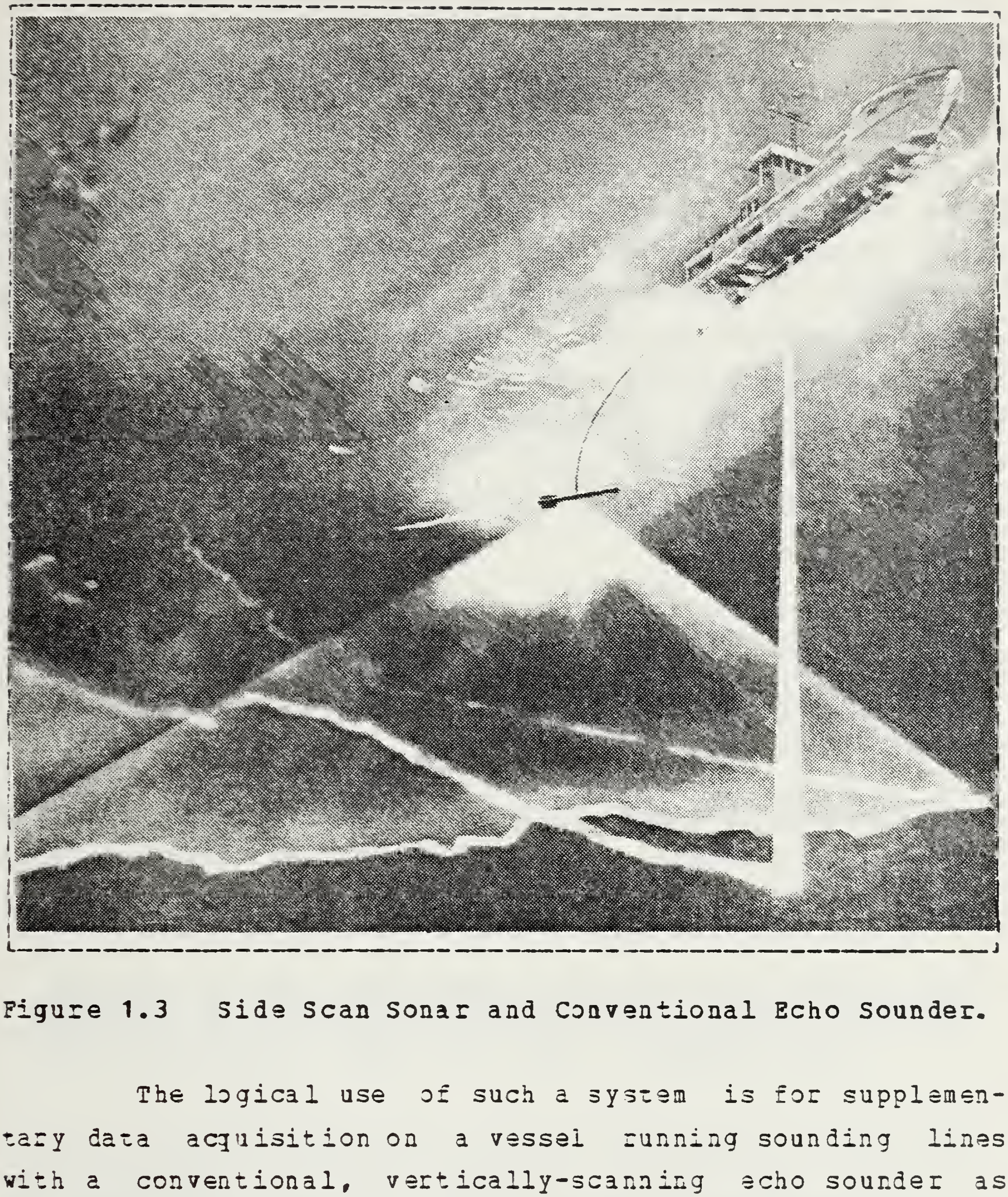

Figure 1.3 Side Scan Sonar and Conventional Echo Sounder.

The logical use of such a system is for supplementary data acquisition on a vessel running sounding lines with a conventional, vertically-scanning echo sounder as shown in Figure 1.3 [EE&G Technical Presentation]. In this capacity, the side-looking sonar is not used to measure depth, but to image the area lying between adjacent survey lines. This capability ensures the location and delineation of bottom features that may have escaped detection on

conventionally-spaced sounding lines, thereby calling attention to the surveyor of the necessity for an increased density of depth measurements in the suspect area.

It is in the phase of survey operations dealing with the verification or disproval of obstructions and wrecks on the ocean floor that the application of side scan sonar lends itself most admirably. The overall efficiency of the system in light of the apparent detection reliability coupled with enormous premiums in reduced survey time allocations and cost-effectiveness has found great favor with many of the world's leading hydrographic surveying agencies and organizations. Indeed, Great Britain's Hydrographic Service has incorporated the use of Dual Channel Sidescan Sonar (DCS-3) since 1970.

> "It is now accepted as being an essential aid to modern hydrographic surveying to the extent that no survey on the Continental Shelf is considered complete that has not included a comprehensive DCS-3 sweep." [Hydrographic Department Professional Paper No. 24, 1977]

Additionally, a memo originating from the National Ocean Service (NOS) of the National Oceanic and Atmospheric Administration (NOAA) states:

> "The use of side scan sonar to locate or disprove the existence of reported or charted sunken wrecks and other submerged obstructions potentially dangerous to navigation was approved April 13, 1982." [Hayes, 1982]

In conjunction with NOAA's interest in the use of this equipment, a field evaluation was performed in 1975 by the NOAA Ship DAVIDSON, utilizing one of the leading state-of-the-art 100-kHz systems [Special Report OPR 511, 1975]. One of the interesting results of this study was a relative cost-effectiveness comparison of side scan sonar techniques to wire-sweep surveys in the detection of underwater obstructions (Table I).

TABLE I

Technique Cost Comparison

Expense	Side Scan	Wire Drag
Launches	1	2
Skiffs	0	1
Crew	6	12
Load/unload time	0 hr	1 hr
Transit time	1 hr	1.5 hr
Deployment time	0 hr	1.5 hr
Search time	1 hr	2.5 hr
Recovery time	0 hr	0.5 hr
Total time	2 hr	6 hr
Total man hours	12 man hours	72 man hours

[Special Report OPR 511, 1975]

B. FOCUS OF RESEARCH

Does the side scan sonar provide an all-encompassing solution to the dilemma of obtaining blanket sea floor coverage? After all, if the system appears to be functioning properly, how could one possibly doubt the veracity of the constant outpouring of visually-discernible data? This sense of security is an easy trap to fall into when using this system. The succession of shapes and patterns emerging from the recording unit challenge the operator to correlate these presented images into recognizable features. Indeed, at first inspection, this appears to be a remarkable device capable of penetrating the once opaque water column to allow the observer to witness the continual unfolding of a previously unseen terrain. In this manner, misconceptions may develop as to what is actually being observed, or more importantly, what isn't.

A major area of concern in using side scan sonar is the system's varying capability of detecting targets of various size and shape (i.e. shipwrecks, rock pinnacles, sand waves, etc.) on sea beds of differing material composition. This problem is inherent in acoustic imaging by bottom back-scatter when a portion of the incident sound energy is reflected back toward the receiver not only by the target itself, but by the sea bed material as well. If the nature of the bottom is such that it is at least as good a reflector as the target, the pulse reflected from the target will be masked by the return from the sea bed and will not survive as an identifiable echo on the sonogram.

The intensity of the echo is related to the area of the reflecting surface that is perpendicular to the incident sound pulse. A larger area reflects more sound energy than a smaller area. The material composition of the reflecting surface also affects the amount of reflected energy. A rocky bottom usually provides the most backscatter, followed by sand, with mud being the least reflective [Urick, 1975].

The backscattering properties of the bottom have proven to be extremely pertinent in real-world situations dealing with the verification or disproval of submerged wrecks or natural obstructions presenting a hazard to navigation. Is it reasonable to assume that a wreck may not be as easily identified on a rock bottom as on a sand bottom? What kind of range capability, as a function of bottom type, may be expected for some of the most widely used 100-kHz side scan sonars commercially available today? How acoustically reflective does the target need to be for detection by these systems and how will that vary from location to location?

These are a few of the fundamental questions that stimulated the interest for research in this area. It was the intention of this investigation to determine the practical target-detection capabilities of basic, contemporary 100-kHz

side scan sonar systems in terms of maximum detection ranges with differing degrees of bottom backscatter.

Two similar side scan sonar systems, produced by leading manufacturers in this field, were used. Data were acquired by towing the systems on controlled passes at varying ranges from targets with a measured target strength, mounted on different bottom types of known material composition. All field work was performed in Monterey Bay, California. Based on the known properties of the sea bed, empirical values for bottom-backscatter coefficients were incorporated into the sonar equation to obtain the maximum range of detection for targets of known target strength. These theoretical results were then compared to the results obtained in the field. Briefly, the objective of this study was to obtain a qualitative gauge concerning the practical performance capabilities of these side scan sonar systems in the uncooperative ocean environment, thereby assessing their ability to aid the hydrographer in accurately and confidently surveying the sea floor.

II. SIDE SCAN SONAR

A. HISTORY

Post-World War II commercial applications of surplus military sonar systems led to a discovery fundamental for side scan sonar imaging. A consistent correlation was observed between echo intensity and sea-floor topography from high frequency sound reflections off the ocean bottom. Kunze (1957) and Chesterman et al. (1958) conducted experiments directed specifically at employing this phenomenon for sea floor mapping [Flemming, 1982]. Based on the results of these experiments, the first operational side scan sonars were developed by Tucker and Stubbs (1961) at the National Institute of Oceanography in Great Britain [Flemming, 1976]. These systems were designed specifically for geological investigations of that country's continental shelf [Leenhardt, 1974]. Since that time, the side scan sonar concept has evolved at a rapid pace, Belderson et al. (1972).

The extensive diversity of applications of the side scan sonar technique has resulted in numerous variations to the basic concept. In response to the user's particular needs and economic constraints, there exists a wide range in the degree of sophistication and specific operating parameters of available instruments (Figure 2.1).

B. BASIC SYSTEM COMPONENTS AND THEORY OF OPERATION

A typical side scan sonar system used in hydrographic surveying consists of three main components: a transducer assembly which comprises the submerged operating unit, commonly referred to as the "fish", a reinforced cable

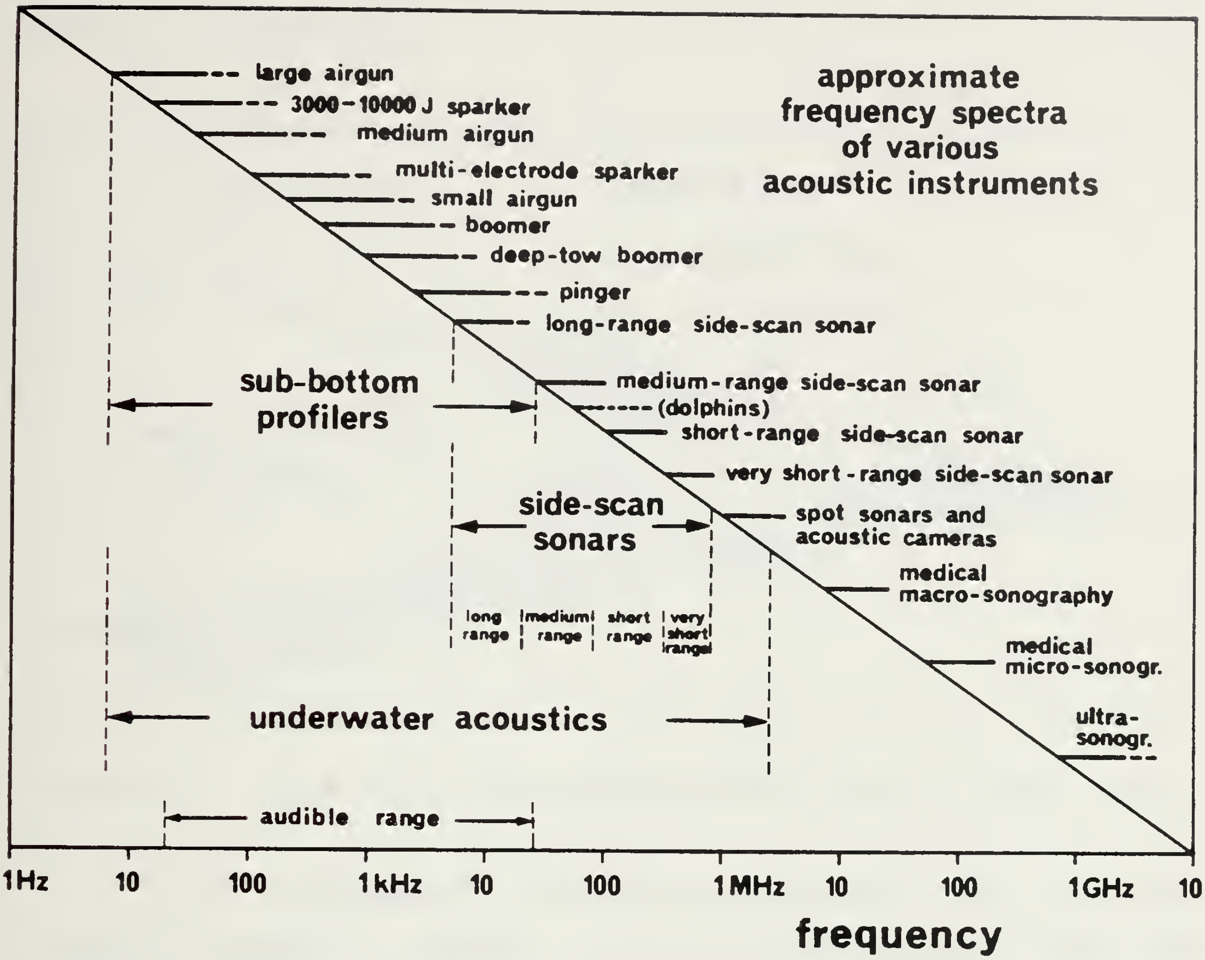

Figure 2.1 Acoustic Imaging Methods [Flemming, 1982].

serving as the transmission link and tow line, along with a dual-channel recorder aboard the survey vessel.

1. Tow Fish

This component is a balanced, towed vehicle approximately 1 m in length, containing two sets of transducers mounted on either side of the body, a transducer driver, and preamplifiers. The transducers in use today incorporate piezo-electric ceramics while older models used magneto-strictive vibrators [Leenhardt, 1974]. A representative

side scan sonar tow fish and its projected sound beam is shown in Figure 2.2.

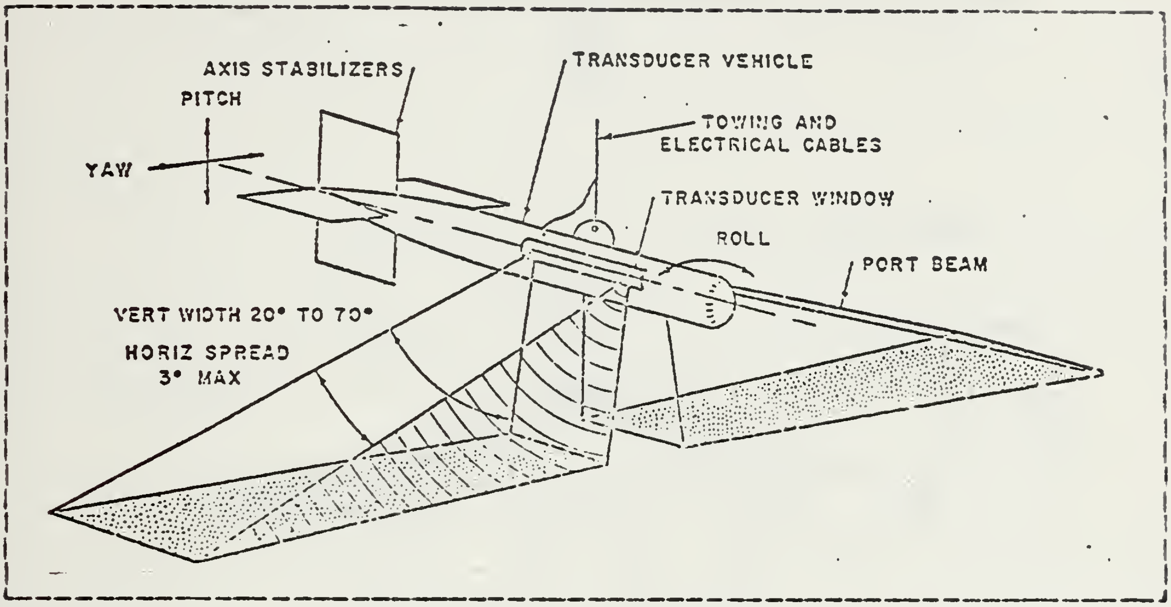

Figure 2.2 Tow Fish and Projected Sound Beam [Cole, 1968].

The transducer's main lobe provides the principle source of acoustic imaging, with side lobes insonifying the sea floor directly below the fish. These side lobes enable the operator to directly determine the height of the fish above the bottom. The shape of the beam in combination with the high frequency and a very short pulse length permits the system to resolve minute topographic detail. One of the beam patterns used by a leading manufacturer of 100-kHz systems is illustrated in Figure 2.3.

Since the graphic records produced from these acoustic signals are a product of both the main lobe and the less intense side lobes, for some particular systems the portion of the record attributed to the receipt of the side lobe information will be of inferior quality in resolution [Flemming, 1976]. Large objects are still recorded easily

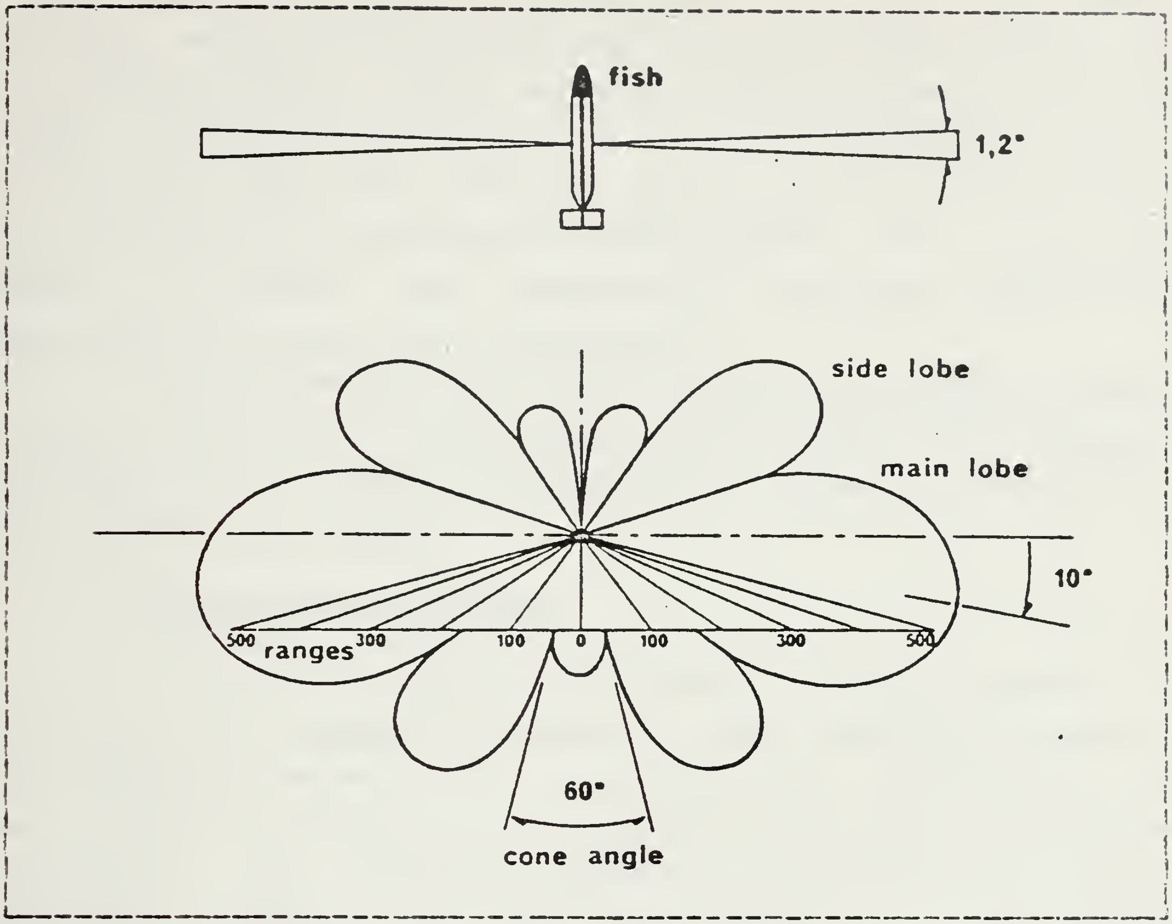

Figure 2.3 Beam Pattern [EG&G Instruction Manual, 1975].

enough, but less significant ones may be poorly defined, if at all. With some systems, the inner portion of the sonogram for each channel will display a very noticeable white gap, this being the result of the dramatic loss of resolution in the area where the side lobes overlap with the main lobes. For each particular system used, it is important to know the precise geometry of the beam pattern formed to reliably ascertain the extent of the area corresponding to this reduced resolution.

Upward-facing side lobes insonify the sea surface and will consequently be recorded. It will appear, depending on the sea state at the time, as either a thin

undulating line barely discernible, or as a relatively strong, solid, dark undulation with subsequent indications of surface waves at their respective slant ranges across the paper. This initial surface return can be helpful in calculating the total water depth by adding the sea surface range to the height of the fish above the bottom, but it can also serve to clutter and confuse the desired information concerning the sea floor topography.

The recommended tow fish height during survey operations is 10% to 20% of the range scale in use. This measure ensures that the area of coverage is largely insonified by the powerful main lobe.

2. <u>Dual-Channel Recorder</u>

This unit serves as the graphic printing mechanism as well as a housing for most of the system electronics. The signals received at the transducer are preamplified and sent up the tow cable to the recorder where they are further amplified. The amplified current is directed to a helix electrode sweeping out from the middle of a revolving recording drum. The current is transmitted through electrically-sensitive recording paper being fed at a constant rate dependent on the selected range scale, to a printer-blade electrode and subsequently to a ground. In this way, marks are produced on the recording paper with intensity proportional to the received signal strength; stronger signals producing darker marks. The distance from the center line of the plot is proportional to the travel time for the acoustic pulse to travel from the fish to the target and back and, therefore, indicates the range from the fish. The backscatter from the sea floor will be displayed through the succession of these pulses recorded as the drum turns.

Each operational range scale of the system is split into equal time intervals which plot automatically as parallel lines on the record. These fixed time intervals represent fixed slant ranges.

A fundamental operational characteristic of the system is that increasing the range scale by a factor of two, decreases the pulse repetition rate (prr) by a factor of one half to compensate for the longer travel times of the acoustic signals (i.e., for a range scale of 75 m, the prr is 10 pulses per second; for the 150-m scale it is 5 pulses per second). The paper feed rate is reduced by the same factor to avoid gaps in the printout. In addition, the relative size of objects recorded will be half as large as they would be on the shorter range scale.

A key feature of the side-looking sonar is that objects large enough to block out insonification of the bottom area behind them will not only produce a dark, distinguishable mark on the sonogram, but will also leave an acoustic shadow zone, easily recognized as a white patch on the far side of the object. This shadow serves as an immediate indication of a significant contact. The shadow zone width in conjunction with the position of the object relative to the fish can be used to calculate the height of the object above the sea bed.

3. System Tuning

Due to the nature of the sonar beam employed in this system, proper tuning of the apparatus is of the utmost importance in order to realize its full potential. Similarly, the echo strength will vary directly in response to a target's reflective properties and size, as well as to its orientation as presented to the incident sound pulse. The echo strength will also vary inversely with the square of the slant range.

> "Typically, due to attenuation as a result of beam spreading, absorption, and other time dependent effects which occur as the acoustical signal travels through the fluid medium, the dynamic range of the incoming signal is very large, typically being on the order of 120 decibels." [Clifford, 1980]

The use of the Time Varied Gain (TVG) circuitry allows the operator to adjust the overall graphic data display throughout the range of coverage. As its name suggests, the TVG automatically increases the system gain in a linear fashion in relation to the elapsed time from the pulse transmission to the receipt of the echo.

> "As a result, the large dynamic range of the input signal is reduced to provide electrical signals representing the acoustical return signals which have a dynamic range more closely adaptable to the output display apparatus." [Clifford, 1980]

With a proper TVG control setting for a flat, homogeneous bottom, the return echoes will be of essentially constant amplitude, regardless of range. Obviously, careful and persistent attention to system tuning is mandatory, and only the wisdom gained through operating experience will dictate the optimum control settings.

4. <u>Suggested References</u>

The foregoing discussion briefly touched on the principle theory and hardware of side scan sonars. An excellent source for detailed information is, of course, the system manufacturer's manuals. There have also been some outstanding papers written both on the theory of these systems, most notably by Leenhardt (1974) and Cole (1968) and on the practical considerations in the use of this equipment by Flemming (1976) and Hydrographic Department Paper No. 24 (1977).

C. SPECIFIC SYSTEMS USED IN RESEARCH

1. Theory of Selection

With the ever-evolving state of the art of side scan sonar techniques and equipment for sea floor mapping, there exists a multitude of accessory components not heretofore mentioned. For example, digital and microprocessor electronics allow for on-line correction of inherent compression and slant range distortions, as well as account for the removal of the water column from the graphic display. The more common, less sophisticated recorders do not possess this capability. An important contribution has been digital processing with memory for data storage which allows post-proccessing playback of tape recordings along with selective image expansion to further enhance original images.

It was of deliberate intent, with some consideration for system complexity and economy, that this particular investigation would use only the "traditional", practical concept of this device. Just the three main components previously mentioned would be used in the field. This approach, in fact, allows the study to more realistically simulate common field systems.

2. Systems Used

The two systems selected for investigation were comparable 100-kHz side scan sonars manufactured by Klein Associates, Inc. of Salem, N.H. and the Environmental Equipment Division of EG&G of Waltham, MA. The Klein system was graciously provided on loan by the U. S. Navy's Submarine Development Group 1; Unmanned Vehicles Detachment in San Diego, CA. The EG&G equipment was similarly provided courtesy of NOAA's Atlantic Oceanographic and Meteorological Laboratories in Miami, FL. Additionally, a 50-m tow cable for the EG&G system was kindly loaned by the

U. S. Geological Survey's Office of Marine Geology in Menlo Park, CA. Systems specifications may be referred to in Appendix A.

III. THEORETICAL CONSIDERATIONS

A. SELECTION OF TARGETS

Before testing could begin to determine the range capabilities of the selected side scan sonar systems given a specific target strength, suitable targets had to be designed. To better mirror practical applications, the targets used were passive. In this situation, a portion of the transmitted signal is reflected back to the sonar system, as opposed to active targets (i.e. transponders). Target characteristics desired in this study were: a sufficient target strength to allow detection over several different bottom types, small physical size for ease of handling, reflective characteristics independent of the hydrostatic pressure, and target strength independent of reflective surface orientation.

The depth of water for the tests was planned to be approximately 30 m (100 ft). This depth was decided upon for various reasons. Shallow towing depths allowed the use of lightweight towing cable so that the fish could be easily streamed at its desired depth and retrieved by hand, eliminating the necessity of a heavy towing winch. In addition, the targets could be deployed and recovered by hand or by the towing vessel's anchor windlass. Similarly, numerous bottom samples in prospective test sites could be easily collected. Visual inspection of bottom type and topography by amateur scuba divers could also be conducted without requiring any complicated decompression measures.

At this water depth with the tow fish flown at the optimum height above the bottom (10% to 20% of the range scale in use), the limiting range scale that could be used

was, at most, 300 m. Therefore, a target had to be obtained which would have sufficient target strength to be detected within, but not beyond 300 m. Otherwise, a maximum detected range for the given target could not be determined.

The target strengths were measured in an anechoic water tank, 7-m length by 2-m width by 2-m depth, using conventional acoustic electronic equipment. A Model ITC-5001 transmitter operated at 116 kHz was positioned at one end of the tank with an omnidirectional Celesco Model LC-32 hydrophone located 1.0 m from the transducer. The calculations verified that the target was in the far field of the transmitter at known distances from the transmitter and hydrophone. The hydrophone received both the incident pulse from the transmitter and the reflected pulse from the target, allowing a relative comparison of intensity to be made. The locations in the tank were chosen to minimize surface and side reflections.

The following formula was used to calculate target strength (in dB):

$$TS = 20 \log \frac{P(1m)}{PI}$$

where P(1m) = the pressure 1 m from the target

PI = the pressure at the target

Given that R1 is the distance between the transmitter and the hydrophone, R2 is the distance between the target and the transmitter, and R3 is the distance between the target and the hydrophone, the equation is:

$$TS = 20 \log \left[\frac{(R3)(P\,R)}{\frac{R1}{R2}(P\,D)} \right]$$

where PR = the measured voltage of the echo reflected from the target

PD = the measured voltage of the direct echo from the transducer

The first target to be investigated was a corner reflector (three mutually-perpendicular, diamond-shaped planes) which is supposed to provide a high target strength, but is aspect dependent [Wallace, 1975]. An aluminum radar reflector was tested. It consisted of aluminum plates 64 cm in diagonal, 1-mm thick, with holes varying in size from 5 mm to 40 mm in diameter in a grid pattern to reduce current effects on the target. The corner reflector was secured 1 m above a 55-lb weight by a thin wire. The target strength measured varied from -21 dB down to values too low to be measured on the equipment. As expected, the target was found to be aspect dependent with only an incident signal normal to a plane of the target being of sufficient target strength for the experiment. The problems of securing a corner reflector rigidly on the sea floor at 30-m depth and ensuring normal incidence on a plane of the target would be virtually insurmountable. Covering the triplane with a reflective material such as neoprene or expanded foam was considered as a way of increasing target strength and reducing the effect of angle of incidence. However, a study of the effects over time of hydrostatic pressure at 30-m depth on these materials was deemed to be beyond the scope of this research.

To obtain a target strength that was independent of target orientation, spheres were tested. Various choices were available: air- or water-filled spheres, or spheres filled with a low-sound-velocity fluid. There were several sphere material options for consideration: stainless steel, aluminum, plastic, or glass. The chosen diameter of the

sphere was restricted by the weight required to anchor the bouyant sphere in 30 m of water, since as mentioned before, all targets were planned to be deployed and recovered by hand.

Measurements have been made by D. L. Folds (1971) comparing target strengths of precision-made, 15-cm diameter hollow spheres with different fluid interiors. At 100-kHz frequency, the stainless steel spheres with 0.1-cm wall thickness and filled with low-sound-velocity fluids producing sound focusing properties, had target strengths between -17 and -11 dB depending on the index of refraction of the fluid. The water-filled sphere had a target strength of -32 dB and the air-filled sphere's target strength was measured as -30 dB.

The low-sound-velocity fluid-filled sphere offers a higher target strength than those filled with air or water. However, it is difficult to achieve the exact mixture of fluorocarbons needed for the correct sound velocity characteristics. Therefore, only water- and air-filled spheres were tested for this investigation.

Handblown glass fishnet floats, 16 cm in diameter, and aluminum deep water fishnet floats, 20 cm in diameter with 6-mm thick walls, were purchased from a local marine supply store. The aluminum float had one large ridge about its circumference and a rough surface. The target strength was too low to be measured when water- or air-filled. The aluminum float was therefore abandoned as a target.

The air-filled glass float was placed in the tank secured to a 55-lb iron weight by a 3/8-in polypropylene line. The float was secured within a light, 1/2-in mesh fishnet. The target strength of the float was measured at approximately -23 dB.

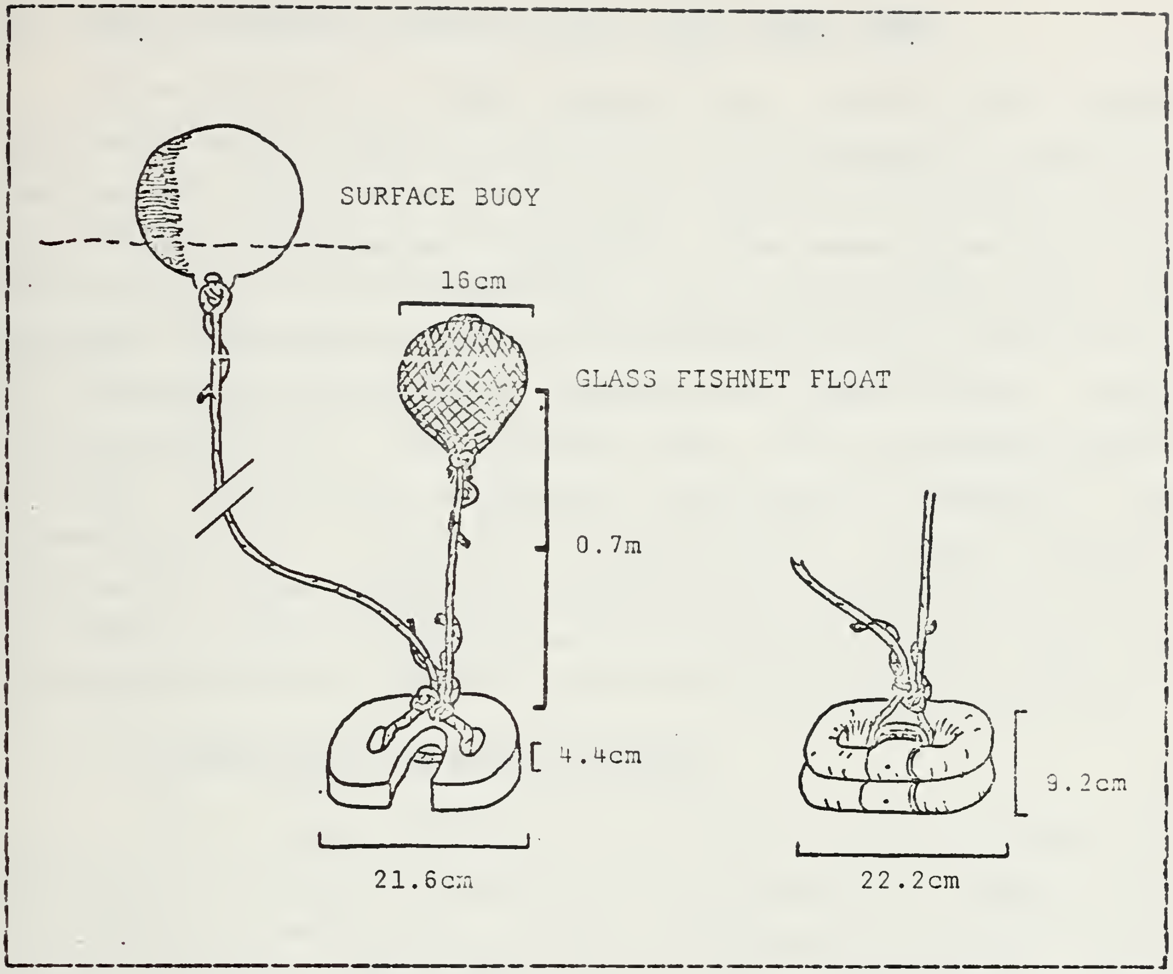

Figure 3.1 Target Configurations.

Five targets were constructed, three with 55-lb iron disks as anchors. The remaining targets had anchors made from two anchor chain links secured together, each weight totaling 58 lbs. The glass floats were attached by 3/8-in polypropylene line 0.7 m above the weights with a separate line extending from the weights to a surface float to allow easy target recovery (Figure 3.1). It was intended that these targets be "bottom mounted" so that the full backscattering effect of the bottom material during target detection could be observed.

B. SONAR EQUATION DEVELOPED FOR SIDE SCAN SONAR

To be assured of 100% coverage of a survey area during side scan sonar towing operations, some prediction must be made as to the range capabilities of the sonar system under the given environmental conditions. The sonar equation is a tool to aid in that prediction. By substituting into the equation the specific operating variables of the sonar unit, the bottom and sea-surface backscatter coefficients, water characteristics of the working area, and expected target strength (either an estimated value for a target to be investigated in an in situ situation or a target strength determined under laboratory conditions), a theoretical value of maximum operating range can be calculated which will aid in determining the minimum prescribed survey line spacing.

1. Developing the Sonar Equation

The sonar equation is based on the theory of detecting an acoustic signal in the presence of noise, which is ambient or self noise, and/or reverberation, which is the signal returned from scatterers in the environment. When the signal is received from the target, the echo level (EL) has to exceed the level of the detected noise level (DNL) by the detection threshold (DT), a quantity based on the system in use and the expertise of the operator. DT is the required signal-to-noise ratio to adequately distinguish the target for a specified probability of detection.

$$EL \geq DNL + DT \qquad (3.1)$$

Side scan sonar is an active system generating a series of pulses of acoustic energy with a specified source level (SL). The signal propagates to the target and is reflected back with a target strength (TS) that is dependent on frequency and on target composition, texture, size,

shape, and orientation. As the signal travels to and from the target there is transmission loss (TL) each way.

$$EL = SL - 2TL + TS \tag{3.2}$$

In most cases the DNL for an active system may either be dominated by the noise or the reverberation. Both cases must be examined to determine the limiting factor so that the appropriate form of the sonar equation may be used.

a. Noise-Limited

The sonar equation for the noise-limited case is:

$$EL = SL - 2TL + TS \geq NL - DI + DT$$

The equation can be written in terms of minimum target strength required for detection:

$$TS = NL - DI + DT - SL + 2TL \tag{3.3}$$

The terms are discussed below:

- NL is the ambient noise level dependent on ocean turbulence, shipping traffic, and sea state. At frequencies above 50 kHz at low sea states [Kinsler, 1982: p. 412], thermal noise of the molecules begins to predominate. For frequency (F) in kHz, the formula to calculate thermal noise for a perfectly efficient, nondirectional hydrophone is: [Urick, 1975: p. 187]

$$NL = -15 + 20 \log F \ \ \text{dB re } 1\mu\text{Pa} \tag{3.4}$$

- DI is the directivity index, a measure of the receiver's ability to distinguish between target returns and noise from other directions. The rectangular transducer of the side scan sonar contains two independent line arrays with an approximation of the directivity index being [Tucker, 1966]:

$$DI = 10 \log \frac{4\pi}{\theta_1 \theta_2} \quad (3.5)$$

where θ_1 = horizontal beamwidth (radians)

θ_2 = vertical beamwidth (radians)

- **DT** is the detection threshold.
- **SL** is the sonar's source level expressed in dB re 1μPa at 1 m.
- **2TL** is the two-way transmission loss. For spherical spreading with absorption the transmission loss is:

$$TL = 20 \log r + a(r-1) \quad (3.6)$$

where r = range in meters

a = absorption coefficient in dB/m

The absorption coefficient for seawater [Kinsler, 1982: p. 158] corrected for salinity other than 35ppt is:

$$a = \frac{Af_1 f^2}{f_1^2+f^2} + \frac{SBf_2 f^2}{35(f_2^2+f^2)} + Cf^2 \quad (3.7)$$

where $f_1 = 1.32\times10^3 (T+273)\exp[-1700/(T+273)]$

(the relaxation frequency (Hz) of boric acid)

$f_2 = 1.55\times10^7 (T+273)\exp[-3052/(T+273)]$

(the relaxation frequency (Hz) of $MgSO_4$)

$A = 8.95\times10^{-8}(1+2.3\times10^{-2}T-5.1\times10^{-4}T^2)$

$B = 4.88\times10^{-7}(1+1.3\times10^{-2}T)(1-0.9\times10^{-3}P)$

$C = 4.76\times10^{-13}(1-4.0\times10^{-2}T+5.9\times10^{-4}T^2)(1-3.8\times10^{-4}P)$

where P = pressure in atmospheres

f = frequency in hertz

S = salinity in parts per thousand

T = temperature in degrees Centigrade

f_1 and f_2 are empirical values for salinity of 35ppt and pH=8.0

- <u>TS</u> is the target strength, the dB measure of the ratio of the intensity of the signal reflected back toward the receiver 1 m from the target, to the intensity of the sound incident on the targets.

b. Reverberation-Limited

The sonar equation for the reverberation-limited case is:

$$SL - 2TL + TS \geq RL + DT$$

Written in terms of minimum target strength required for detection, the equation is:

$$TS = RL + DT - SL + 2TL \quad (3.8)$$

where RL, reverberation level, is given by the source level reduced by the two-way transmission loss to and from the target plus the target strength of the reverberating region, TS(R).

$$RL = SL - 2TL + TS(R) \quad (3.9)$$

where $TS(R) = s + 10 \log(\text{unit surface area})$

s = scattering strength for a unit area

Both the sea surface (S) and sea floor (B) are insonified since the side scan sonar projects a vertically-wide acoustic beam. The surface area insonified by the beam varies depending on the grazing angle (or slant range) and can be calculated (Figure 3.2).

$$\text{surface area} = \theta_1 h$$

where θ_1 is the horizontal beamwidth of the transducer and h is the distance insonified in the transverse direction.

$$h = R - \sqrt{[(SR) - ct/2]^2 - M^2}$$

where R is the true range: $R = \sqrt{(SR)^2 - M^2}$

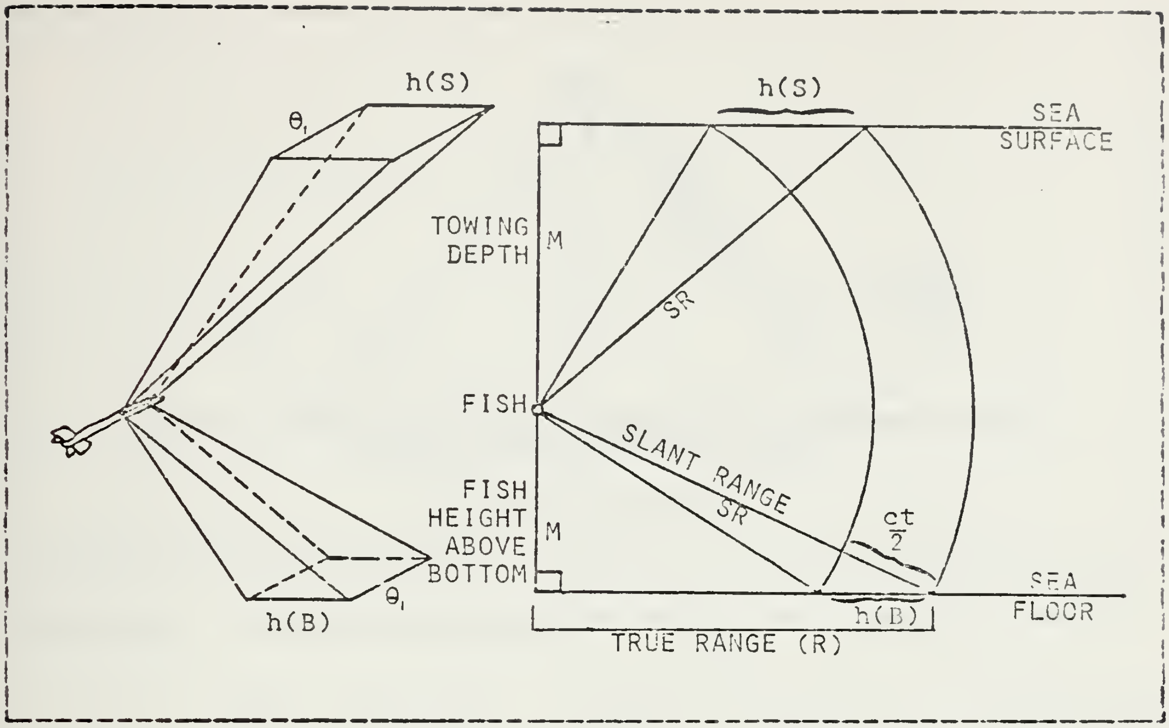

Figure 3.2 Insonified Area.

M = Towing Depth when determining sea-surface insonification area, or Fish Height Above Bottom when determining sea floor insonification area

t = pulse length (sec)

c = speed of sound through water (m/sec) using the nine-term equation presented by Mackenzie (1981) with temperature, salinity, and depth values suitable for the working area

$$c = 1448.96 + 4.591T - 5.304\times10^{-2}T^2 + 2.374\times10^{-4}T^3 + 1.340(S-35) + 1.630\times10^{-2}D + 1.675\times10^{-7}D^2 - 1.025\times10^{-2}T(S-35) - 7.139\times10^{-13}TD^3 \quad (3.10)$$

where T = temperature in °C

S = salinity in ppt

D = depth in meters

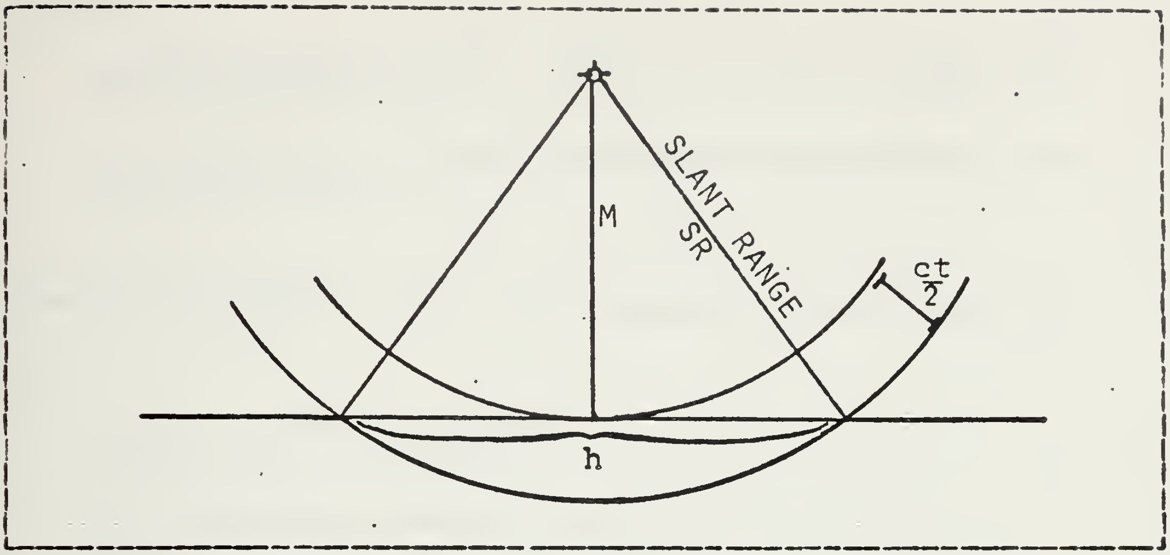

Figure 3.3 Insonified Area for Very Large Grazing Angles.

For very large grazing angles the insonified area is $\theta_1 h$, where the distance h in the transverse direction is (Figure 3.3):

$$h = 2\sqrt{SR^2 - M^2} = 2R$$

This situation occurs when the following is true:

$$M \geq (SR) - ct/2$$

The target strength of the reverberating region is:

$$TS(R) = s + 10 \log r + 10 \log \theta h$$

Since both the sea surface (S) and floor (B) are insonified, there is reverberation from these areas. Combining the two terms (in dBs) to obtain the reverberation level (RL):

$$RL = 10 \log \left\{ \text{antilog}\left[\frac{RL(S)}{10}\right] + \text{antilog}\left[\frac{RL(B)}{10}\right] \right\} \quad (3.11)$$

where:

$$\text{antilog } RL(S) = 10^{(SL(S) - 2TL + s(S) + 10\log r + 10\log\theta_1 h(S))}$$

$$\text{antilog } RL(B) = 10^{(SL(B) - 2TL + s(B) + 10\log r + 10\log\theta_1 h(B))}$$

Substituting into (3.11) and combining terms results in:

$$RL = 10\left\{\log 10^{-2TL/10}\, 10^{\log r} \left[10^{[SL(B) + s(B) + 10\log\theta_1 h(B)]/10} + 10^{[SL(S) + s(S) + 10\log\theta_1 h(S)]/10}\right]\right\}$$

Simplified:

$$RL = -2TL + 10 \log r + 10 \log\left[10^{[SL(B) + s(B) + 10\log\theta_1 h(B)]/10} + 10^{[SL(S) + s(S) + 10\log\theta_1 h(S)]/10}\right] \quad (3.12)$$

Substituting (3.12) into (3.8):

$$TS = 10 \log r + DT - SL(B) + 10 \log\left[10^{[SL(B) + s(B) + 10\log\theta_1 h(B)]/10} + 10^{[SL(S) + s(S) + 10\log\theta_1 h(S)]/10}\right]$$

Simplified:

$$TS = 10 \log r + DT + 10 \log \left[10^{[s(B) + 10 \log \theta_1 h(B)]/10} + 10^{[-SL(B) + SL(S) + s(S) + 10 \log \theta_1 h(S)]/10} \right] \qquad (3.13)$$

Bottom backscatter, s(B), is dependent on signal frequency, grazing angle, and bottom composition and relief. Studies have been made by McKinney and Anderson (1964) resulting in empirical values of bottom-backscatter coefficients between 2° and 60° grazing angles for 100-kHz systems that can be substituted into equation 3.13 (Figure 3.4). Garrison (1960) experimented to determine sea-surface backscatter coefficients at 60 kHz over a range of different atmospheric conditions. Wind speed correlated more closely with the surface reverberation than wave height. Also, large rain drops on a smooth water surface caused maximum scattering strength. Sea-surface backscatter is also dependent on grazing angle and frequency. Through empirical methods, Urick (1956) formulated a graph to approximate sea-surface reverberation at 60 kHz as a function of grazing angle and wind speed (Figure 3.5). The grazing angles can be calculated for specific ranges from the measured tow fish depth and the corresponding height above bottom along with the slant range to the insonified bottom and sea-surface area.

The source level (SL) varies with the angle off the acoustic axis θ according to the beam pattern inherent to the system. The beam pattern, B(θ), can be approximated by:

$$B(\theta) = 20 \log H \qquad (3.14)$$

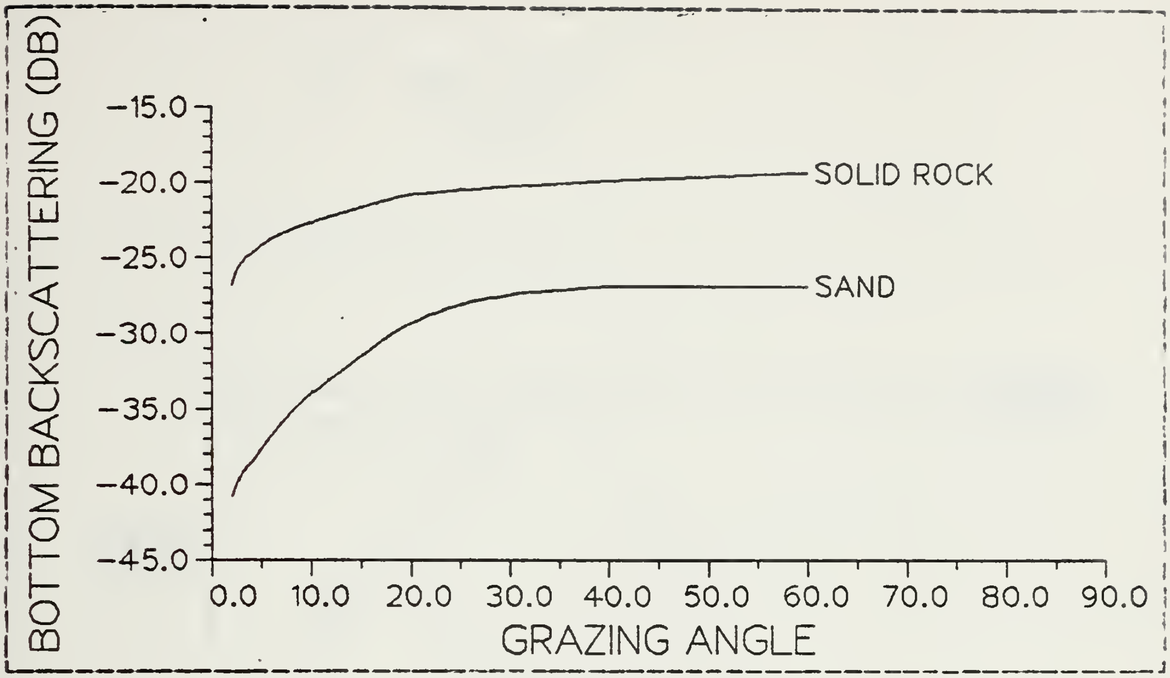

Figure 3.4 Bottom Reverberation at 100 kHz [McKinney, 1964].

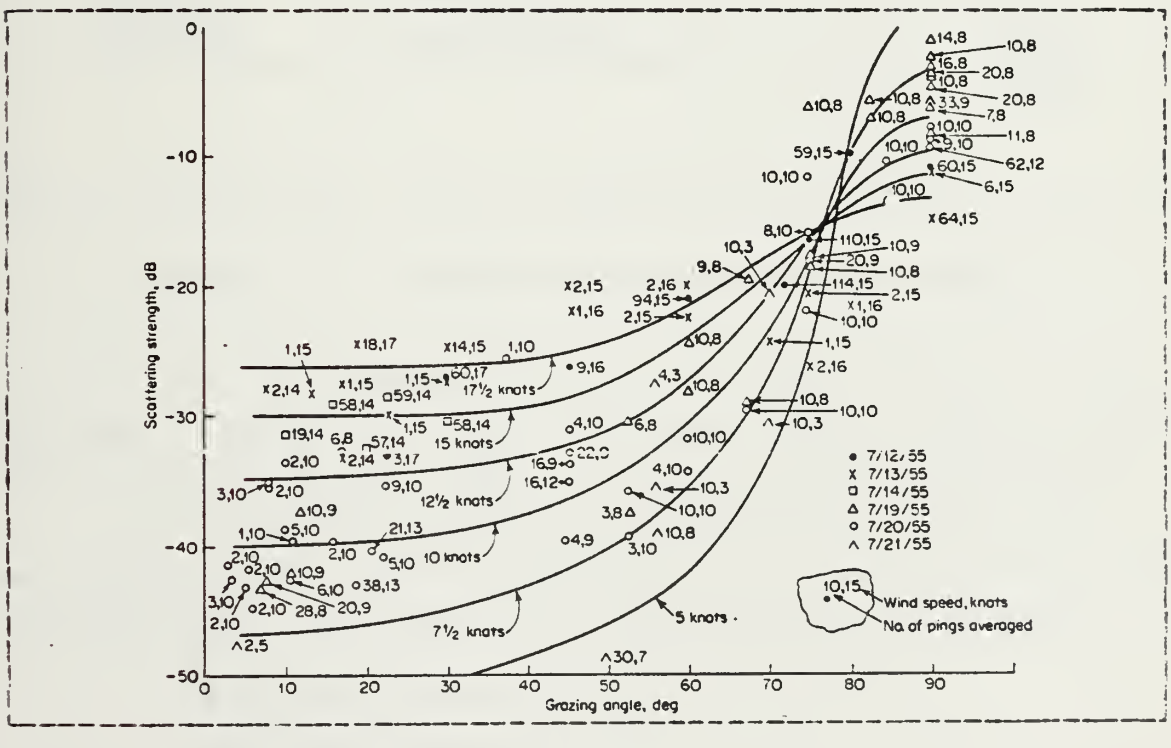

Figure 3.5 Sea-Surface Reverberation at 60 kHz [Urick,1956].

where H is the directional factor:

$$H = \frac{\sin(b \sin\theta)}{b \sin\theta}$$

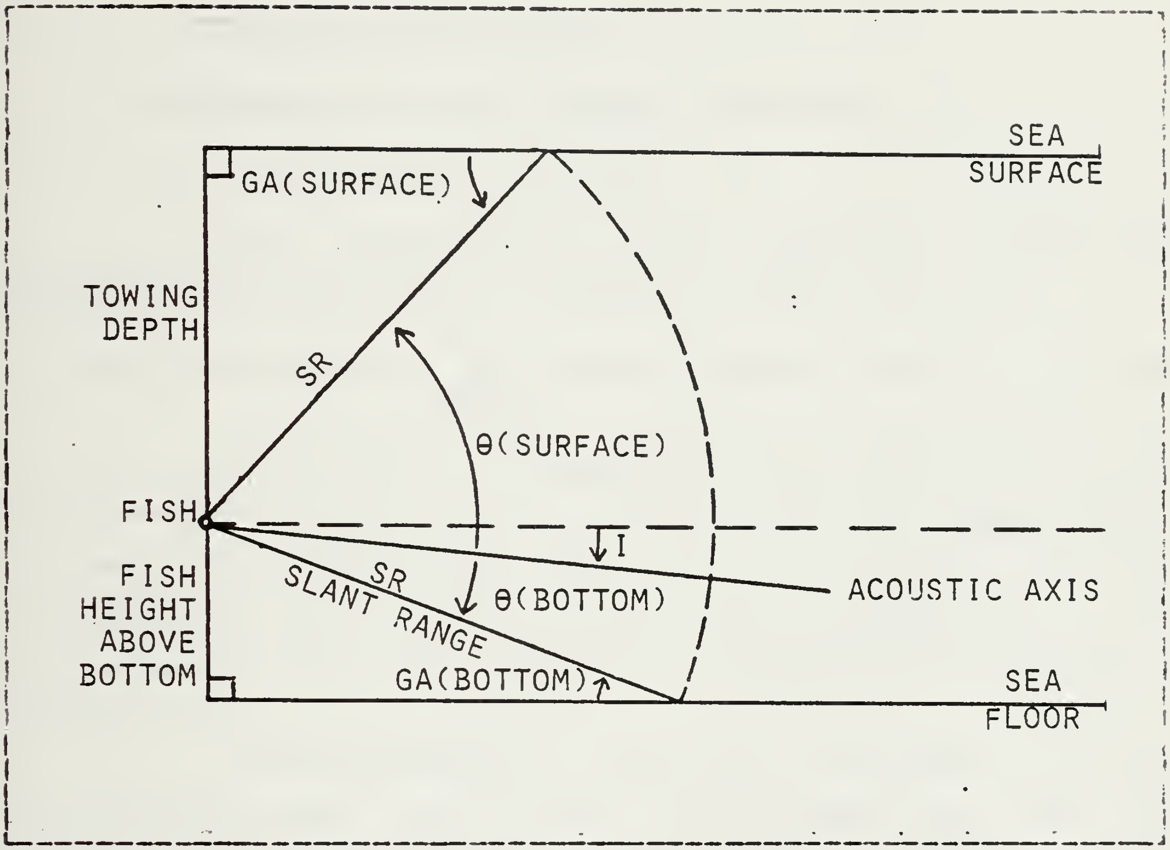

Figure 3.6 Calculation of the Source Level.

The constant b can be found from the beam pattern. Given the angle from the acoustic axis at which 20 log H = -3 dB ($H = 1/\sqrt{2}$), b can be computed iteratively.

The source level for the surface, SL(S), and the sea floor, SL(B), can be computed for a given angle off the acoustic axis. This angle can be calculated as follows:

$$\theta(\text{surface}) = GA(\text{surface}) + I$$

$$\theta(\text{bottom}) = GA(\text{bottom}) - I$$

where GA is the grazing angle and I is the angle of inclination below the horizontal of the side scan sonar system's beam pattern (Figure 3.6).

The source level can be computed as follows:

$$SL(S) = SL + B[\theta(surface)]$$

$$SL(B) = SL + B[\theta(bottom)]$$

2. <u>Defining the Sonar Equation Variables</u>

a. Noise-Limited Variables

The noise-limited sonar equation, found by substituting equations 3.4 through 3.6 into 3.3, is:

$$TS = -15 + 20\log F - 10\log \frac{4\pi}{\theta_1 \theta_2} + DT - SL + 2[20\log r + a(r-1)] \quad (3.15)$$

The operating frequencies (F) specified in the manufacturer's manuals for the Klein General Purpose Model 422 tow fish and the EG&G Model 272 tow fish used in this investigation are 100 kHz and 105 kHz respectively. The source levels for each system are identical at 228 dB re 1μPa at 1 m.

The beamwidths of the Klein are fixed at 1° in the horizontal (θ_1) and 40° in the vertical (θ_2) with the axis of the acoustic beam inclined 10° down from the horizontal. The EG&G system has adjustable vertical-beam depression angles of either 10° or 20° and vertical beamwidths of 20° or 50° with a fixed 1° horizontal beamwidth. In shallower water depths (less than 40 m) a vertical beamwidth of 20° with a depression angle of 10° is recommended in the manual and was used for this project.

The detection threshold (DT) cannot be easily specified as it is system- and operator-dependent. The more experienced an operator the higher the probability of detection, hence there would be a correspondingly lower DT than

there would be for an inexperienced operator. Flemming (1982) suggests using the following formula for side scan sonars:

$$DT = x + 10 \log B + 30 \qquad (3.16)$$

where x = required signal-to-noise ratio in dB

B = bandwidth in kHz

Flemming uses 15 dB as a typical side scan sonar value for x. The Klein and EG&G systems in the present study have bandwidths of 100 kHz and 10 kHz, respectively. Inserting these values into 3.16 results in a DT of 65 dB for the Klein and 55 dB for the EG&G. A value of 0 dB has also been suggested as an estimation for the EG&G system.[1] When noise-limited and reverberation-limited results were compared to determine which dominated, DT was immaterial since the shape of the curve generated from the sonar equation doesn't vary with changes in DT. (See Figures 3.8 through 3.13)

The absorption coefficient (a) from equation 3.7 is dependent on the frequency, water temperature, pressure, and salinity. The appropriate values pertinent to the water column at the test sites were determined and used in this calculation. (See Chapter 5, Section A, and Figure 5.1)

The side scan sonar systems were actually operated in a depth of 31 m with the fish being towed from 7 to 30 m above the sea floor (Appendix C), corresponding to tow depths of 1 to 24 m. These measures translate into gauge pressures of 0.1 to 2.4 atmospheres.

Errors in temperature and salinity values of 2°C and 2ppt respectively result in a maximum change of ±0.007 dB/m in the absorption coefficient. The difference

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[1]Reference a telephone conversation with Mr. Peter J. Clifford of EG&G, 8/29/83.

in transmission loss due to the error in the absorption coefficient is ±4 dB at the maximun range tested, 300 m.

b. Reverberation-Limited Variables

The reverberation-limited sonar equation 3.13 is:

$$TS = 10 \log r + DT + 10 \log\left[10^{[s(B) + 10\log\theta_h(B)]/10} + 10^{[-SL(B) + SL(S) + s(S) + 10\log\theta_h(S)]/10}\right]$$

The manuals for both systems tested state that the pulse length (t) is 0.1 milliseconds. The horizontal beamwidth, detection threshold, and surface and bottom back-scatter coefficients used in this equation have been discussed previously.

The sound speed (c) was determined from equation 3.10 using the values of temperature, salinity, and depth discussed under the noise-limited case. An error in temperature and salinity of 2°C and 2ppt, respectively, results in a negligible error of ±0.01dB in target strength.

The beam pattern can be approximated for each system using equation 3.14 (Figure 3.7).

	EG&G	Klein
Vertical Beamwidth:	20°	40°
3-dB Down Points: (Half Power)	$\frac{1}{\sqrt{2}} = \frac{\sin(b \sin 10^\circ)}{b \sin 10^\circ}$	$\frac{1}{\sqrt{2}} = \frac{\sin(b \sin 20^\circ)}{b \sin 20^\circ}$
Solving for b:	b = 8.01366	b = 4.068642

The beam pattern for the EG&G system is:

$$B(\theta) = 20\log \frac{\sin(8.01366\ \sin\theta)}{8.01366\ \sin\theta}$$

The beam pattern for the Klein system is:

$$B(\theta) = 20\log \frac{\sin(4.068642\ \sin\theta)}{4.068642\ \sin\theta}$$

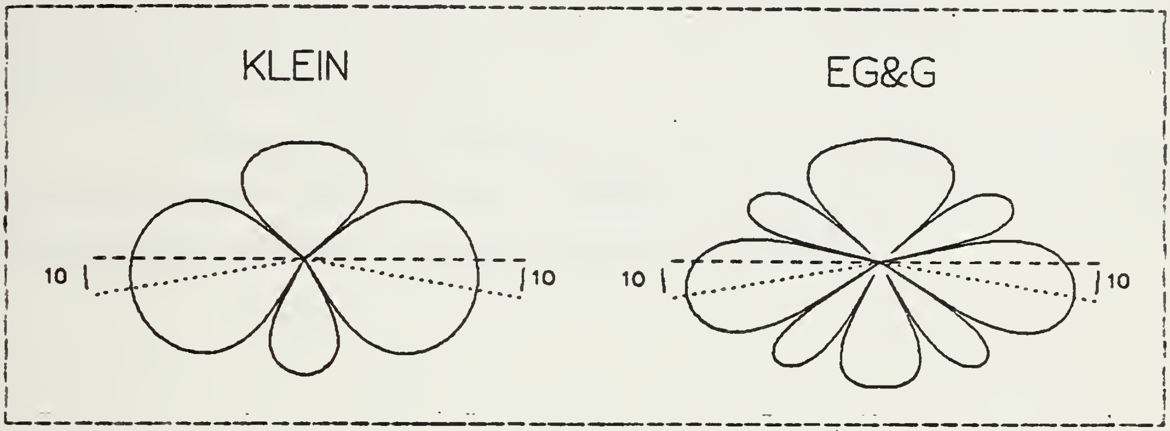

Figure 3.7 Calculated Beam Patterns.

With the estimated beam pattern calculated, the source level (SL) can be computed depending on the angle off the acoustic beam.

3. Results

The results from the noise-limited sonar equation 3.15, plotting minimum target strength required for detection versus slant ranges from 0 m to 300 m using representative towing heights, are shown in Figures 3.8 and 3.9. The target strengths required when noise dominates vary from -192 dB to -98 dB.

The results of the reverberation-limited cases are shown in Figures 3.10 through 3.13. Two bottom types were used, solid rock and sand. Target strengths were calculated

for bottom grazing angles between 2° and 60° since bottom-backscatter coefficients are available only for those angles. Sea-surface backscatter coefficients were taken from Urick's data using 5 knots for wind speed. The target strengths required, when reverberation dominates, range from -44 dB to greater than 13 dB at the peaks.

The tow heights used in the calculations were obtained by averaging the tow heights employed for each range scale during field operations (Appendix C). The Klein fish was towed at heights of 10, 15, and 20 m while the EG&G was towed at 16 and 28 m.

A comparison between the noise-limited case and the reverberation-limited case clearly shows that the two side scan sonar systems are reverberation-limited.

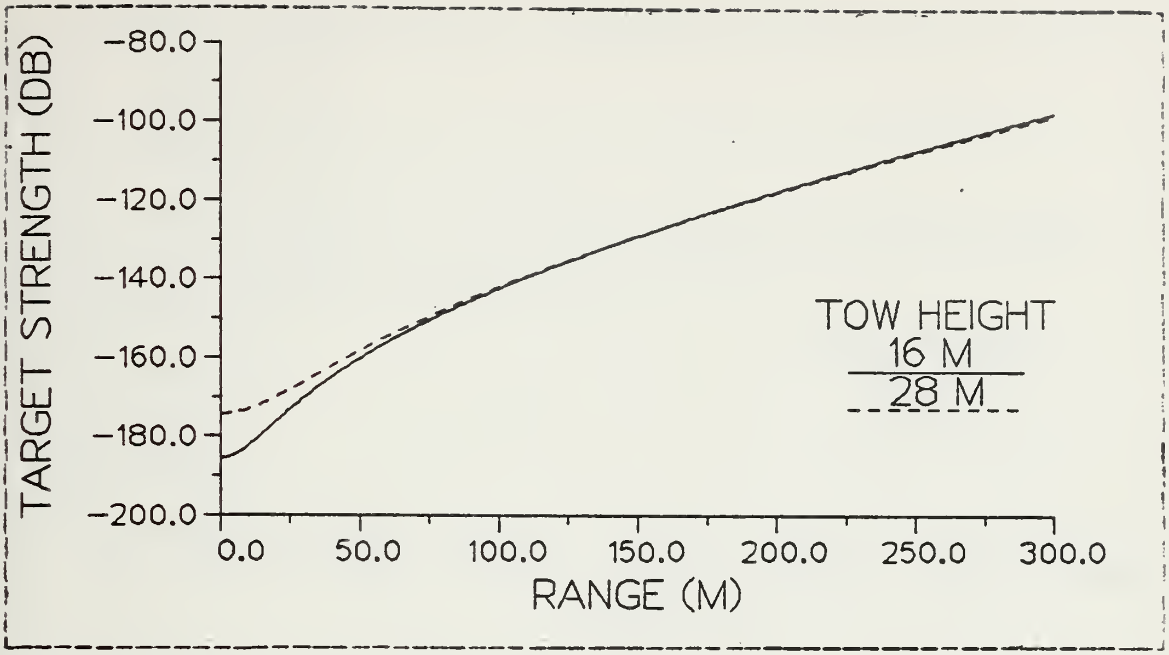

Figure 3.8 EG&G Noise-Limited Case.

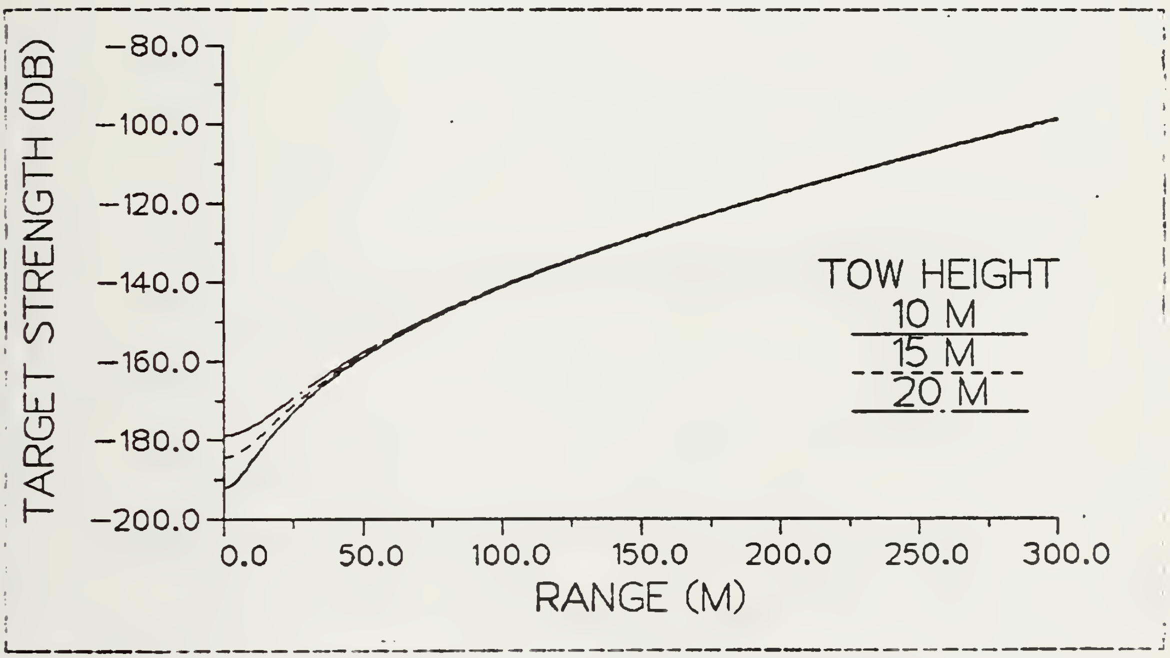

Figure 3.9 Klein Noise-Limited Case.

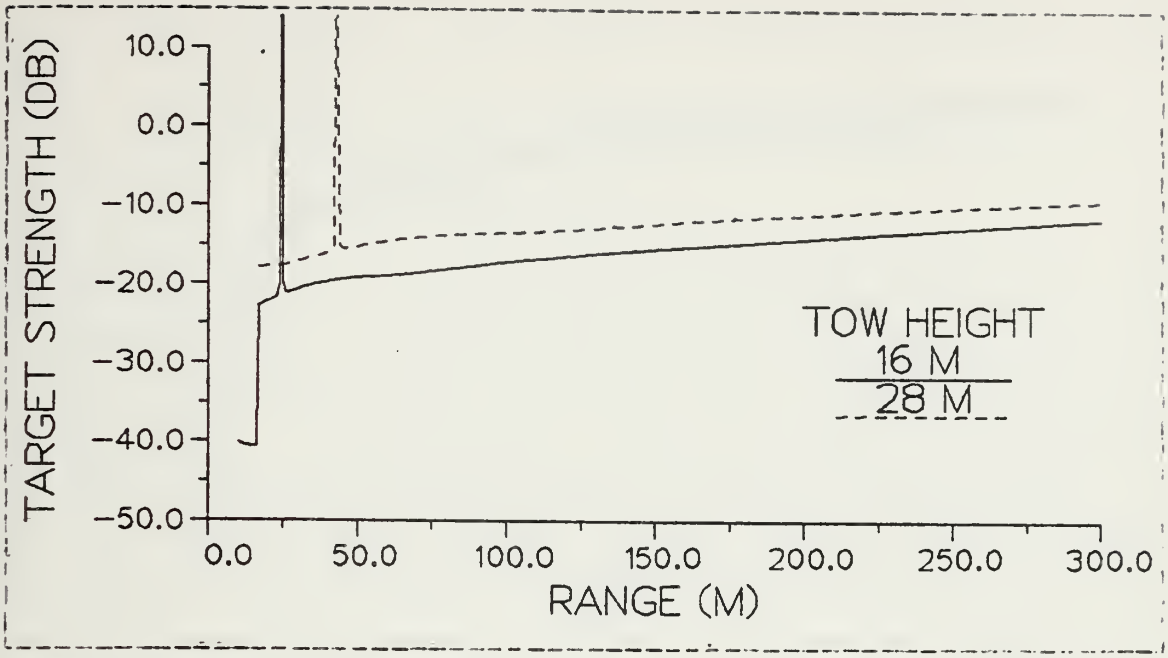

Figure 3.10 EG&G Reverberation-Limited Case Over Sand.

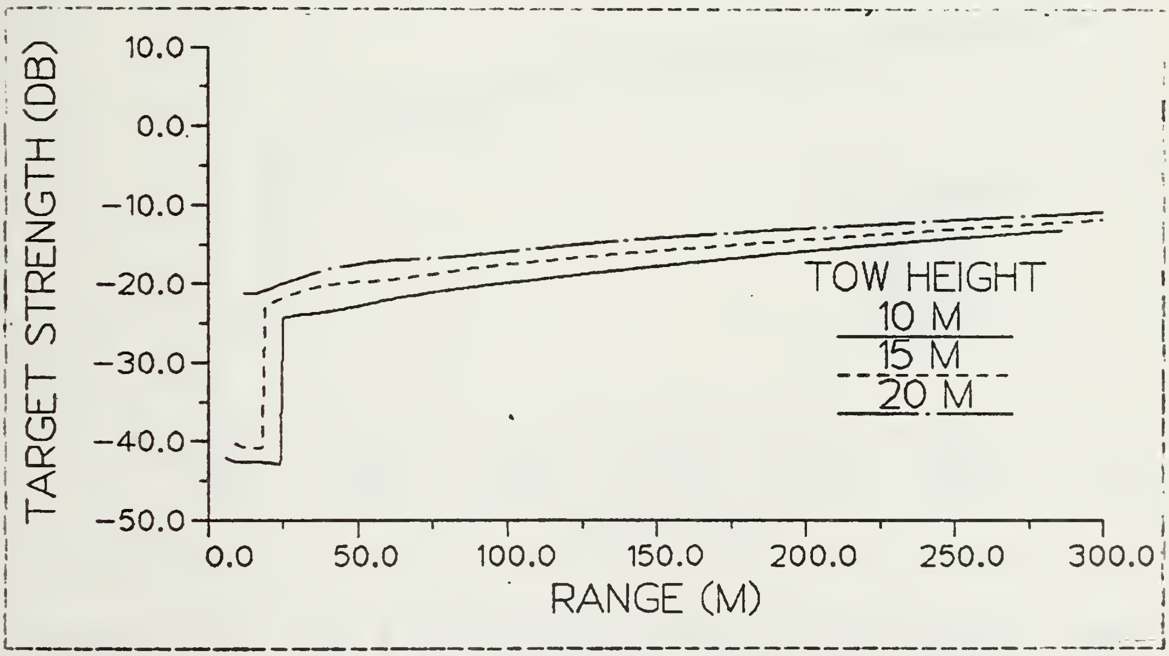

Figure 3.11 Klein Reverberation-Limited Case Over Sand.

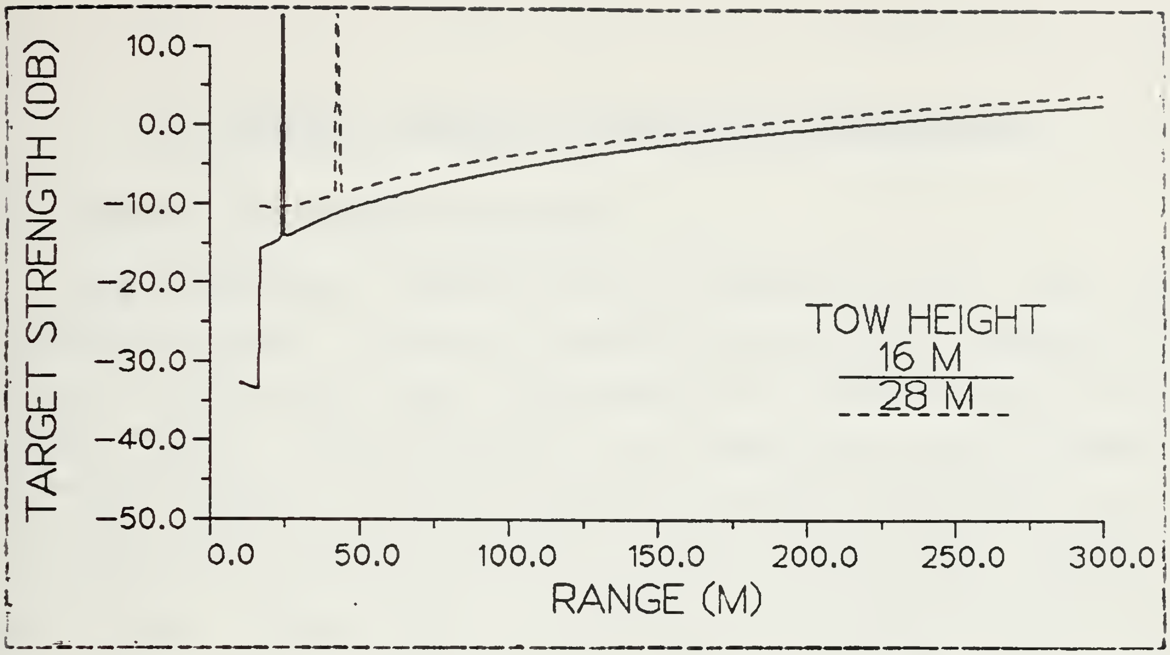

Figure 3.12 EG&G Solid-Rock Reverberation-Limited Case.

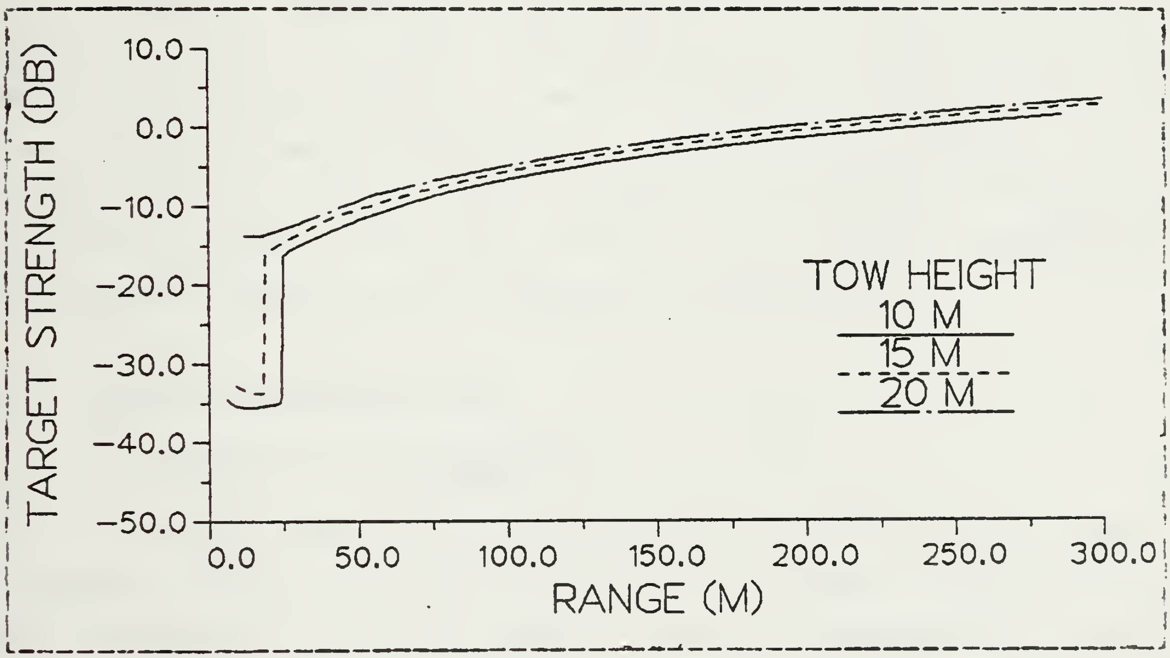

Figure 3.13 Klein Solid-Rock Reverberation-Limited Case.

IV. PROJECT DESIGN AND FIELD WORK PROCEDURES

A. PROJECT OBJECTIVES RESTATED

The underlying theme of this research was to test the practical target detection capabilities in the presence of bottom backscatter with representative 100-kHz side scan sonar systems. Specifically, an attempt was made to determine the maximum range of detection given a specific target strength and shape for differing types of material composition of the ocean floor. To derive the desired detection and range information, an artificial target array was deployed in test areas of differing bottom types. Pragmatism was lent to the experiment through the guidance of an expert thoroughly experienced in the use and maintenance of side scan sonar equipment and the manual operation of the analog recorder, as well as visual interpretation of the recorded images (Appendix B). This investigation emphasized the real-time, human element for judgment of target detection rather than the use of the optional mechanical peripherals mentioned in Chapter II, Section C.

B. PROJECT CONSIDERATIONS

1. Test Site Requirements

It was hoped that three bottom types could be investigated: rock, sand, and mud. Since Monterey Bay, California was the area used in the investigation (Figure 4.1), information from the nautical chart of the Bay and prior hydrographic surveys indicated that a sandy bottom could be found and quite possibly a favorable rocky bottom. Mud was not as generally evident, but some indications were found in a few isolated areas.

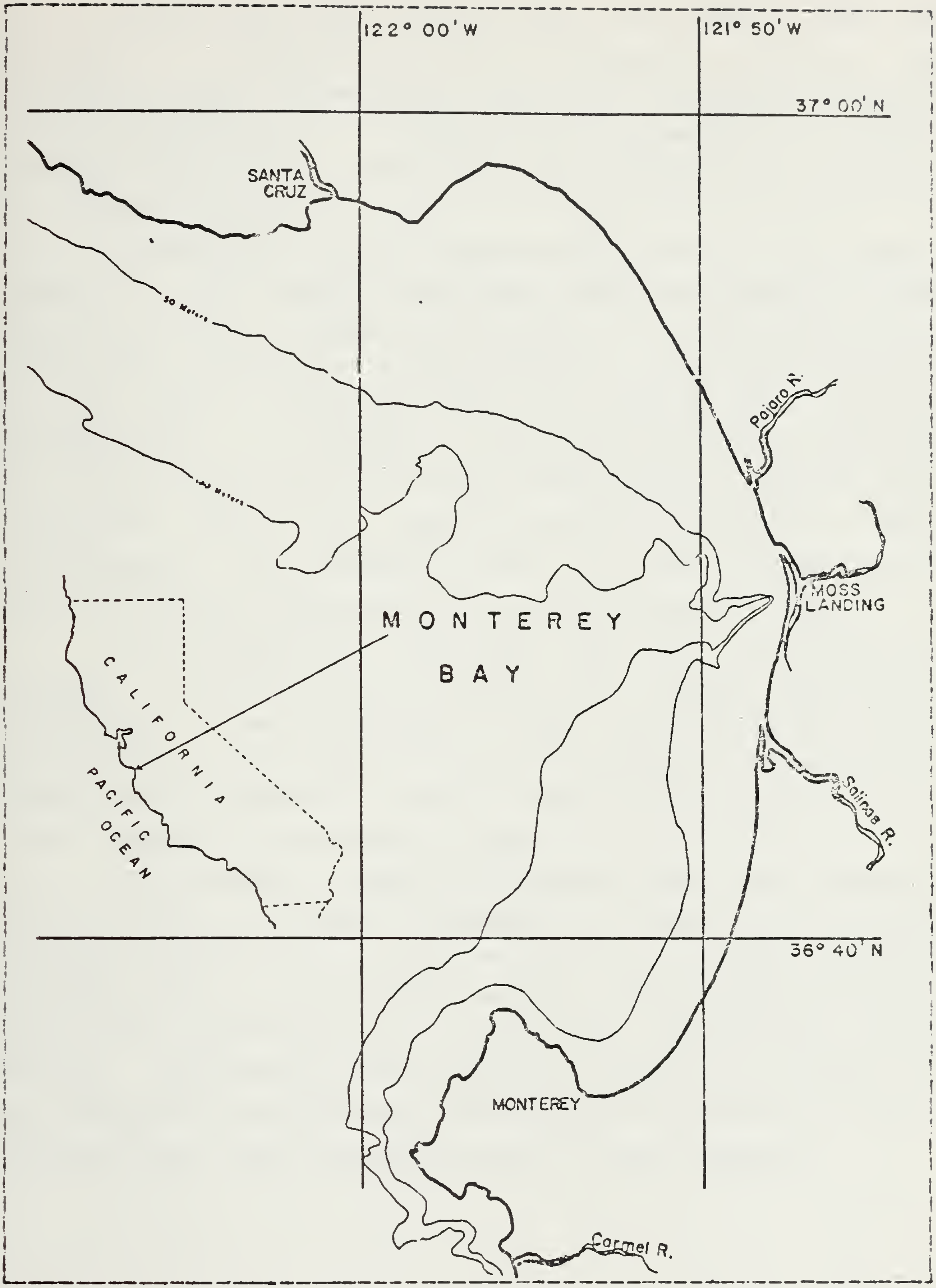

Figure 4.1 Monterey Bay.

The test sites were to be as nearly level as possible. A steeply sloping or irregular bottom at the location of the target array would have provided inconsistent backscattering. A slight bottom slope could be tolerated as long as the targets were all located approximately at the same depth.

Another test site consideration was to find working areas that were somewhat sheltered from the effects of wave action. It was hoped that throughout the duration of the field work, geophysical factors would be relatively constant so that all of the data would be acquired under similar circumstances. By working in relatively sheltered portions of the Bay with close proximity between test sites, this objective could be at least partially fulfilled. This consideration also ensured that the water column would exhibit similar properties at the various test sites.

The prospective test sites were also evaluated for logistic compatibility to vessel and target positioning techniques. These techniques could have employed either line-of-sight electronic navigation systems with suitable, shore station setups or visual range markers erected on the beach adjacent to the working area.

The southern portion of Monterey Bay near Monterey Harbor offered obvious advantages as to meeting the above criteria (Figure 4.2). Sand was known to be there in great abundance and, to a limited extent, rock in the form of shale was indicated on the charts and hydrographic survey sheets. Information obtained from long-time residents of the Monterey area supported the existence of shale to a much greater extent than was indicated on these documents.

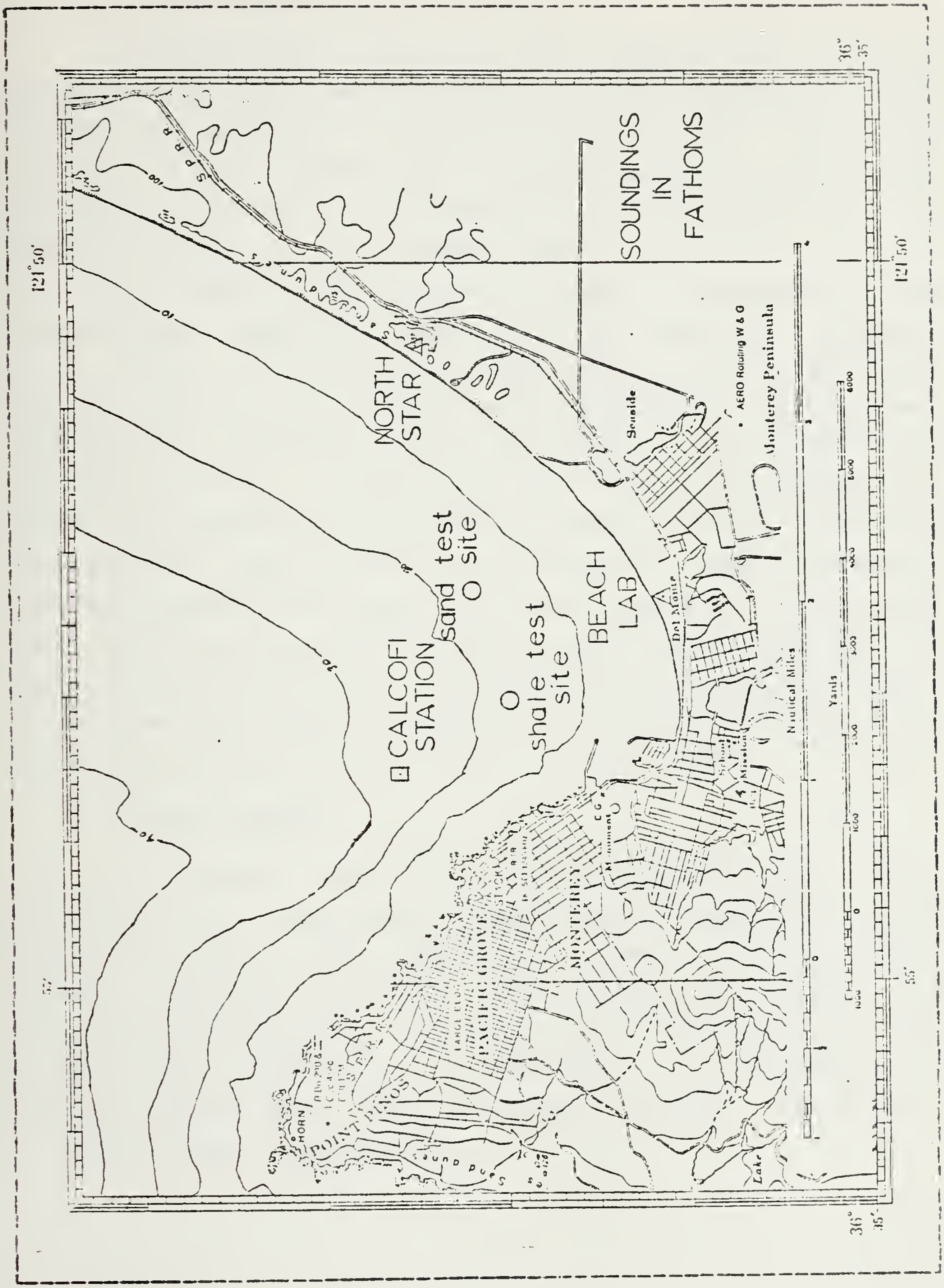

Figure 4.2   Southern Monterey Bay.

2. Target Array

Since it was desired that all targets be at the same depth, the targets were deployed along an appropriate depth contour to essentially simulate a flat bottom. The depth contours at the proposed test site run generally parallel to the shore, therefore the targets would be deployed in a line roughly parallel to the adjacent beach.

A linear array of five targets was chosen. The targets were spaced at 10-m intervals covering a span of 40 m. Thus, with each successive pass by the targets with the tow fish on a course perpendicular to this linear configuration, detection range information was provided over this span of 40 m. If only one target had been deployed, at least five passes would have been needed to acquire the same information. This 40-m span of possible target detection coverage reduced the time and runs required on each range scale used to attain statistically significant results. The range scales that were to be used included a minimum of 75 m up to a maximum range of detection, or ultimately the 300-m scale limit imposed by the test site water depth.

3. Towing Vessel

A locally owned and operated recreational scuba diving boat was chartered for the towing operations. The 36-ft, twin-screw SILVER PRINCE was chosen for its maneuverability, favorable deck plan for installing navigation and sonar-system equipment, and available work space for easy launching and recovery of the tow fish. It satisfied the desired towing-launch specifications typically encountered in shallow water applications.

4. Positioning Technique

Since an automated vessel positioning system was not available for this project, careful planning and consideration was called for in the selection of the proper positioning method to employ, particularly in reliable positioning of the tow fish a fixed distance from the targets during passes by the array. If such a system with the capability of providing a continuous automatic plot of the vessel's track line had been available, the choice between electronic or visual positioning methods would have been obvious. The consideration of using temporary visual range markers appropriately mounted on shore as a positioning system was discarded due to its lower degree of positioning accuracy and overall less efficient and practical characteristics.

Vessel and target positioning during the course of this investigation was carried out through the use of a Motorola Mini-Ranger III, a microwave ranging system. Existing, documented geodetic control stations in the general vicinity of the anticipated test area were evaluated as control points for remote shore station setups. Security from vandals and available shore power for the remote stations were important factors in the evaluation.

Station BEACH LAB, located ashore of an area exhibiting indications of a sandy bottom, was selected because of its security and availablility of shore power. This station had been established using Third Order geodetic surveying standards for a hydrographic survey of southern Monterey Bay in the fall of 1982.

None of the other existing control stations would provide the desired positioning geometry for the proposed test site. It was necessary that this station be displaced a sufficient distance from the work area for one important

reason: positioning of the tow vessel, and more importantly the tow fish, at fixed ranges from the targets would be accomplished by steering the vessel perpendicularly to the linear array along the desired range arc from this station. This station's displacement, in excess of 1 mile from the working area, meant that the radius of curvature of the range arcs would be sufficiently large so that, for all practical purposes, the range arcs in the immediate vicinity of the target array could be considered straight lines. This factor would enable the tow vessel to approach the array for a short distance along a designated range arc, with the assurance of the tow fish being at the approximate desired distance from the known target positions at the moment of their insonification.

With this in mind, a suitable point was chosen high on a sand dune overlooking the proposed test site, approximately collinear with the site's 30-m depth contour along which the targets were to be deployed. Subsequently, the position was geodetically established to Third Order standards, and the geographic coordinates computed. The station was designated as NORTH STAR.

5. Water Temperature and Salinity Considerations

It was assumed that water temperature and salinity information could be reliably obtained from surface values. Considering the relatively shallow working depth and the particular time of year of this test, it was felt that the water column would be essentially well mixed. Consequently, the water temperatures were recorded from bucket samples in the field, and water samples were collected for subsequent laboratory salinity determinations.

C. FIELD PROCEDURES

Field research using the two side scan sonar systems involved a total of 12 working days, 10 of which involved actual data acquisition. This field work was conducted intermittently, as weather and scheduling would allow, throughout the period of April 13 to May 2, 1983.

1. Selection and Delineation of Sand Bottom Test Site

The first two days of field work involved equipment installation aboard the SILVER PRINCE, familiarization with the EG&G system operation, and deployment of targets at the test site. The additional benefit of input from the sonar technician, who had not yet arrived, was not available at this time. This period allowed the opportunity to perform a field test of the electronic navigation system and to confirm the favorable geometry of projected range arcs in the general vicinity of the proposed sand bottom test site.

The fortuitous location of station BEACH LAB relative to the intended working area provided a quick and easy means to determine vessel towing speeds. The vessel was maneuvered toward the station on both engines at low idle speed with the tow fish deployed. This course coincided with the general direction of the local prevailing wind and seas. The ranges from BEACH LAB were recorded at the start and end of a fixed period of time, in this case one minute, and the vessel's approximate true speed was then computed. This procedure was also followed running out from the station, or into the seas, and subsequently repeated for both directions with only one engine to reveal the vessel's towing speed and maneuvering capabilities. A determination of minimum towing speed was necessary so that the maximum number of acoustic "pings" off the targets would be obtained to aid in their detection.

Following this task, a small, but thorough hydrographic survey was conducted in the proposed test site to establish the general location of the 30-m depth contour and to delineate a 40-m portion approximately collinear with station NORTH STAR that deviated little from a consistent depth of 30 m. This process was accomplished through a series of systematic sounding lines indicating the desired location and recording the appropriate ranges at the near and far test site boundaries from NORTH STAR. The depths along this selected site varied less than 1 m.

Bottom samples were then attempted with a 2-in diameter, spring-loaded clamshell bottom sampler. Numerous efforts were made to obtain a sample with only slight traces of fine-grain sand being collected in two casts. The remaining casts failed to collect any bottom material. This failure was attributed, at the time, more to a malfunctioning bottom sampler than to the likelihood of the existence of a hard bottom. With the indication and presumption of a sand bottom, the targets were deployed with surface buoys for recovery. A 10-m spacing between targets in the linear array was attempted by appropriately maneuvering the vessel according to the predetermined ranges received from NORTH STAR and BEACH LAB, along with simultaneous observations of the recorded fathometer depth. The method proved to be satisfactory for yielding the approximate desired deployment objectives.

With the arrival of the sonar technician whose degree of operator experience was essential to this experiment, it was revealed through observation and interpretation of the side scan sonogram from just the first pass over this test site, that the bottom material was not sand as suspected, but a very hard material, probably shale. This deduction was indicated by an extremely strong return which created a very dark presentation that actually caused the

recording paper to burn through in portions. It was theorized that the returns from the targets were obscured in the overwhelming backscatter from this bottom material. Subsequent passes were made that supported this theory. Continued scanning in areas adjacent to the site revealed a much lighter, consistent display that indicated a sand bottom, along with the appearance of sand waves in some areas. It was then decided to relocate the targets to one of these areas to perform the target detection tests over the desired sand bottom, and to ascertain if the targets presented a sufficiently strong and identifiable return to be detected at all by this system. In essence it had been concluded that a sand bottom would be more favorable to reveal this information initially than would be the shale bottom with its higher degree of backscatter.

A hydrographic survey was conducted in a similar fashion as at the first site to pinpoint the location for target deployment. The soundings in this area, roughly half a mile north of the original site, showed the desired degree of consistent depths again approximately collinear with NORTH STAR.

A much heavier 18-in wide clamshell bottom sampler was employed in this proposed test site with large samples of coarse-grain sand collected. The targets were then relocated and positioned accordingly (Figure 4.2). Verification of a consistent sand bottom with no outstanding depth irregularities over the length of the target array was accomplished by diver inspection.

2. Data Acquisition Routine

With the test site selected and the targets deployed, actual data acquisition began. The first exercise of each work day was calibration of the electronic positioning system. A site that coincided with the intersection

of a pair of visual shore ranges was chosen just outside of the SILVER PRINCE's berth in Monterey Harbor. Appropriate landmarks with known geographic coordinates were selected to comprise these ranges. By maneuvering the vessel at the precise location where the pair of shore ranges lined up visually with the master antenna, the range measures aboard the vessel were repeatedly observed and compared to the appropriate range arcs of a previously determined position computed via geodetic inverse and intersection methods. In this manner, proper functioning of the electronic navigation system to produce accurate and consistent results was verified twice daily at the start and end of side scan sonar data acquisition.

The vessel then transited the short distance to the test site, where surface water samples were collected and the water temperature was recorded using a Hewlett-Packard Digital Quartz Thermometer. This routine exercise was also performed twice daily to note the average change of these values throughout the data acquisition period.

The last preliminary duty was to record weather observations and run a vessel speed check with the tow fish deployed. The method of running toward and away from station BEACH LAB was employed as previously mentioned. In addition, subsequent "on-line" speed checks were performed during actual controlled passes by the target array by recording the ranges from both stations over the period of one minute. The vessel's estimated curved path of travel was then plotted and the distance measured to compute the approximate true speed under these slightly different wind and sea conditions. It was consistently determined that the vessel's average towing speed was between 2.4 and 3.0 knots.

On the first day of operation at this test site, controlled passes were run with the Klein fish towed perpendicular to the array at varying distances from the closest

target. Indeed, on the first pass all five targets were detected on the 75-m range scale. Target detection was verified on subsequent runs, and the resulting target array configuration was revealed. Due to placement of the targets at intervals close to, but differing from a straight line as intended, an identifiable target pattern was formed that served to aid in their identification (Appendix D, Figure D-1).

With the assurance that the targets could be detected and identified, all that remained was to make repeated passes with the tow fish positioned at the desired distances from the targets. The objective was to determine the maximum range of detection over this sand bottom by placing them at the extreme detection limit of each range scale. The number of targets detected and their minimum and maximum ranges along with the fish height were recorded in the field for each run and were checked and verified again in the post-processing phase ashore. A minimum of 10 passes, and often more, were run on each range scale used. In this way, a reasonably accurate probability of detection and confidence level could be computed. The more passes that could be made in a reasonable allotment of time, the more the confidence interval could be narrowed from the resulting increased sample size.

It was found that if the wind and sea conditions were approximately similar running both inshore and offshore so that a relatively steady vessel tow speed could be maintained, many passes could be made in a minimum amount of time. The method consisted of maneuvering the vessel around the array in a circular fashion, making a test run while heading inshore on the appropriate range arc, turning the vessel about and conducting another pass running offshore on the opposite end of the target array. Careful attention was paid on the turns to ensure that the vessel was on a set

course long enough following these turns and just prior to steering the designated range arc, to allow the tow fish to return to the vicinity of the vessel's track line. This routine provided reasonable assurance that the tow fish was the prescribed distance from the targets to insonify them, in most cases, at the edge of the range scale in use.

At the conclusion of data acquisition (112 controlled passes) to obtain the maximum range of target detection for the sand bottom area, some question remained as to what actually contributed to the returns identified as the artificial targets. It was questionable whether the glass spheres were solely responsible for the intensity of the returns, or whether they were a product of contributions from both the spheres and their respective anchor weights. To resolve this dilemma, it was decided to recover two of the targets, remove the spheres, and return the weights to their former positions to observe whether or not they presented the same earlier-identifiable returns on the sonogram. Accordingly, Runs 117-126 were made on the 75- and 100-m range scales, having the higher system pulse repetition rates (Appendix C). It was shown in some of these runs that a return was still received from all five targets. The ones without the spheres presented roughly half as strong a return as those with the spheres still intact (Figures D-2 and D-3). The remainder of the runs generally showed just three targets. Runs were also made along a track line parallel to the target array which yielded similar results (Figure D-4). Thus, it was concluded in the field that the target returns were most likely a product of the contributions of acoustic reflections from both the glass spheres and their anchors. It was decided that further laboratory tests were needed to determine the effect of the weights, and possibly the synthetic mooring line, on the target strength.

The original research concept was to use the Klein system initially for the tests over the sand and rock bottoms, and if time and other considerations allowed, the EG&G system would then be used. Therefore, all of the targets were recovered and a search was conducted with the Klein system for a suitable rocky-bottom test site. It was concluded that the apparently-flat shale bottom area originally encountered would offer the best chances for target detection. The sonogram presentation had a relatively-consistent dark display, in contrast to a jagged, inconsistent display from large rocks found in other areas (Figures D-5 and D-6). Consequently, a hydrographic survey was run at this test site as was done previously to locate the suitable target deployment region.

Bottom samples were again attempted with the large bottom sampler, producing a piece of a certain type of shale. It was later classified as Miocene shale, or chert, of the Monterey Formation.

The targets were then deployed as before and controlled passes conducted, again on runs both perpendicular and parallel to the array using the 75- and 100-m range scales. This test significantly resulted in no apparent target detection.

Subsequently, the EG&G system was employed in this area with similar results, but with the exception of possible indications of target detection, although target returns were not sufficiently strong for conclusive verification (Figure D-7). It was observed that the relatively-flat, rock bottom produced many returns similar in appearance to the presentation of the targets themselves as they appeared on the sand bottom, namely small, dark dots. Most significantly, it was found that distinguishing the targets from this overall display proved impossible under the given backscatter conditions of a flat, rocky bottom.

The targets were once again recovered and deployed in the previously-used sand bottom test site. Runs 166-202 were conducted in this area using the EG&G system, producing favorable results (Figure D-8). Perpendicular and parallel runs to the target array with two of the glass spheres removed were also made at the conclusion of the maximum detection range data acquisition period to observe the target return contribution effects using this system (Figures D-9 and D-10).

With the investigation completed in sand and shale areas after 203 controlled passes, the targets were recovered and a search was made for mud that was thought to exist in certain areas. The closest area showing this indication on the chart and survey sheets was just off the shore of Moss Landing at the origin of the great Monterey Canyon, 14 miles north of Monterey Harbor in the central portion of Monterey Bay (Figure 4.1).

A hydrographic survey was run to locate a suitable test site, employing only station NORTH STAR for relative positioning control. Reception of station BEACH LAB was interrupted with the loss of line of sight to the station from this location.

A mud bottom sample was finally obtained with the 18-in clamshell device after several attempts along the periphery of the steep walls of the canyon. This location was suitably flat, in approximately 30 m of water. The sample consisted of fine, silty mud overlaying a trace of fine-grain sand. The targets were again deployed at 30-m depths with approximately 10-m spacing as determined from NORTH STAR ranges.

A total of 14 passes were made perpendicular and parallel to the array. It was significantly observed that the target returns were generally only half as strong as those recorded over the sand bottom and did not present

readily-identifiable returns in all cases (Figures D-11 and D-12). Two targets were recovered and deployed again with the glass spheres removed to note the resulting effect. Usually only the targets with the glass spheres remaining exhibited a signal return indication, with the faint indication of a fourth target being noted in some cases. It was concluded that the anchor weights sank so deeply into the mud that they no longer provided a significant acoustic reflection. In addition, the noticeably more extreme sea conditions encountered in this exposed portion of the Bay appeared to have a possible negative effect on the detection capability of the tow fish due to imparted vessel action on its in-flight attitude and the more apparent surface backscattering effects noted on the sonogram. This apparently altered or lowered target strength forced the conclusion that a fair and similar test of the system's maximum range of target detection could not be conducted in this area. The field work portion of the research was therefore concluded.

D. OBSERVED NOISE INTERFERENCE

At the start of the operations utilizing the Klein system, there appeared to be an ever-present, easily-distinguishable noise pattern in the sonogram. Several attempts were made to secure a good ground for the system at numerous contact points thoughout the vessel and overboard in the water as well. None of these measures corrected this pattern of fine, zigzag lines throughout the display, which were most prominent at the extreme limits of the range scale in use, the chief area of interest for this research (Figure D-13).

Finally, after Run 65, it was discovered that vibrations from the vessel's engine through the engine cover deck boards on which the cable had been coiled during towing operations, were being imparted into the tow cable, which in turn were displayed on the sonogram. This problem was partially solved by subsequently coiling the cable on cushioning laid out on deck to buffer the vibration transmission. The EG&G system, however, never appeared to be affected by this interference.

V. RESULTS

A. POST-PROCESSING

1. Data Processing

The side scan sonar field data consisted of numerous rolls of labeled recording paper. The first step in the processing phase was to find the portions of the continuous record corresponding to target passes and cut the sonogram into a collection of individual test runs. Careful labeling of the sonogram during the run sufficiently aided in this task; on every pass the sonogram was marked with the precalculated ranges from station BEACH LAB whenever possible to note the start and conclusion of each test run.

Since these sonograms had been recorded on chemically-treated "wet" paper, which is known to fade and bleed with time, it was imperative that the scanning of these records be performed as soon as possible following the field work. This routine was necessary to verify the target detection range values determined in the field and check their accuracy with careful measurements. Each run was analyzed, noting the particular range arc steered by the tow vessel, the direction of the vessel relative to the shore, the appropriate side or recorder channel on which the targets were observed, the measured height of the tow fish above the bottom, and the number of targets observed along with their respective minimum and maximum slant ranges (Appendix C).

Some of the records corresponding to a specific paper roll had in fact faded and bled enough to complicate the scanning and measuring procedure. In these cases, the slant ranges and number of detected targets determined at

the time it was run in the field were relied on quite heavily. This alternative method was deemed acceptable and sufficiently reliable based on comparison with the many other accurate field judgments that were verified in the record-scanning procedure. Scanning for the desired information on some of the Klein sonograms was made more difficult by the induced tow-cable noise previously mentioned. A substantial difference was noticed in ease of visual scanning between sonograms because of recording inequalities and varying amounts of visible noise.

2. Water Temperature and Salinity

The salinities of the sea water samples collected were determined in the laboratory using a Plessey Environmental Systems Salinometer, Model 6230N. Salinity values ranged from 31.675ppt to 31.894ppt, averaging 31.821ppt. Salinity measurements were repeated using an Autosal Model 6400. Similar results were obtained with the salinities ranging from 31.672ppt to 31.890ppt, for a 31.818ppt average.

Water temperature and salinity data had been acquired bi-weekly at a station very close to the test sites for many years as part of the Hopkins Marine Station's hydrobiological survey for the California Cooperative Oceanic Fisheries Investigations (CALCOFI). One of the CALCOFI stations was located approximately 1.0 mile and 1.5 miles respectively from the rock and sand bottom test sites (Figure 4.2). Water temperature and salinity had been determined to a water depth of 32 m. The most recent CALCOFI data acquired at this station was examined using the values from the period 1970 to 1975, corresponding to the same time of year as this research. All of these salinities were between 33.5ppt and 34.0ppt.

There is no apparent explanation for the difference between the CALCOFI data and the present measurements. Rain had been encountered only once throughout the field period, and had not been excessive. There also was no obvious fresh water run-off source in the form of a river or stream in this general working area.

In an effort to accurately represent the test sites, the measured average surface temperature of 13.15°C for the two working areas was retained. Since the historical surface salinity values ranged from 33.586ppt to 33.889ppt, which were much higher than the values obtained in this research, it was decided to use the historical values over the entire water column. Estimating a salinity profile based on the field surface value and the historical data values would not be realistic. The sound speed calculation was necessary only for the water column below the fish. Therefore, an error in near-surface salinity values would not effect true target range determinations. By developing average water-temperature and salinity profiles from the CALCOFI data and applying the average surface temperature observed in the field, suitable models were obtained (Figure 5.1) to compute the average speed of sound propagation for the test sites. A sensitivity analysis was also performed to determine the effects on the calculation of sound speed due to errors introduced by faulty water temperature and salinity values. An error in temperature and salinity of 2°C and 2ppt respectively, causes a deviation from the average sound speed of ±10 m/sec. This result translates to an error in the slant range of ±2 m at the maximum range of 300 m. It should be noted that temperature has a much more pronounced effect than does salinity.

The sound speed at mid depth was calculated to be 1491 m/sec. This value may be used to compute the true target ranges from the observed target slant ranges determined by the side scan sonar systems.

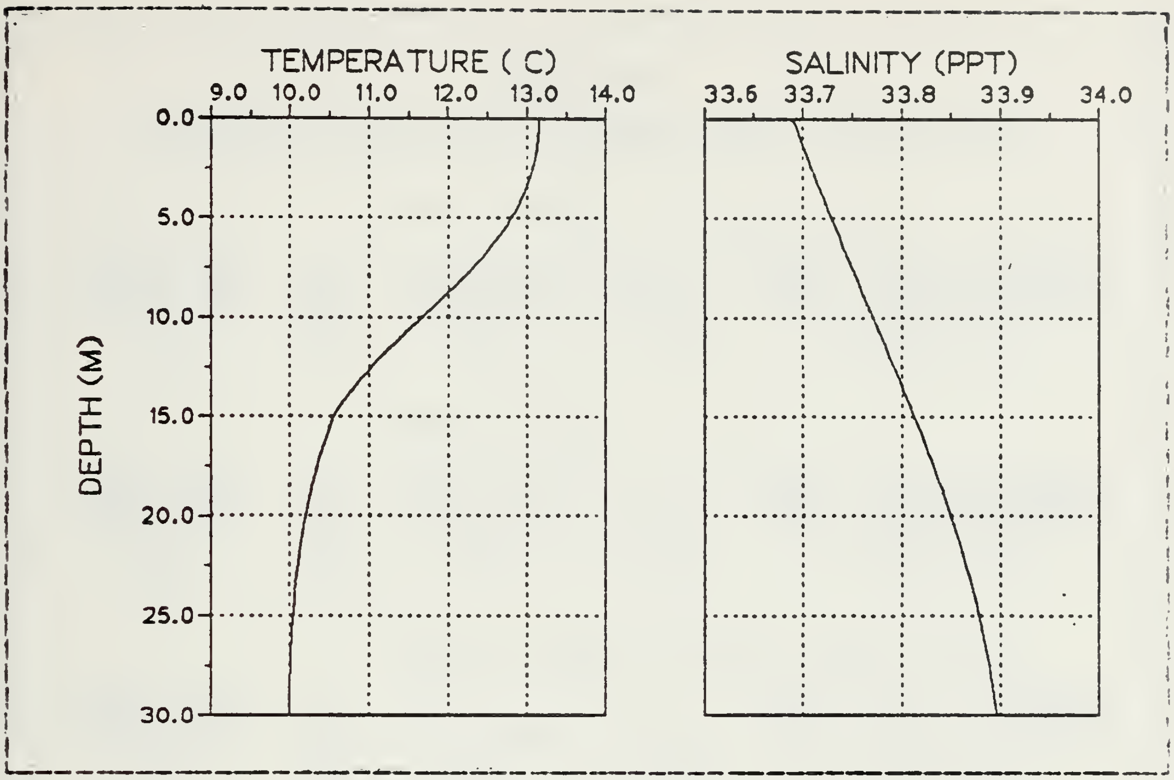

Figure 5.1 Salinity and Temperature Profiles.

B. STATISTICS

The results of test runs served as the basis for compiling statistics relative to system performance. Each range scale used was divided into appropriate intervals. From the total number of passes attempted and the number of successful target detections for each range interval, the probability of detection, P(D), and a 95% confidence interval for detection based on the binomial distribution were computed (Tables II and III).

Statistics were compiled only for the runs over sand. The targets were never detected on the shale bottom and no data were acquired over the mud bottom due to the unknown target strength.

TABLE II

Statistics for Klein System Over Sand Bottom

75-M SCALE

DETECTION RANGE (M)	RUNS	SUCCESSES	P(D)	CONFIDENCE INTERVAL 95% LOWER/UPPER
75	22	22	1.00	0.85/1.00

100-M SCALE

DETECTION RANGE (M)	RUNS	SUCCESSES	P(D)	CONFIDENCE INTERVAL 95% LOWER/UPPER
100	19	19	1.00	0.82/1.00

150-M SCALE, NO TOW-CABLE NOISE

DETECTION RANGE (M)	RUNS	SUCCESSES	P(D)	CONFIDENCE INTERVAL 95% LOWER/UPPER
150	19	19	1.00	0.82/1.00

150-M SCALE, WITH TOW-CABLE NOISE

DETECTION RANGE (M)	RUNS	SUCCESSES	P(D)	CONFIDENCE INTERVAL 95% LOWER/UPPER
39	1	1	1.00	0.02/1.00
49	3	3	1.00	0.29/1.00
59	5	5	1.00	0.48/1.00
69	6	5	0.83	0.36/1.00
79	28	25	0.89	0.72/0.98
89	23	19	0.83	0.61/0.95
99	44	34	0.77	0.62/0.89
109	22	17	0.77	0.55/0.92
119	23	13	0.57	0.34/0.77

200-M SCALE

DETECTION RANGE (M)	RUNS	SUCCESSES	P(D)	CONFIDENCE INTERVAL 95% LOWER/UPPER
69	16	12	0.75	0.48/0.93
79	17	11	0.65	0.38/0.86
89	17	13	0.76	0.50/0.93
99	19	10	0.53	0.29/0.76
109	9	5	0.56	0.21/0.86
119	5	1	0.20	0.01/0.72
129	4	2	0.50	0.07/0.93

TABLE III

Statistics for EG&G System Over Sand Bottom

152-M SCALE (500-FT)

DETECTION RANGE (M)	RUNS	SUCCESSES	P(D)	CONFIDENCE INTERVAL 95% LOWER/UPPER
152	17	17	1.00	0.80/1.00

305-M SCALE (1000-FT)

DETECTION RANGE (M)	RUNS	SUCCESSES	P(D)	CONFIDENCE INTERVAL 95% LOWER/UPPER
228	14	12	0.86	0.57/0.98
244	13	7	0.54	0.25/0.81
259	13	6	0.46	0.19/0.75

For the Klein side scan sonar over a sand bottom, the targets were detected out to the maximum range possible 100% of the time for the 75-m and 100-m scales. When the noise was eliminated by raising the coiled cable off the boat deck, the targets were detected 100% of the time out to 150 m on the 150-m scale. On the 200-m scale detection was greatly reduced even at the nearer ranges.

On the 500-ft (152-m) scale over a sand bottom, the EG&G system worked well, detecting the targets at maximum range 100% of the time. The system was also tested at the 1000-ft (305-m) scale. Success in detecting the targets at 228 m was achieved 86% of the time with the array being detected out to 259 m 46% of the time. The EG&G could not be tested at the 1000-ft scale under optimum towing conditions; due to the depth of water in the working area (102 ft), the suggested towing height above the bottom of 10% to 20% of the scale (100 to 200 ft) could not be adhered to without

towing at the surface. While the entire potential of the EG&G on the 1000-ft scale could not be fully examined, the target detection range results were most interesting.

C. SUBSEQUENT LABORATORY TARGET STRENGTH MEASUREMENTS

Since the field tests suggested that the target strength of the artificial targets was at least partially from reflectors other than the glass spheres, further laboratory tests were felt necessary. As described in Chapter 3, Section 1, tank tests were again performed. A more sensitive receiving hydrophone, Celesco Model LC-10, was used at this time.

The target strength was determined for the glass sphere and its anchor system, and for these components separately. (The individual components were suspended from thin stainless steel wire.)

Complete Target (Figure 3.1)	-24 dB
16-cm diameter glass spheres	-33 dB
3/8-in polypropylene line	-33 dB
55-lb iron weight	------

The target strength of the anchor weight was too low to be measured above the noise from surface and side reflections of the tank. Both types of anchor weights were tested yielding the same negligible contribution. The line used in the tests simulated the amount of line found between the anchor and sphere, including knots, and the line and knot in the vicinity of the weight leading to the surface buoy.

Readings of the target strengths were not precise due to the interference from side and surface reflections of the tank. Values for the complete target varied from -21 dB to as low as -33 dB. The most consistent reading was -24 dB.

Calculations were made to determine the size of an air bubble in water that is in resonance at 100 kHz [Urick, 1975].

$$a = \frac{326}{f} \sqrt{1 + (0.03d)}$$

where a = bubble radius (cm)

f = frequency (Hz)

d = depth (ft)

At the system frequency of 100 kHz and a depth of 31 m (102 ft), the diameter of a bubble in resonance is 0.07 mm. This calculation supported the discovery that 3/8-in (9.5-mm) polypropylene line acted as a reflector. A synthetic line of this diameter could contain this size bubbles.

These findings supported the results obtained over a sand bottom comparing runs with and without the glass fishnet floats attached to the weights. When the glass spheres were removed, 0.7 m of 3/8-in polypropylene line with two knots was also removed. Subsequent passes by the targets showed a corresponding decrease in signal return. This drop in target strength was due to both the removal of line and the glass sphere. The remaining line knotted above the weight was sufficient to allow detection at 75, 100, and 150 m.

Over a mud bottom, returns from complete targets were generally only half as strong as returns obtained over sand. With the glass spheres and adjoining line removed, the targets were rarely indentifiable. The original theory that the weights were sinking into the very soft mud bottom is supported by the results of the tank test. Two large knots attaching the surface buoy and glass sphere to the weight were located immediately above the weight. It was assumed

that when the weight sank into the mud, the two knots were also submerged, resulting in a reduced target strength.

Comparisons of measured target strength of the glass sphere to theoretical expectations were made. The target strength of a perfectly-reflecting, rigid sphere can be approximated by [Urick, 1975]:

$$TS = 10 \log \frac{a^2}{4}$$

where a = radius in meters

For the 16-cm spheres used in this investigation, the theoretical target strength is -28 dB. This value compares favorably with the measured target strength of -33 dB. The spheres used in this test were not perfectly reflecting due to surface irregularities and hence, a lesser target strength was expected.

D. COMPARISON OF FIELD RESULTS WITH SONAR EQUATION

Before a comparison could be made between the calculated target strengths from the sonar equation and the maximum range capabilities of the Klein and EG&G systems, given a target of -24 dB target strength, the sonar equation results must be examined.

1. Sonar Equation Results

The effect of sea-surface reverberation on the maximum target strength required to detect a target at a given range is very apparent. (See Figures 3.10 through 3.13) At the lower tow heights of 10, 15, and 16 m, the surface backscatter is not a factor when the slant range to the bottom-mounted target is less than the depth of the fish. There is an obvious increase of approximately 18 dB in the required target strength when surface reverberation interferes with the echo.

As the grazing angle decreases with increasing range from the tow fish, the surface- and bottom-backscattering interference decreases as does the return signal; therefore, the rise in required target strength with range is due only to the distance the pulse must travel. This rise over a 300-m range is approximately 11 dB over sand and 18 dB over solid rock.

Theory supports the "white gap" found on EG&G sonograms. This gap is shown as a peak on the EG&G reverberation figures of sonar equation results in Chapter 3. The peak occurs at a range corresponding to the angle off the acoustic beam where the side lobes interfere with the main lobe (Figure 3.7).

Comparing the Klein and EG&G side scan sonar systems at a common tow height shows similar target strength requirements except for the "white gap" peaks of the EG&G system. From theory, given the same environmental conditions and same detection thresholds, the two systems should detect the same targets. However, since the detection threshold of the Klein system is higher than the EG&G system due to the wider bandwidth of the Klein, the EG&G should detect targets out to a greater range and targets of a lower target strength.

2. Comparisons

It was difficult to compare field results to the sonar equation since there were conflicting values for detection threshold of each system. If the suggested DTs of 55 dB and 65 dB were used, the minimum target strength required for detection would be unrealistically high.

The target strength of the targets deployed was measured at approximately -24 dB. Comparing these values to the curves in Figures 3.10 and 3.11 and the measured ranges (Tables II and III) allows the detection threshold to be

estimated as -14 dB for the EG&G system and -8 dB for the Klein system. The difference between these values is not inconsistent with the 10-dB difference between system DTs calculated using equation 3.16.

The accuracy of these results depends on the accuracy of the sea-surface and sea-floor backscatter coefficients. The coefficients for the sand and solid-rock bottom types were taken from a study for a 60-kHz system. They are known to be affected by sand waves (roughness of the bottom) and grain size which casts some doubt on the validity of this study's flat bottom assumption. The divers investigating the sand bottom found evidence of sand ripples. McKinney (1964) allows a spread of ±5 dB for the values over sand. The tabulated coefficients for solid rock vary by ±4 dB. Calculations of sea-surface reverberation coefficients at 5 knots are based on a small sample size with an average difference of 3 dB from the curve [Urick, 1956].

VI. CONCLUSIONS

Side scan sonar detection of bottom-mounted targets in shallow water at 100-kHz frequency is significantly affected by the bottom type at the target location. A 16-cm glass sphere and adjoining 3/8-in polypropylene mooring line having a combined target strength of -24 dB was readily detected on a sand bottom, while a shale bottom masked all returns, thereby eliminating target detection. Due to the type of target used in this investigation, a mud bottom could not be evaluated.

The maximum range of detection of this target over a sand bottom with a Klein side scan sonar system was 150 m. This measure was achieved on the 150-m range scale when there was no visible tow-cable noise and during calm-weather conditions. The targets were detected 100% of the time. The maximum range of detection was less on the 200-m range scale which has a reduced pulse repetition rate.

For the EG&G system the maximum range of detection was 152 m on the 152-m (500-ft) scale 100% of the time. However, the overall maximum range of detection for this sonar was 259 m on the 305-m (1000-ft) range scale with detections made 46% of the time. The system also detected targets at a range of 228 m 86% of the time.

Comparing the 100-kHz bandwidth of the Klein system to the EG&G system 10-kHz bandwidth, it is expected that the EG&G system should detect a given target at a greater range than the Klein system. The detection threshold is higher for the Klein due to its wider bandwidth.

Taking into consideration the variables associated with these side scan sonars and such circumstances as degree of operator expertise, sea conditions, and composition of the

bottom, comparisons can be drawn between the two systems in this particular application. However, this is only a relative gauge of system performance under the specific operating conditions encountered. Statistical results for general conditions were not obtained.

During the performance of this research it was abundantly demonstrated that the efficiency of side scan sonars depends greatly on operator profiency. Proper system tuning for the given environmental conditions and accurate sonogram interpretation are of paramount importance.

Research on the effects of bottom backscatter on side scan sonar should be extended to other bottom types. A suggestion would be to construct a target array in the form of a recognizable configuration that could be distinguished on the sonogram amidst the bottom backscatter. To allow equitable use on various bottoms, the reflections from the mooring line should be eliminated by use of a non-reflecting line. A larger glass sphere could be used to counteract the loss in target strength due to a non-reflecting mooring line.

Given the environmental conditions and the operating variables of a side scan sonar system, it is possible to use the sonar equation to estimate the minimum allowable target strength of a target to be detected at a given range. This method can only be used as a guide because of the variability of the geophysical conditions and operator-dependent detection threshold. However, relative comparisons can be made between different bottom types, surface interference, and towing heights.

Detection thresholds were estimated by comparing field results to theoretical ranges calculated from the sonar equation using reasonable sea floor and sea surface backscatter coefficients. The detection thresholds were estimated as -14 dB for the EG&G system and -8 dB for the

Klein system. These values were consistent with the lack of target detection results over the shale bottom.

Further research on target detection in the presence of bottom backscatter should provide a relative measure for spacing survey lines when using side scan sonar in search patterns for locating obstructions over different bottom types. These line spacing criteria would also apply when side scan sonar systems are used to complement conventional echo sounders in shallow water hydrographic surveying.

APPENDIX A
SYSTEMS SPECIFICATIONS

1. KLEIN Side Scan Sonar System

TOW FISH, MODEL 402S-001A

Physical	
Dimensions:	Body: Length 106.7 cm (42")
	Diameter 8.9 cm (3.5")
	Tail: Diameter 30.5 cm (12")
Weight:	20.2 kg (44.5 lbs) in air
	13.6 kg (30 lbs) in water
Electrical	
Operating Frequency:	100 kHz
Pulse Length:	0.1 millisecond
Peak Output:	228 dB, ref. 1 μPa at 1 meter
Mechanical	
Horizontal Beamwidth:	1°
Vertical Beamwidth:	40° tilted down 10° from horizontal
Depth Rating:	0 to 670 m (2200 ft)
Normal Tow Speed:	0 to 16 knots

TOW CABLE

Type:	2 channel lightweight
Breaking Strength:	2800 kg (6160 lbs)
Length:	200 m (656 ft)
Nom. Diameter:	1.07 cm (0.42")
Strain Member:	Kevlar
Jacket:	polyurethane

RECORDER, MODEL 421

Physical

Dimensions:	Length: 84.4 cm (33.25") Width: 59.7 cm (23.5") Depth: 25.4 cm (10")
Weight:	43.5 kg (96 lbs) without AC supply 51.7 kg (114 lbs) with AC supply

Electrical

Input Voltage:	DC 23-30 volts (protected from reverse voltage or overvoltage) AC (with optional Model 401-010 AC supply) 105-125 volts or 210-230 volts, 47-63 Hz
DC Input Current:	2-5 amperes (3 amperes average)
Range Scales:	25, 37.5, 50, 75, 100, 150, 200, 300, 400, and 600 meters
Pulse Rate:	according to range scale: 75 meter scale- 10 pulses/sec
Scale Lines:	every 15 meters (adjustable from 2 to 25 meters)

Mechanical

Printout Paper:	Alden Alfax Type A (wet)
Paper Width/Length:	28 cm (11") wide 37 m (120 ft) long
Channel Width:	12.7 cm (5") each channel
Recording Color:	sepia (standard), black (optional)
Paper Feed Speeds:	20, 30, 40, 50, 60, 70, 90, 100, 110, 120 lines/cm and continuously variable

2. EG&G Side Scan Sonar System

TOW FISH, MODEL 272 SAF-T-LINK

Physical

Dimensions:	Body: Length 138.2 cm (54.43") Diameter 11.3 cm (4.5") Fins: Length 17.9 cm (7") Width 61 cm (24") overall
Weight:	24 kg (53 lbs) in air 16 kg (35 lbs) in water

Electrical

Operating Frequency:	105 ± 10 kHz
Pulse Length:	0.1 millisecond
Peak Output:	228 dB, ref. 1 μPa at 1 meter

Saf-T-Link

Shear Pin:	182 kg (400 lbs) breaking strength
Steel Recovery Cable:	2273 kg (5000 lbs) breaking strength

Mechanical

Horizontal Beamwidth:	1° wide at 90° and 270° relative bearing (3 dB down)
Vertical Beamwidth:	20° or 50° wide, tilted down 10° or 20° from the horizontal (3 dB down)
Depth Rating:	0 to 600 m (2000 ft)
Normal Tow Speed:	0 to 15 knots

TOW CABLE

Type:	2 channel shallow tow
Breaking Strength:	491 kg (900 lbs)
Length:	50 m (164 ft)
Diameter:	1.2 cm (0.47")
Jacket:	plastic

RECORDER, MODEL-1/2/3 (modified)

Physical

Dimensions:	Length: 83.8 cm (33") Width: 44.5 cm (17.5") Depth: 27.9 cm (11")
Weight:	38.2 kg (84 lbs)

Electrical

Input Voltage:	DC 24-30 volts (protected against reversed polarity input) AC (Model 283 Power Converter) 115 or 220 volts, 47-63 Hz
DC Input Current:	4-8 amperes average (depending on range scale in use)
Range Scales:	250 ft (76.2 m), 500 ft (152.4 m), 1000 ft (304.9 m)
Pulse Rate:	according to range scale: 250 ft scale- 10 pulses/sec
Range Resolution:	1/250 of full scale
Scale Lines:	every 50 ft (15.2 m); adjustable

Mechanical

Printout Paper:	Alden Alfax Type A (wet)
Paper Width/Length:	28 cm (11") wide 37 m (120 ft) long
Channel Width:	12.7 cm (5") each channel
Recording Color:	sepia
Paper Feed Speeds:	40, 60, 80, lines/cm (100, 150, 200 lines/inch) changed internally with recorder dismantled

APPENDIX B

SIDE SCAN SONAR OPERATION EXPERTISE

The expert guidance in the field was provided by STS-1 (SS) Dean Berkbigler, USN. Petty Officer First Class Berkbigler accompanied the Submarine Development Group 1; Unmanned Vehicles Detachment's Klein side scan sonar equipment from their base in San Diego, CA. This sonar technician had seven years of submarine service and had served at this particular command for two years, benefitting from more than six months sea experience in search operations utilizing the Klein system. The remaining duty was devoted to operation of the facility's Surface Towed Search System (STSS), a more sophisticated side-looking sonar/camera vehicle, as well as repair and preventive maintenance of the two systems.

APPENDIX C

FIELD RESULTS - TEST RUNS

1. Klein System Over Sand

KLEIN - 75-m Scale, Over Sand
Tow-Cable Noise Present
(all values in meters)

20 April 1983
Average Speed: 2.7 kts
Average Tow Height: 9.1 m
Wind: 5-15 kts
Seas: 1 ft
Swell: 1-3 ft

RUN	FISH HEIGHT	POTENTIAL FOR DETECTION	MAXIMUM DETECTION
4	8	56	56
5	8	57	57
6	10	56	56
7	10	58	58
8	8	53	53
9	7	54	54
10	12	65	65
11	10	60	60
12	13	62	62
13	7	54	54
14	11	62	62
15	7	62	62
16	10	62	62
17	7	62	62

Runs 1-3 were made with only 2 targets deployed while adjusting the system tuning.

KLEIN - 100-m Scale Over Sand
Tow-Cable Noise Present
(all values in meters)

20 April 1983
Average Speed: 2.5 kts
Average Tow Height: 11.6 m
Wind: 10-15 kts
Seas: 1 ft
Swell: 2-3 ft

RUN	FISH HEIGHT	POTENTIAL FOR DETECTION	MAXIMUM DETECTION
18	8	93	93
*19	11	95	77
20	11	90	90
*21	16	91	91

22 April 1983
Wind: light
Seas: 0 ft
Swell: 3 ft

RUN	FISH HEIGHT	POTENTIAL FOR DETECTION	MAXIMUM DETECTION
22	12	88	88
23	12	93	93
24	11	96	96
25	11	98	98
26	12	98	98
27	11	99	99
28	12	97	97
29	11	97	97
30	11	97	97
31	12	96	96
32	12	98	98
33	11	97	97
34	13	100	100

* - These runs were not included in the statistics. Both runs were made running into the seas resulting in excessive fish movement. Therefore, they were not compared to runs when fish movement was at a minimum. Runs 18 and 20 were made in following seas.

KLEIN - 150-m Scale Over Sand
Tow-Cable Noise Present
(all values in meters)

22 April 1983
Average Speed: 2.4 kts
Average Tow Height: 16.7 m
Wind: light
Seas: 0 ft
Swell: 3 ft

RUN	FISH HEIGHT	POTENTIAL FOR DETECTION	MAXIMUM DETECTION
35	18	112	97
36	16	107	107
37	18	109	83
38	15	113	113
39	18	112	97
40	17	117	93
41	18	115	100
42	16	108	70
43	17	117	79
44	17	115	115
45	17	115	94
46	16	70	58
47	15	82	82
48	16	91	91
49	17	101	101
50	16	82	82

Average Tow Height: 15 m
Wind: 10 kts
Seas: 0 ft
Swell: 3 ft

RUN	FISH HEIGHT	POTENTIAL FOR DETECTION	MAXIMUM DETECTION
51	15	114	114
52	15	114	114
53	15	111	98
54	15	117	117
55	15	112	99
56	15	112	104
57	15	112	99
58	15	118	118
59	15	112	112
60	15	116	116
61	15	115	115
62	15	117	117
63	15	114	114
64	15	118	118
65	15	112	112

KLEIN - 150-m Scale Over Sand
No Tow-Cable Noise
(all values in meters)

25 April 1983
Average Speed: 2.6 kts
Average Tow Height: 15.5 m
Wind: light, deteriorating to 15-20 kts
Seas: 0 ft, deteriorating to 1-2 ft
Swell: 3-5 ft, deteriorating to 4-6 ft

RUN	FISH HEIGHT	POTENTIAL FOR DETECTION	MAXIMUM DETECTION
66	15	141	141
67	13	140	140
68	15	137	137
69	13	140	140
70	17	144	144
71	14	145	145
72	18	145	145
73	15	144	144
74	18	144	144
75	14	138	138
76	18	142	142
77	14	144	144
78	18	138	138
79	14	143	143
80	18	142	142
81	13	145	145
82	20	142	142
83	14	146	146
84	20	144	144

KLEIN - 200-m Scale Over Sand
(all values in meters)

26 April 1983
Average Speed: 2.6 kts
Average Tow Height: 20.3 m
Wind: 0-5 kts
Seas: Ripples
Swell: 1-3 ft

RUN	FISH HEIGHT	POTENTIAL FOR DETECTION	MAXIMUM DETECTION
85	17	160	120
86	21	166	126
87	18	130	-
88	19	130	112
89	19	130	-
90	21	96	96
91	20	115	-
92	19	108	100
93	22	98	85
94	20	102	102
95	21	115	102
96	20	100	-
97	22	93	80
98	20	104	96
99	21	98	85
100	20	100	-
101	22	100	100
102	21	99	99
103	22	103	90
104	21	100	-
105	22	96	96
106	19	106	86

Runs 107-112 were not processed due to fading paper making identification impossible.

KLEIN - Target Test Over Sand

26 April 1983
Average Speed: 2.6 kts
Wind: 3 kts
Seas: Ripples
Swell: 2 ft

100-m Scale

RUN	FISH HEIGHT	POTENTIAL FOR DETECTION	MAXIMUM DETECTION	
113	12	79	79	
114	12	86	86	Runs 113 - 116 have all five spheres intact
		75-m Scale		
115	11	69	69	
116	9	53	53	
		75-m Scale		
		TARGET RETURN		
117	15	3 strong	73	
118	11	5 equally strong	70	
119	15	3 strong	71	
120	11	3 strong, 2 weak	67	
121	15	3 strong, 2 weak	72	Runs 117 - 130 have 2 spheres removed from targets
122	10		69	
		100-m Scale		
123	15	3 detected	85	
124	12	3 strong, 2 weak	68	
125	15	4 detected	67	
126	10	4 detected	79	
		Parallel Runs - 100-m Scale		
127	11	3 strong, 2 weak		
128	15	3 strong		
129	13	3 strong, 2 weak		
130	15	3 strong, 1 weak		

2. Klein System Over Shale

KLEIN - 75-m Scale Over Shale
(all values in meters)

27 April 1983
Average Speed: 2.8 kts
Average Tow Height: 9.8 m
Wind: light
Seas: 0 ft
Swell: 0 ft

RUN	FISH HEIGHT	POTENTIAL FOR DETECTION	MAXIMUM DETECTION
131	8	65	-
132	10	65	-
133	9	65	-
	Parallel Runs - 75-m Scale		
134	12	33	-
135	8	37	-
	Perpendicular Runs - 75-m Scale		
136	10	65	-
137	10	65	-
138	11	65	-
139	10	65	-
140	10	65	-
141	8	65	-
142	10	65	-
143	10	65	-
		100-m Scale	
144	10	60	-
145	11	65	-

3. EG&G System Over Shale

EG&G - 250-ft Scale Over Shale
(all values in feet)

28 April 1983
Average Speed: 2.6 kts
Average Tow Height: 52.0 ft
Wind: 5-10 kts, deteriorating to 15-20 kts
Seas: 0.5 ft, deteriorating to 1 ft
Swell: 1-2 ft

RUN	FISH HEIGHT	POTENTIAL FOR DETECTION	MAXIMUM DETECTION
146	50	50	-
147	28	50	-
148	60	55	-
149	55	75	-
150	54	75	-
151	54	75	-
152	55	75	-
153	51	75	-
154	50	75	-
155	48	75	-
156	49	75	-
157	50	75	-
158	50	75	-
159	50	75	-
	Parallel Runs		
160	55	40	-
161	65	35	-
162	55	35	-
163	58	55	-
	500-ft Scale		
164	52	75	-
165	50	75	-

4. EG&G System Over Sand

EG&G - 500-ft Scale Over Sand
(all values in feet)

29 April 1983
Average Speed: 3.0 kts
Average Tow Height: 53.6 ft
Wind: 0 kts
Seas: 0 ft
Swell: 1 ft

RUN	FISH HEIGHT	POTENTIAL FOR DETECTION	MAXIMUM DETECTION
166	65	472	472
167	55	398	398
168	55	405	405
169	50	495	495
170	55	485	485
171	45	490	490
172	55	499	499
173	50	495	495
174	55	495	495
175	50	498	498
176	55	499	499
177	50	495	495
178	60	490	490
179	50	500	500
180	55	490	490
181	50	497	497
182	60	500	500
183	50	498	498

EG&G - 1000-ft Scale Over Sand
(all values in feet)

29 April 1983
Average Speed: 2.4 kts
Average Tow Height: 93.1 ft
Wind: 5-10 kts
Seas: 0.5 ft
Swell: 1 ft

RUN	FISH HEIGHT	POTENTIAL FOR DETECTION	MAXIMUM DETECTION
184	90	820	820
184a	90	710	710
185	95	820	820
186	95	820	820
187	95	820	710
188	90	820	800
189	95	820	820
190	90	820	760
191	98	820	720
192	90	820	820
193	98	820	-
194	90	820	730
195	98	820	-
196	90	820	730

EG&G - Target Test Over Sand
500-ft Scale
(all values in feet)

29 April 1983
Average Speed: 2.4 kts
Average Tow Height: 59.3 ft
Wind: 5-10 kts
Seas: 0.5 ft
Swell: 1 ft

RUN	FISH HEIGHT	TARGET RETURN	MAXIMUM DETECTION	
197	55	3 strong, 1 weak	500	
198	75	5 equally strong	485	Spheres removed
199	52	4 strong, 1 weak	455	from 2 targets
200	52	3 strong, 2 weak	380	
	Parallel Runs			
201	70	5 equally strong		
202	52	5 equally strong		

5. <u>Klein System Over Mud</u>

KLEIN - 150-m Scale Over Mud
(all values in meters)

2 May 1983
Average Speed: estimated 2.5-3.0 kts
Average Tow Height: 13.8 m
Wind: 5-10 kts
Seas: Ripples
Swell: 3-6 ft

RUN	FISH HEIGHT	POTENTIAL FOR DETECTION	MAXIMUM DETECTION	
1a	15	105	105	
1b	12	108	108	All targets were weak
204	13	133	133	
Parallel Runs - 150-m Scale				
		TARGET RETURN		
3a	16	3 strong	60	
4a	13	unable to distinguish		
Parallel Runs - 75-m Scale				
		TARGET RETURN		
205	14	2 strong, 3 weak	58	
206	16	1 strong, 4 weak	46	
207	7	4 strong, 1 weak	67	
208	14	4 strong, 1 weak	65	
Ball Test - 75-m Scale				
209	12	3 detected	64	
210	12	3 detected	54	Spheres removed from 2 targets
211	13	1 detected	68	
212	12	2 detected	43	
213	11	2 detected	34	

APPENDIX D

SELECTED SONOGRAMS

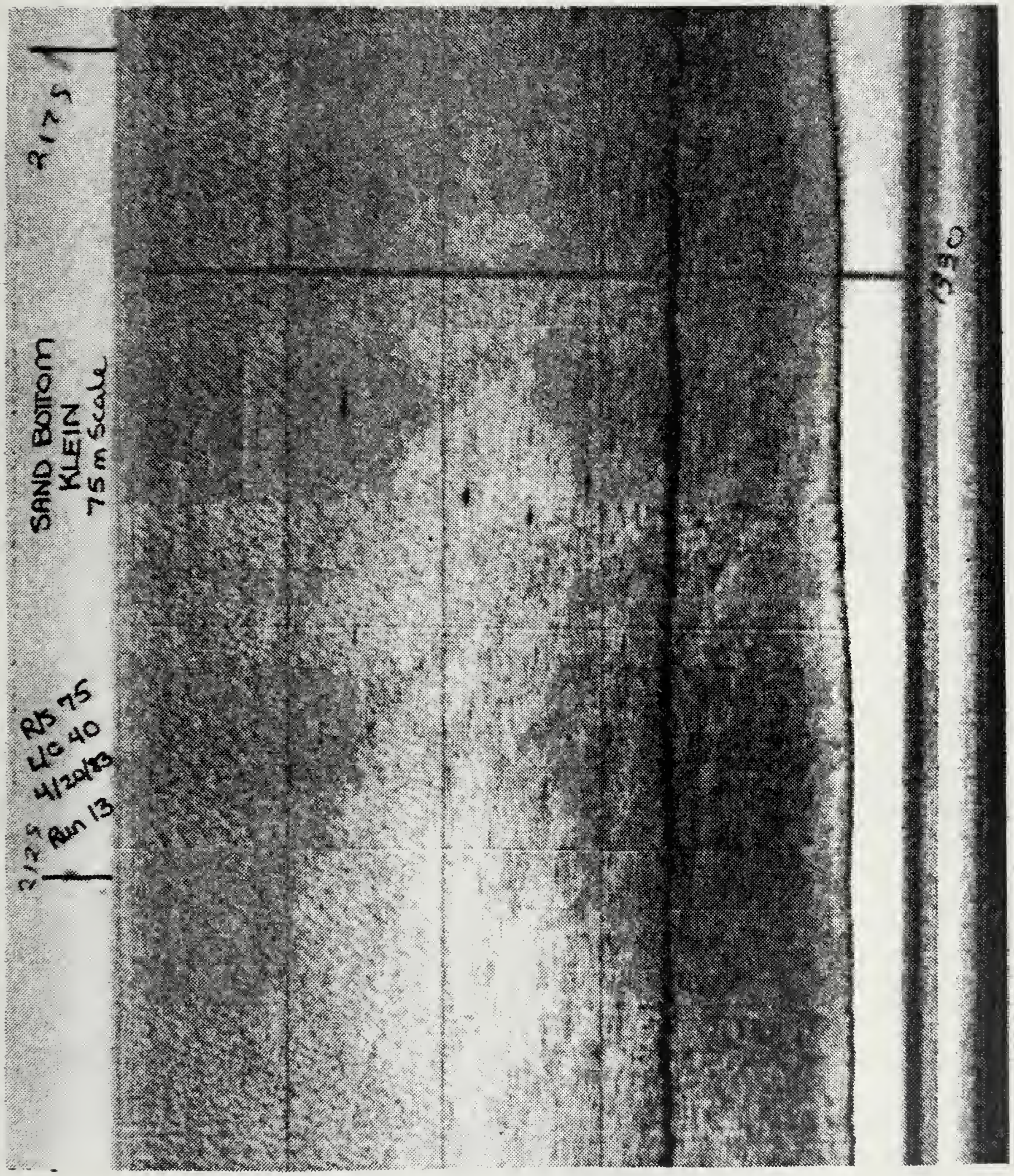

Figure D-1   Klein System Over Sand.

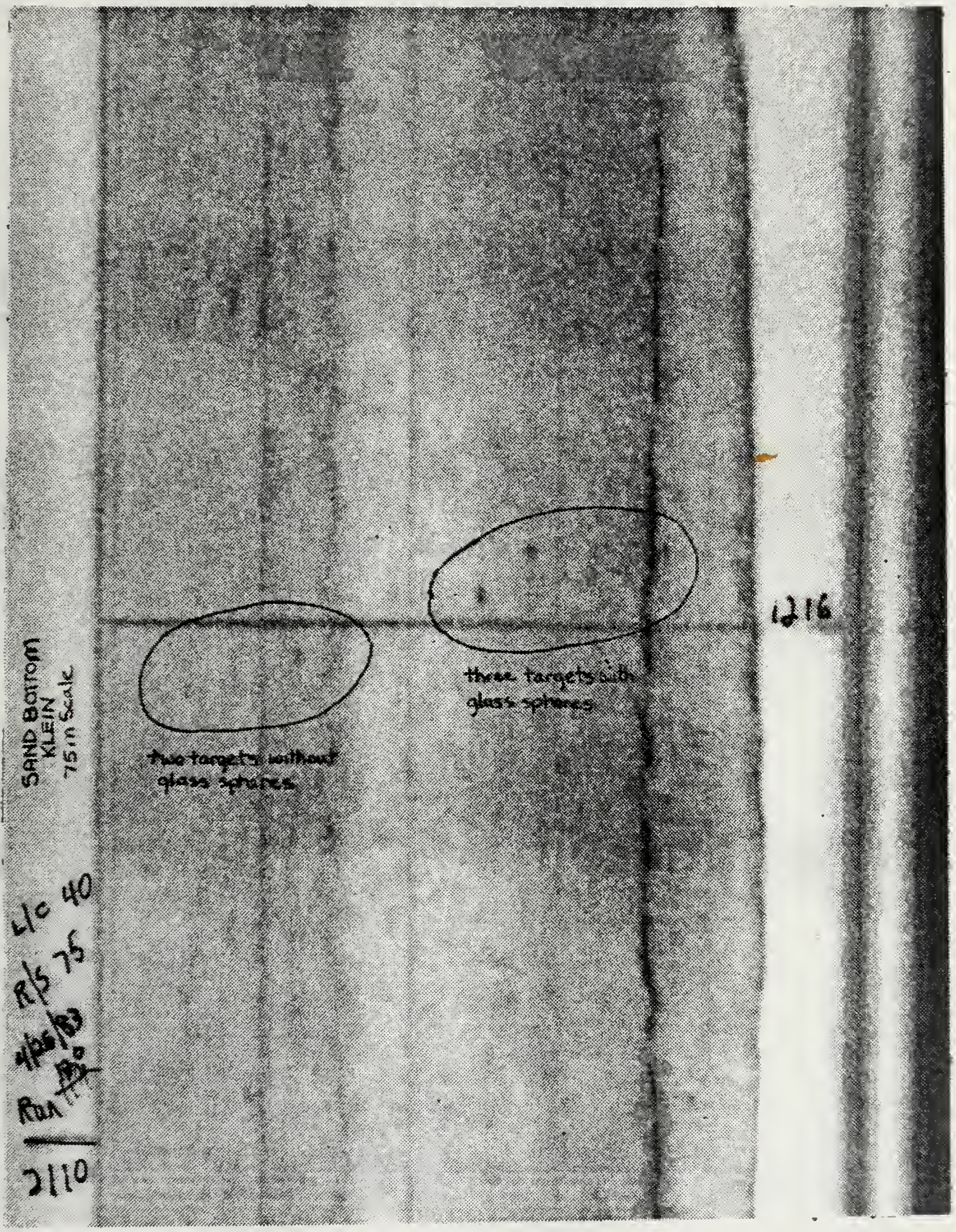

Figure D-2 Target Test with Klein System.

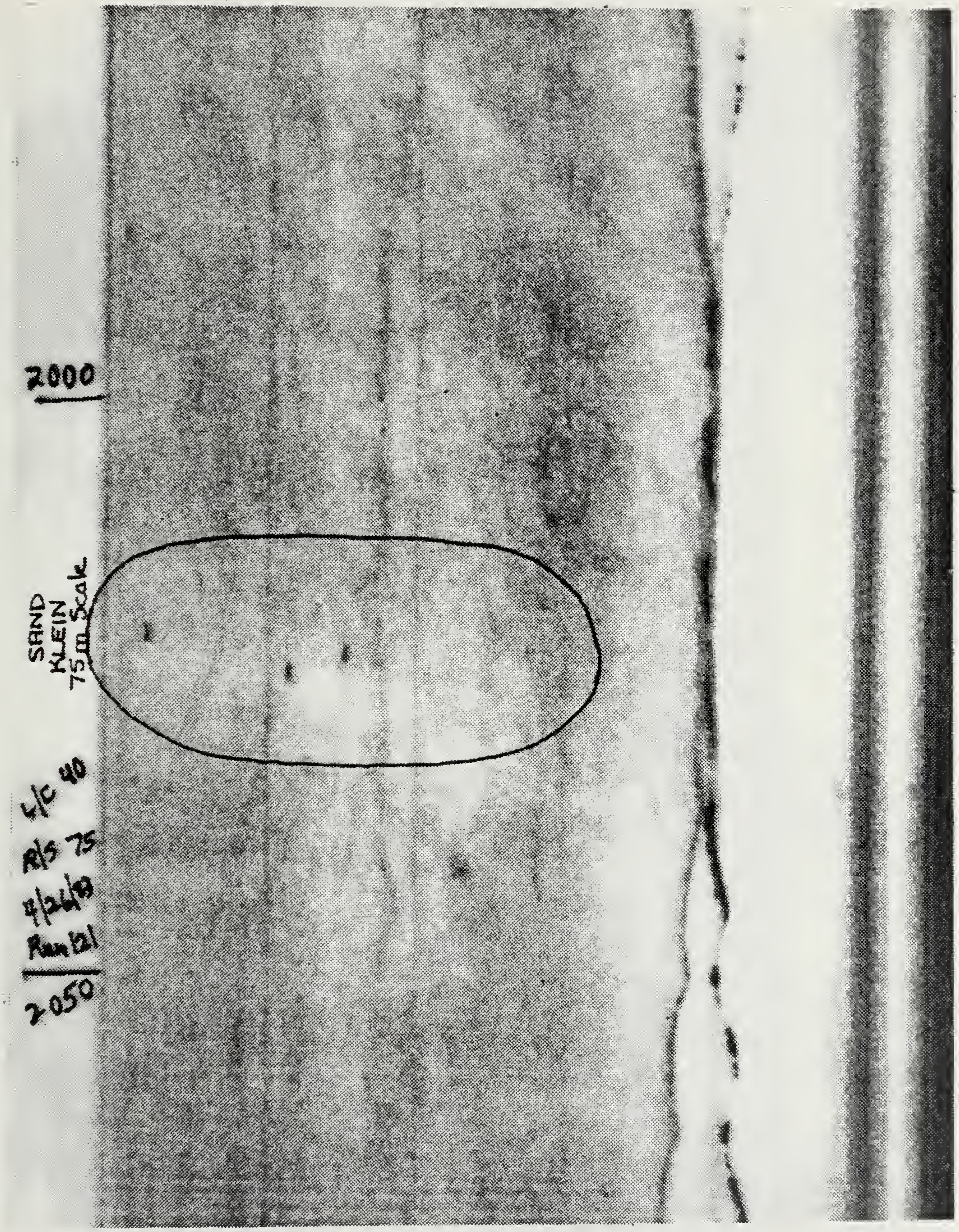

Figure D-3 Target Test with Klein System.

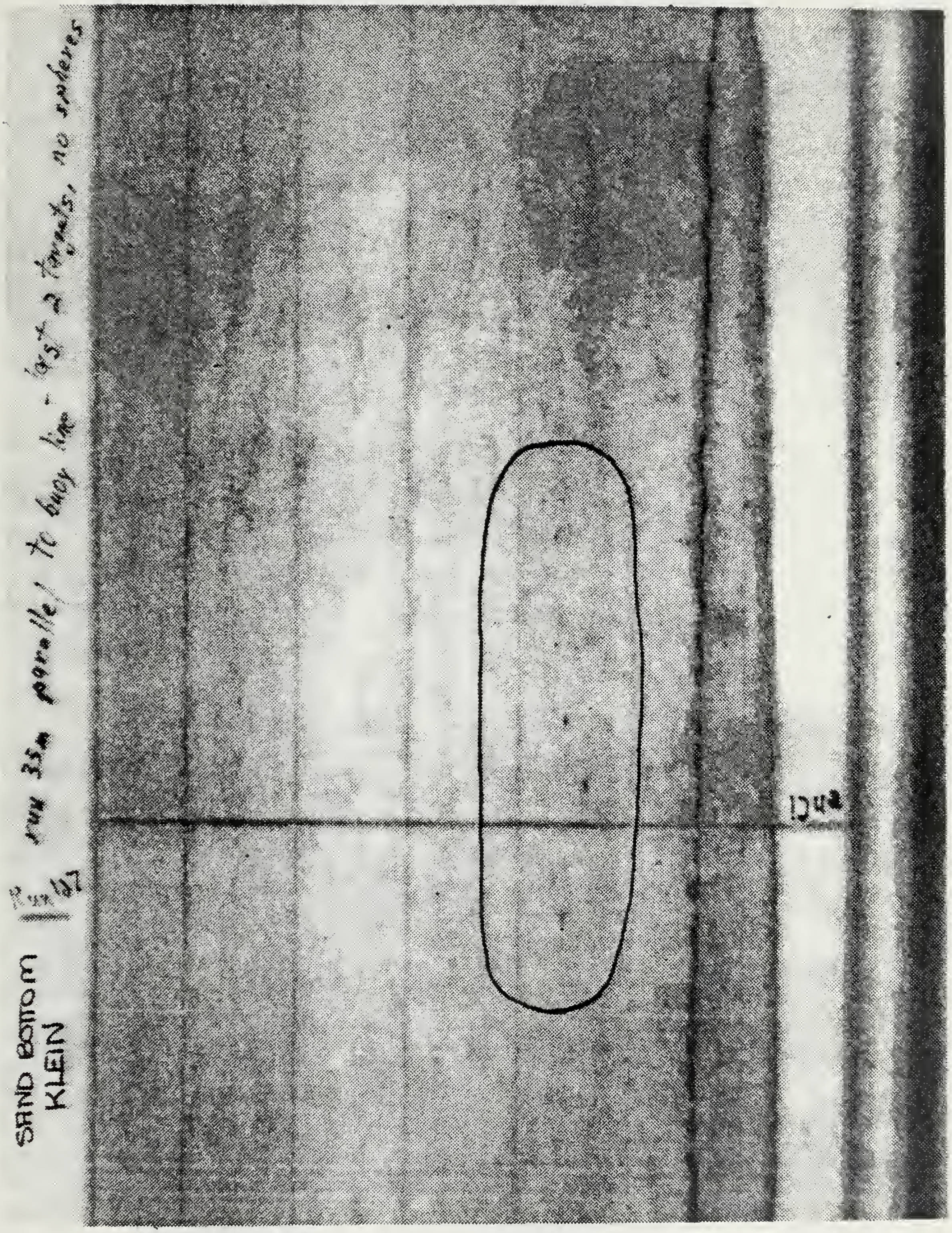

Figure D-4 Target Test with Klein System.

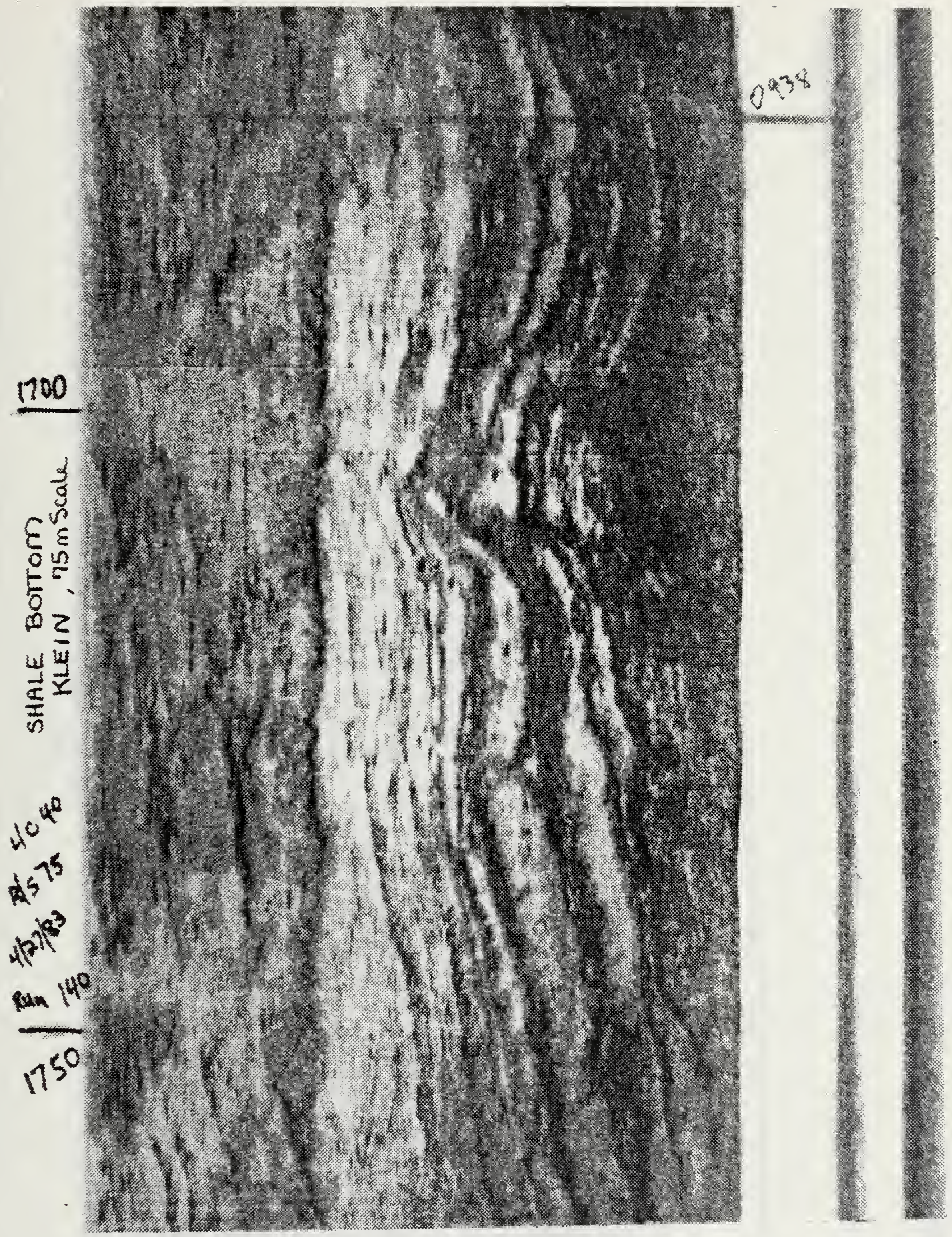

Figure D-5 Klein System Over Shale.

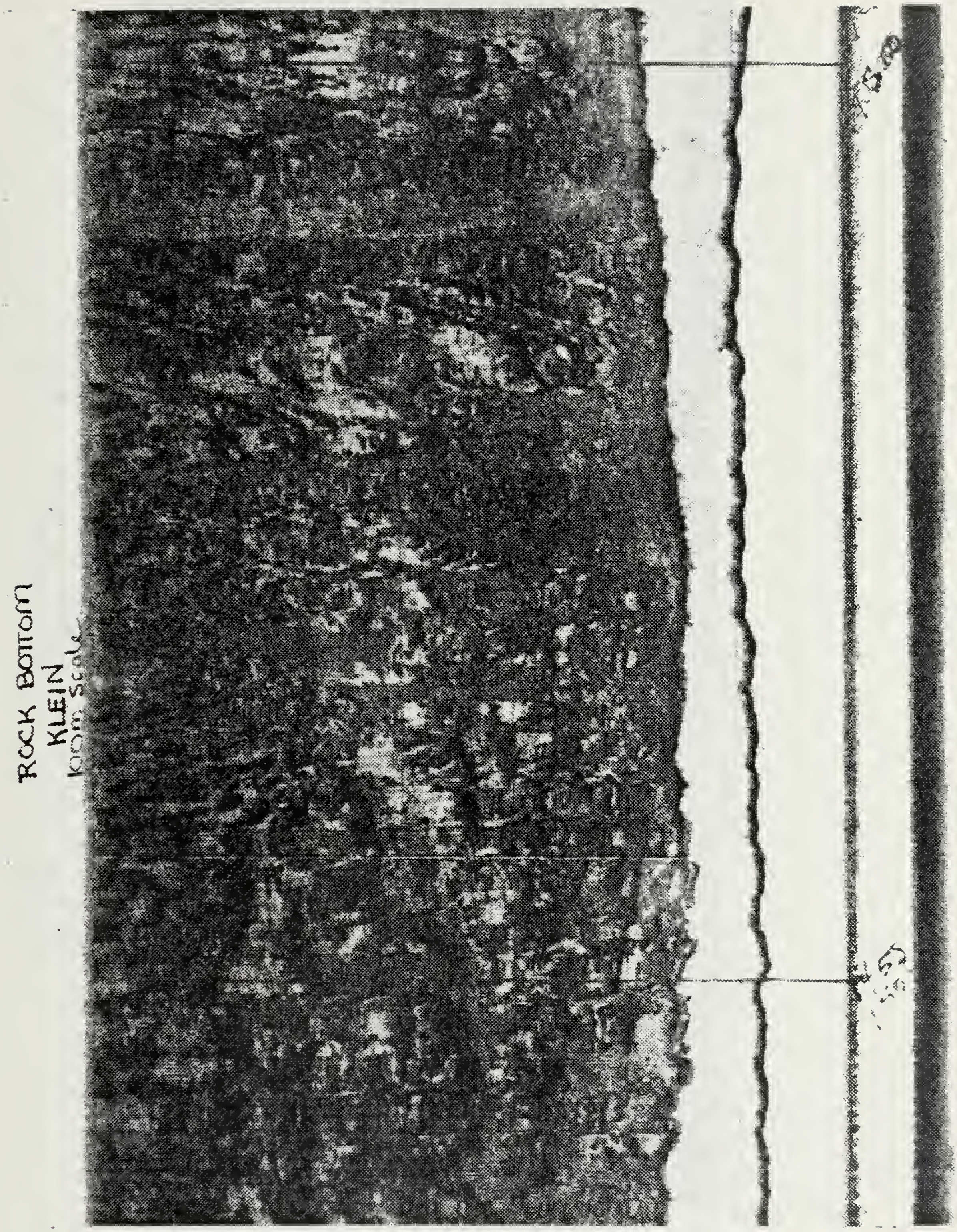

Figure D-6   Klein System Over Rock.

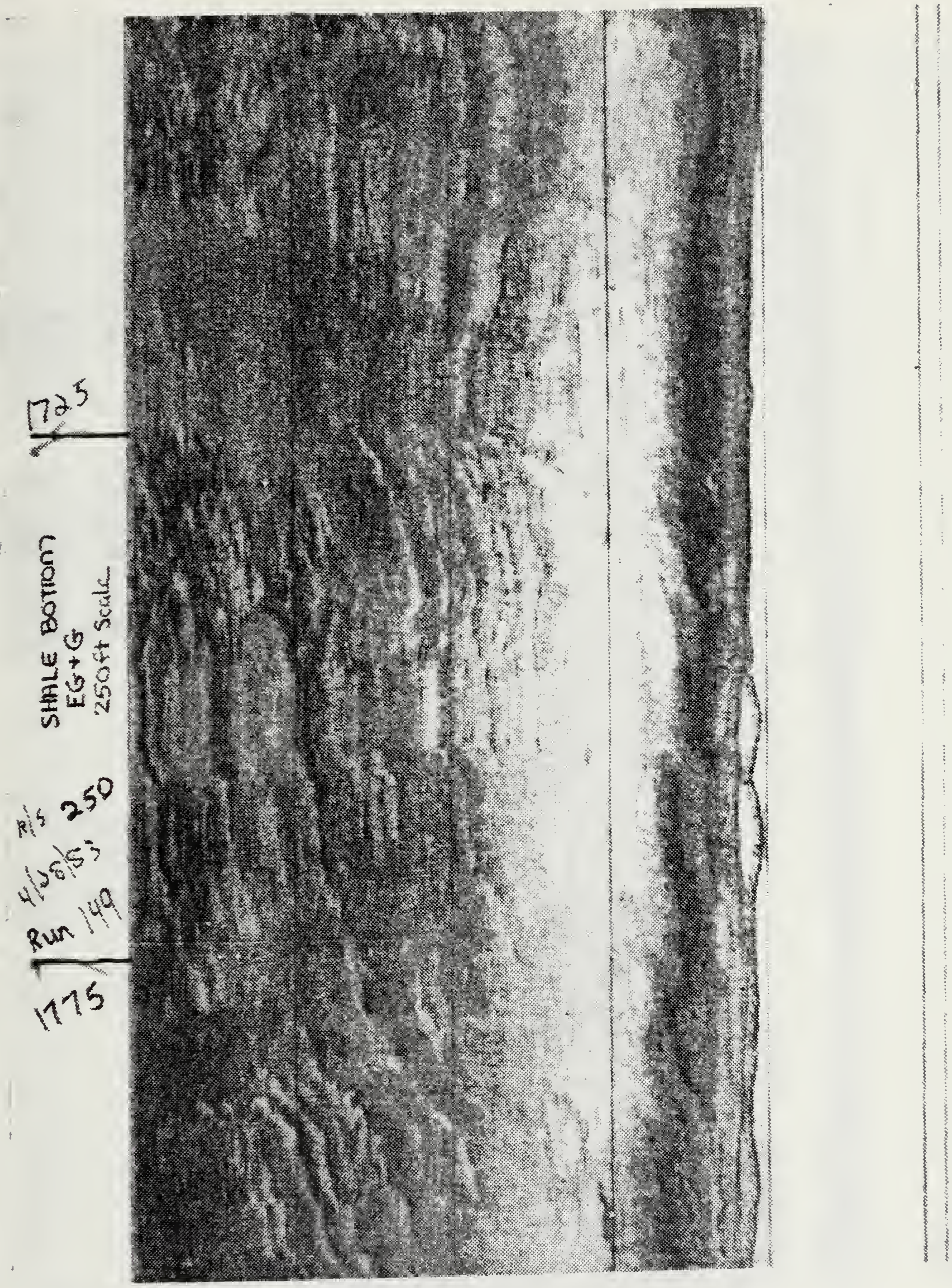

Figure D-7 EG&G System Over Shale.

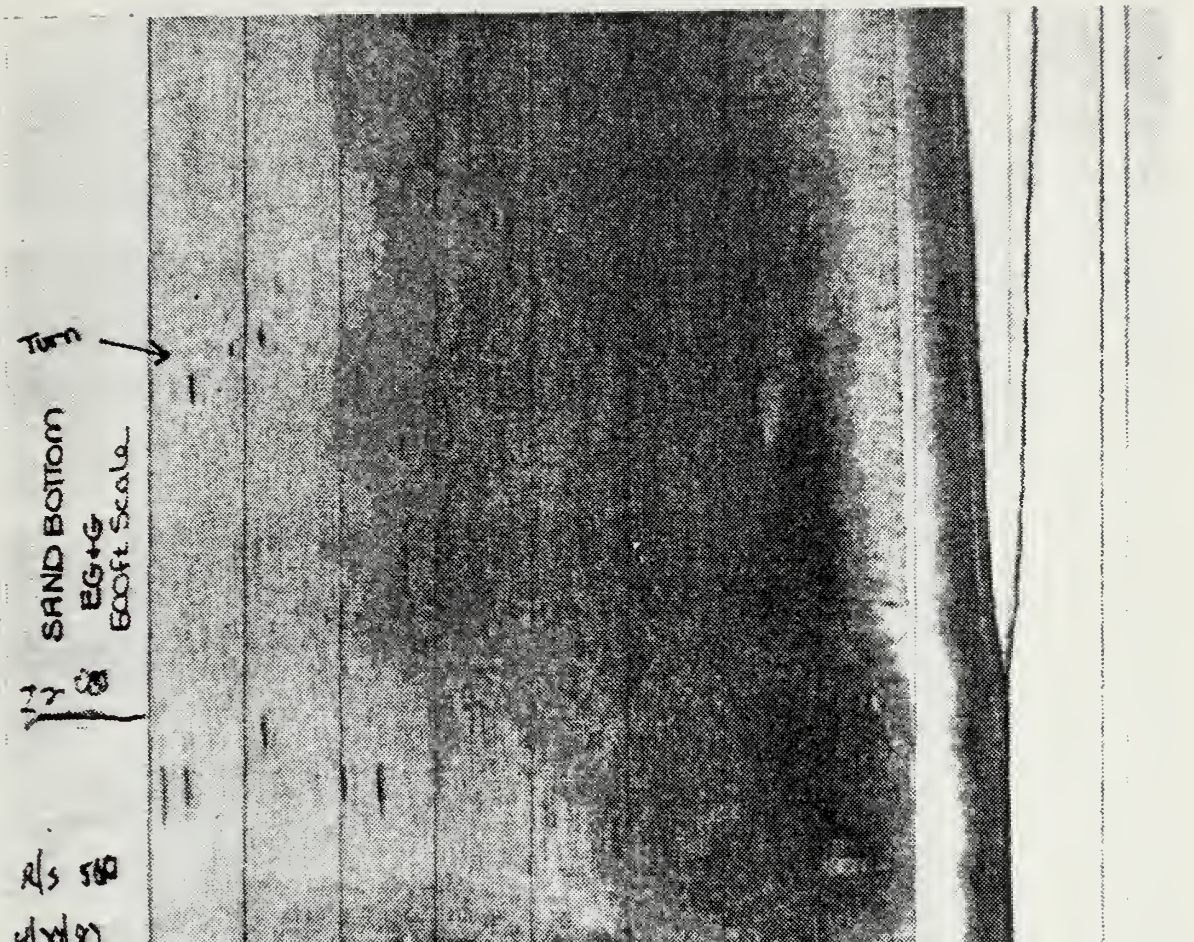

Figure D-8 EG&G System Over Sand.

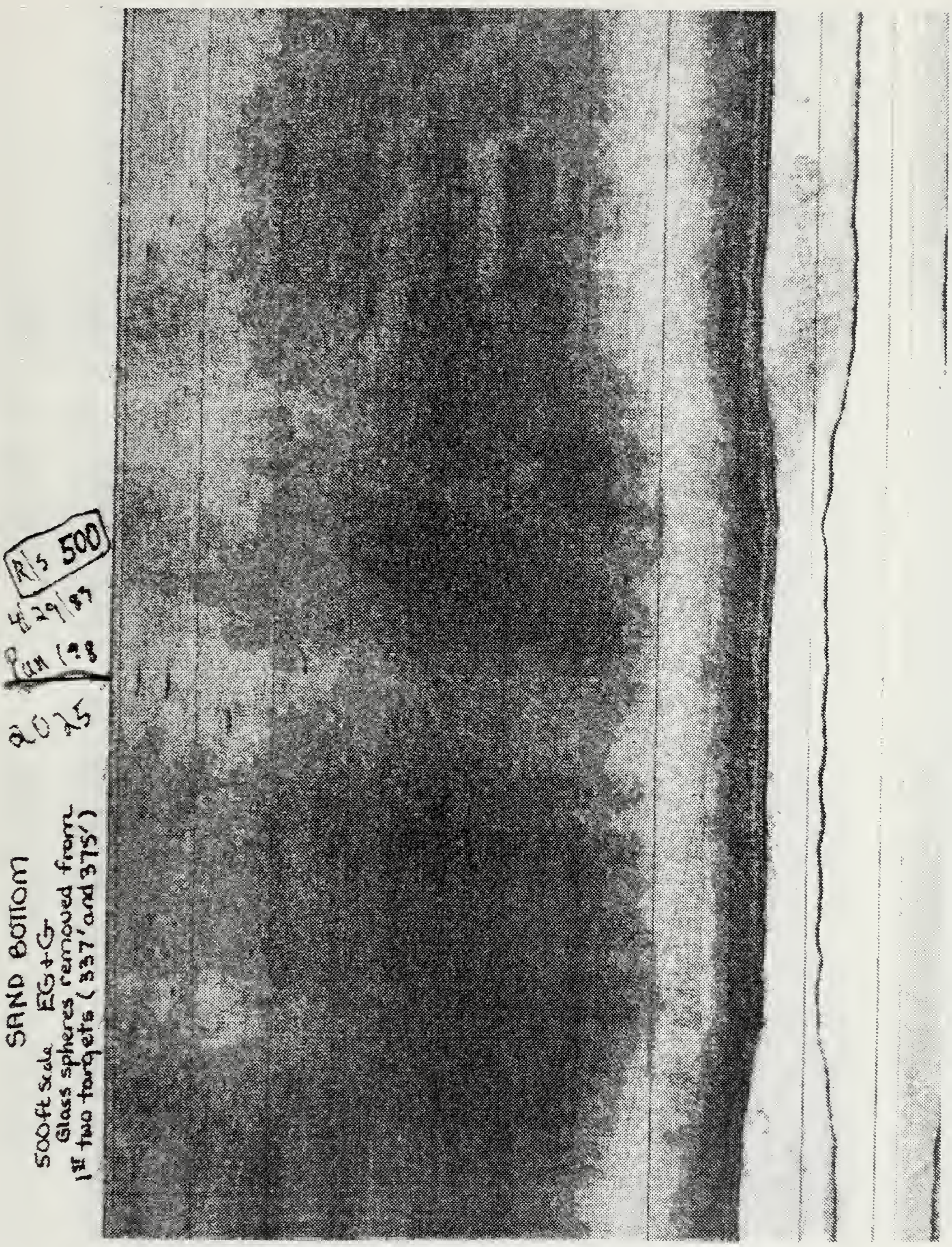

Figure D-9   Target Test With EG&G System.

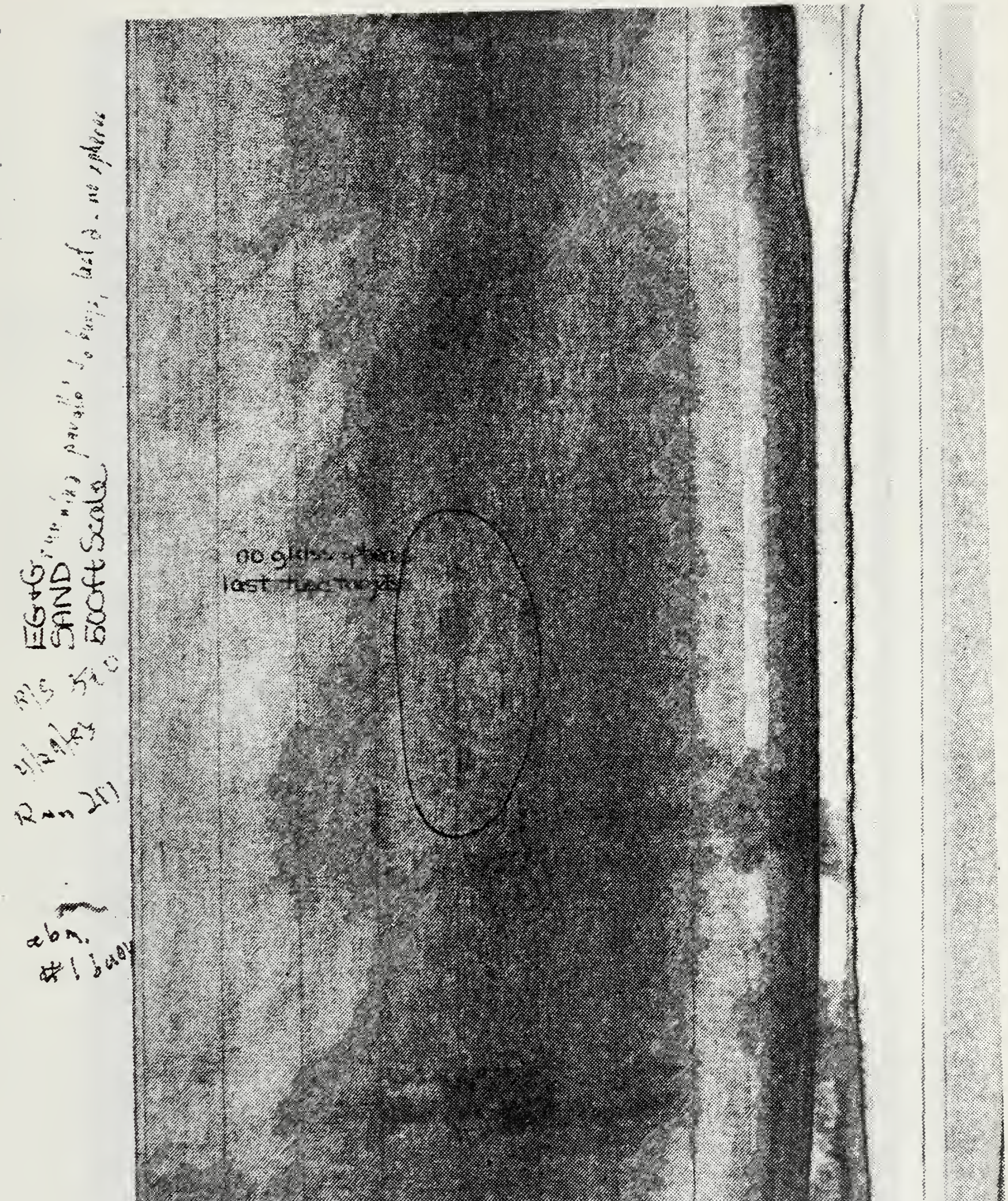

Figure D-10 Target Test with EG&G System.

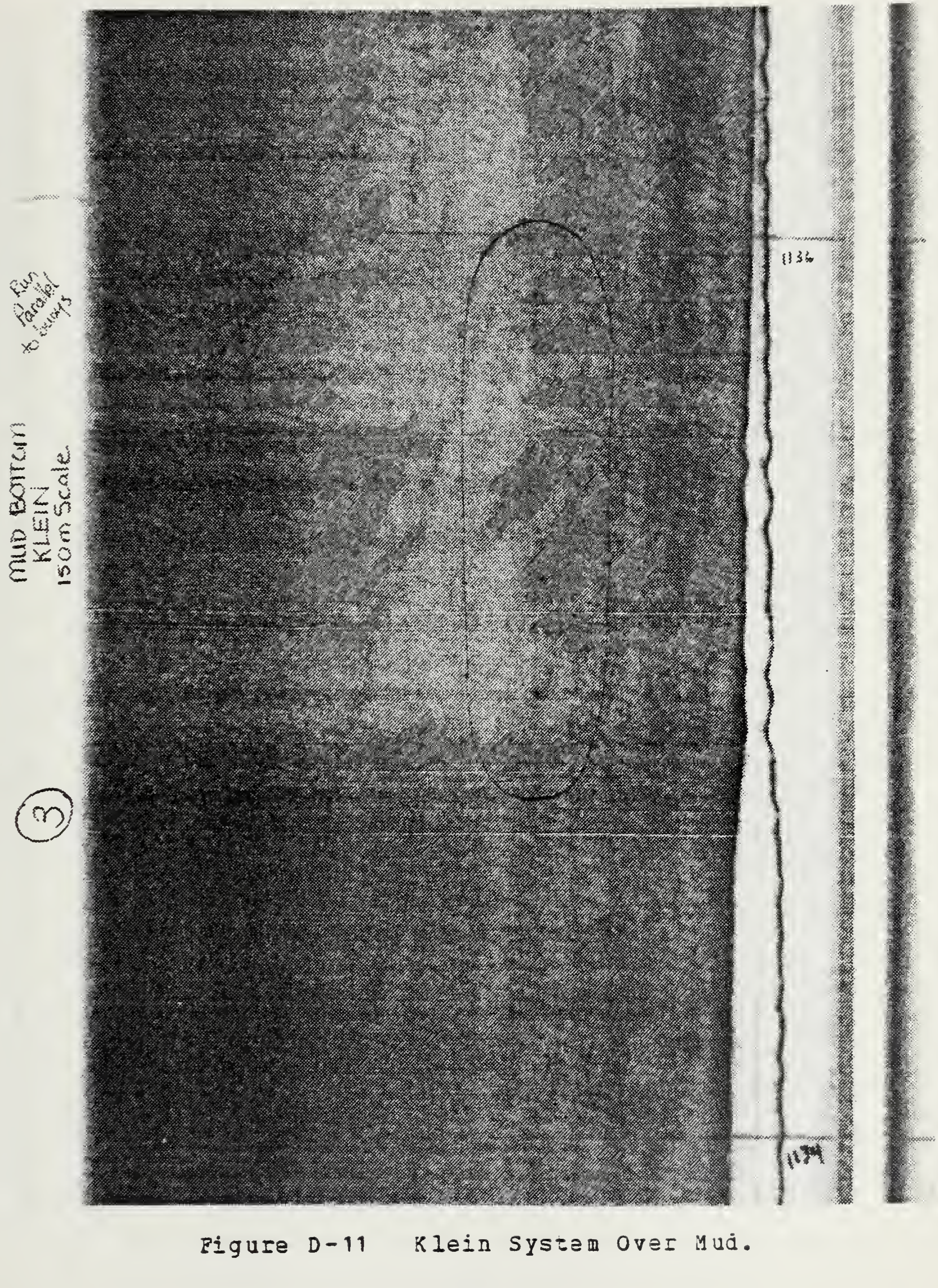

Figure D-11 Klein System Over Mud.

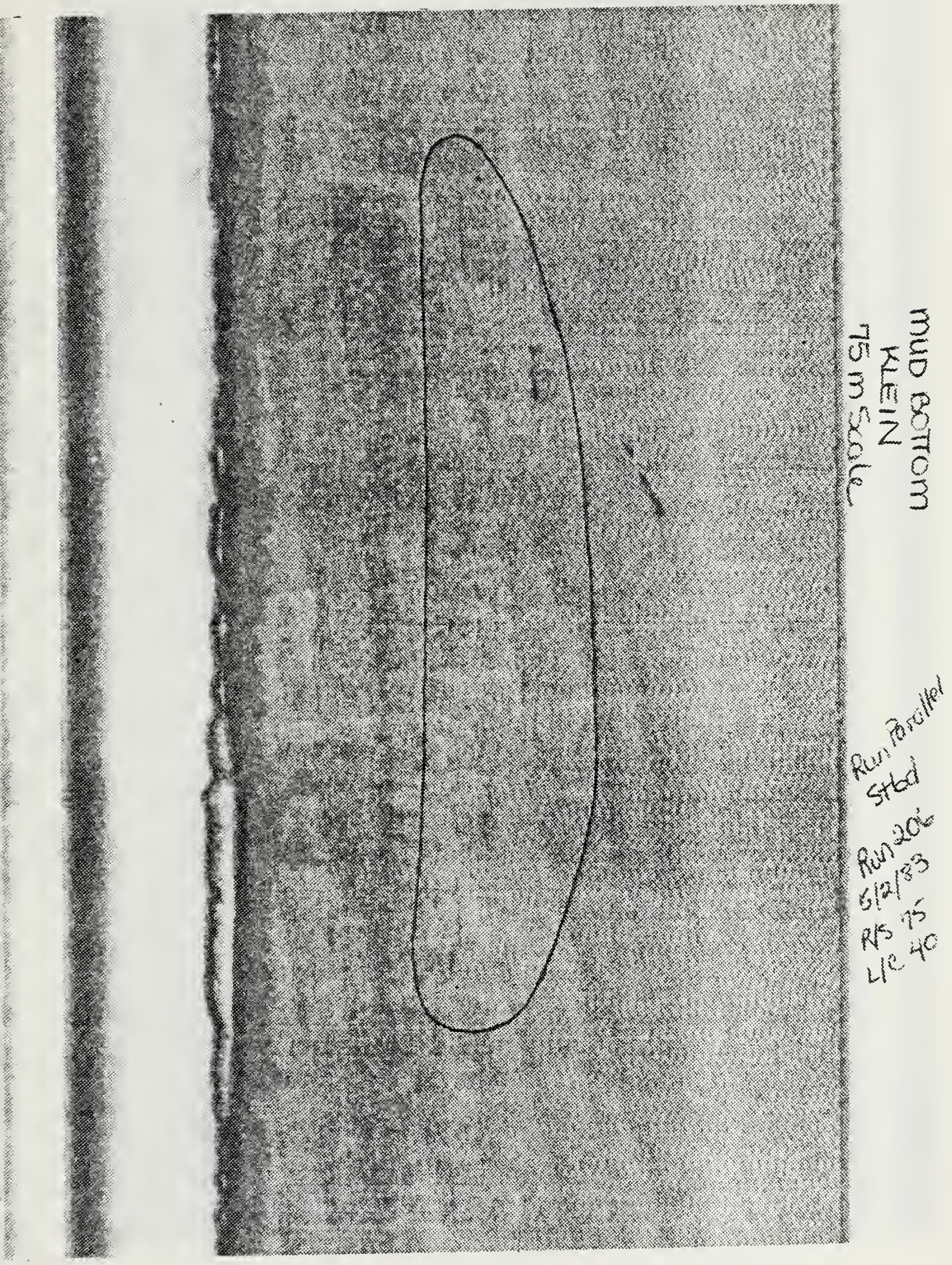

Figure D-12 Klein System Over Mud.

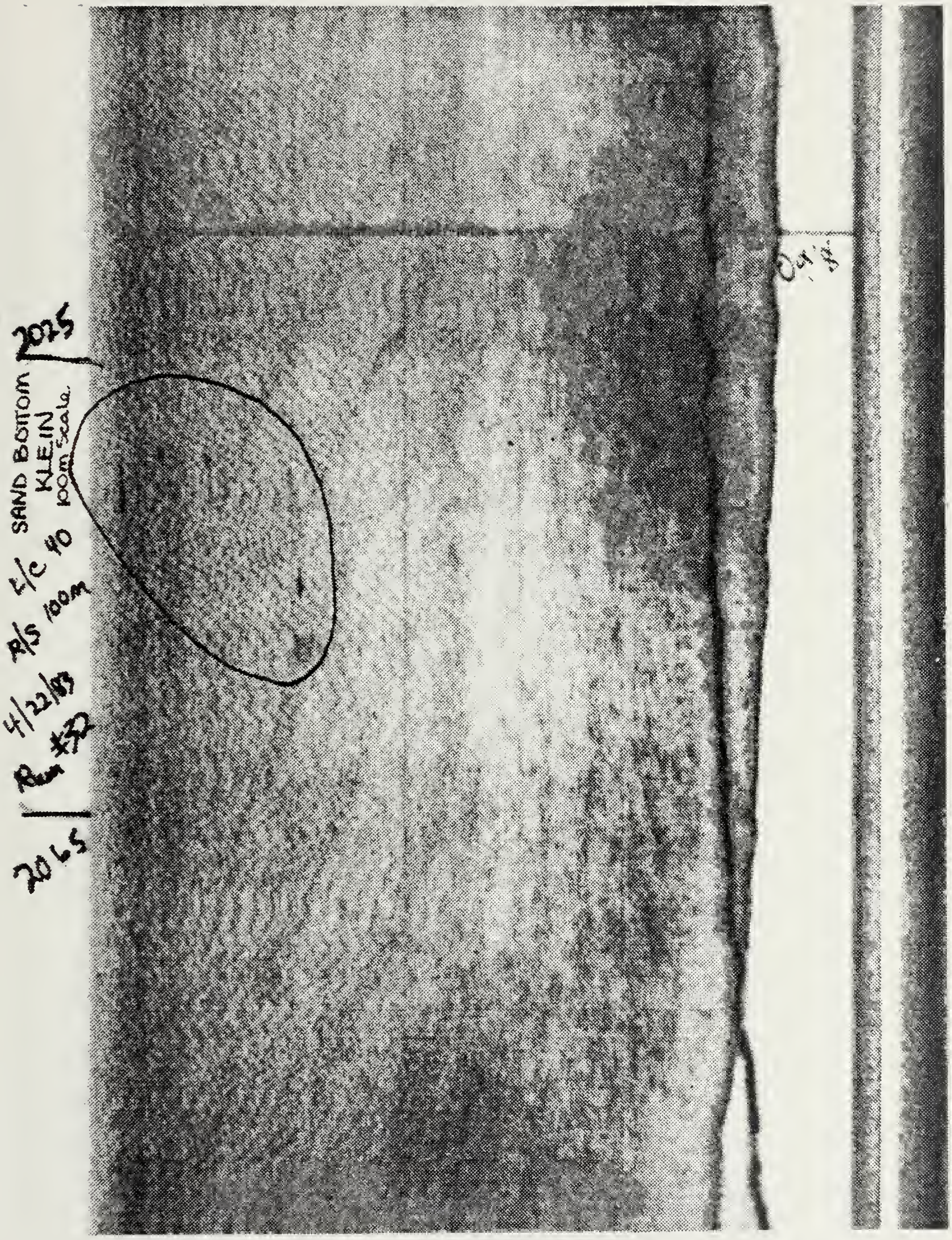

Figure D-13 Noise Pattern in Klein Sonogram.

<u>APPENDIX E</u>

COMPUTER PROGRAMS

A. NOISE-LIMITED CASE

```
C
C  EFFECTIVE RANGE FOR A GIVEN TARGET STRENGTH
C        FOR THE NOISE-LIMITED CASE
C  (FORTRAN PROGRAM RUN ON IBM 3033 COMPUTER)
C
      REAL NL
      DIMENSION TSNOL(400),RLTS(400),RANGE(400)
C
C  HEIGHT OF TOWING FISH (METERS)
C      KLEIN WAS TOWED AT 10M, 15M, 20M ABOVE BOTTOM
C      EG&G WAS TOWED AT 16M, 28M ABOVE BOTTOM
C
C      CHOOSE TYPE OF FISH
C
C  KLEIN
C     ITYPE=1
C  EG&G
      ITYPE=2
C
C         ASSIGN TOW HEIGHT
      IF(ITYPE.LT.1.5)HTOW=10.0
      IF(ITYPE.GT.1.5)HTOW=16.0
C
C  ASSIGN SALINITIES, TEMPERATURES, DEPTHS, AND
C  PRESSURES DEPENDING ON TOW FISH HEIGHT
C
4     IF (HTOW.GT.10.5)GO TO 5
      D=26.0
```

```
      T=10.08
      S=33.868
      PO=2.58
      GO TO 10
5     IF(HTOW.GT.15.5) GO TO 6
      D=23.5
      T=10.15
      S=33.852
      PO=2.29
      GO TO 10
6     IF(HTOW.GT.16.5) GO TO 7
      D=23.0
      T=10.21
      S=33.857
      PO=2.29
      GO TO 10
7     IF(HTOW.GT.20.5) GO TO 8
      D=21.0
      T=10.41
      S=33.839
      PO=2.09
      GO TO 10
8     D=17.0
      T=10.96
      S=33.809
      PO=1.69
C
C  CONSTANTS
10    PI=3.1415926
      RAD=1.74533E-2
C
C  SIDE SCAN SONAR SPECIFICATIONS
C
C    FREQUENCY  (KHZ)
      IF(ITYPE.GT.1.5) GO TO 11
```

```
C         KLEIN SYSTEM
      FKHZ=100.0
      GO TO 12
C         EG&G SYSTEM
11    FKHZ=105.0
C
C    HORIZONTAL BEAMWIDTH (DEGREES)
12    BEAMH=1.0
C
C    VERTICAL BEAMWIDTH (DEGREES)
      IF(ITYPE.LT.1.5) GO TO 13
C  EG&G SYSTEM
      BEAMV=20.0
      GO TO 14
C  KLEIN SYSTEM
13    BEAMV=40.0
C
C    ACOUSTIC OUTPUT(DB REF 1 MICRO PASCAL)
      SL=228.0
C
C  CHANGE DEGREES TO RADIANS, MILLISECONDS TO SECONDS
      BEAMH=BEAMH*RAD
      BEAMV=BEAMV*RAD
C
C  SONAR EQUATION (ACTIVE SONAR)
C                 (KINSLER, 1982: P.411)
C        2TL = SL + DI + TS - NL - DT
C
C  TL - TRANSMISSION LOSS   TL=20 LOG R + A(R-1)
C                 (KINSLER, 1982: P.398)
C        R - RANGE
C        A - ATTENUATION (DB/M)
C                 (KINSLER, 1982: P.158)
C
C    DETERMINE ATTENUATION FOR WORKING AREA
```

```
C
      F=FKHZ*1000.0
      F1=1.32 *  1000.0*(T+273.0)*EXP(-1700.0/(T+273.0))
      F2=1.55 *  1.0D7*(T+273.0)*EXP(-3052.0/(T+273.0))
      A1=8.95*1.0D-8*(1.0+2.3*1.0D-2*T-5.1*1.0D-4*(T**2))
      B=4.88*1.0D-7*(1.0+1.3*1.0D-2*T)*(1.0-0.9*1.0D-3*PO)
      C2=4.76*1.0D-13*(1.0-4.0*1.0D-2*T+5.9*1.0D-4*(T**2))
      C1=C2*(1.0-3.8*1.0D-4*PO)
      A=A1*F1*(F**2)/((F1**2)+(F**2))
      A=A+S*B*F2*(F**2)/(35.0*(F2**2)+(F**2))+C1*(F**2)
C
C  DI - DIRECTIVITY INDEX   DI=10 LOG D
C         D - DIRECTIVITY FOR A LINE ARRAY (2-D)
C                (TUCKER, 1977)
      DI=10*ALOG10(PI*4.0/(BEAMH*BEAMV))
C
C  DT - DETECTION THRESHOLD
      DT=00.0
C
C  NL - AMBIENT NOISE LEVEL FOR 100KHZ SYSTEM
C        IS THERMAL NOISE
C                (URICK, 1975)
C
      NL=-15+20*ALOG10(FKHZ)
C         RJ - HORIZONTAL RANGE
C         R  - SLANT RANGE
      DO 25 J=1,301
      RJ=J-1
      RANGE(J)=RJ
      R = ((RJ**2+HTOW**2)**0.5)
C
C    NOISE LIMITED TRANSMISSION LEVEL
      TL = 20*ALOG10(R) + A*(R-1)
C-------------------------------------------------------
C  CALCULATE TARGET STRENGTH FOR NOISE LIMITED CASE
```

```
C-------------------------------------------------------------
      TSNOL(J) = 2*TL - SL - DI + NL + DT
C
25    CONTINUE
C
C  DISPLAY RANGE AND MINIMUM TARGET STRENGTH
      DO 50 J=1,301
      WRITE(6,800) RANGE(J),TSNOL(J)
 800  FORMAT(1X,F5.0,5X,F15.1)
 50   CONTINUE
      IF(ITYPE.GT.1.5) GO TO 75
C
C   COMPUTE OTHER KLEIN TOW HEIGHTS
C
      IF(HTOW.GT.12) GO TO 432
      HTOW=15.0
      GO TO 4
432   IF(HTOW.GT.17) GO TO 433
      HTOW=20.0
      GO TO 4
C
C   COMPUTE OTHER EG&G TOW HEIGHTS
C
75    IF(HTOW.GT.20) GO TO 433
      HTOW=28.0
      GO TO 4
433   STOP
      END
```

B. REVERBERATION-LIMITED

```
C
C  EFFECTIVE RANGE FOR A GIVEN TARGET STRENGTH
C      FOR THE REVERBERATION-LIMITED CASE
C  (FORTRAN PROGRAM RUN ON IBM 3033 COMPUTER)
C
      REAL*8 AS, AB, R101,R100,RL100, RL101,
     *SLS,SLB,SUR,S,HS,HB,RY
      DIMENSION RLTS(400),RANGE(400)
C
C  HEIGHT OF TOWING FISH (METERS)
C      KLEIN WAS TOWED AT 10M, 15M, 20M ABOVE BOTTOM
C      EG&G WAS TOWED AT 16M, 28M ABOVE BOTTOM
C
C      CHOOSE TYPE OF FISH
C
C  KLEIN
C     ITYPE=1
C  EG&G
      ITYPE=2
C
C          ASSIGN TOW HEIGHT
      IF(ITYPE.LT.1.5)HTOW=10.0
      IF(ITYPE.GT.1.5)HTOW=16.0
C
C
C  ASSIGN SALINITIES, TEMPERATURES, DEPTHS, AND
C  PRESSURES DEPENDING ON TOW FISH HEIGHT
4     IF (HTOW.GT.10.5)GO TO 5
      D=26.0
      T=10.08
      S=33.868
      P0=2.58
      GO TO 10
```

```
5      IF(HTOW.GT.15.5) GO TO 6
       D=23.5
       T=10.15
       S=33.852
       P0=2.29
       GO TO 10
6      IF(HTOW.GT.16.5) GO TO 7
       D=23.0
       T=10.21
       S=33.857
       P0=2.29
       GO TO 10
7      IF(HTOW.GT.20.5) GO TO 8
       D=21.0
       T=10.41
       S=33.839
       P0=2.09
       GO TO 10
8      D=17.0
       T=10.96
       S=33.809
       P0=1.69
C
C  SPEED OF SOUND THROUGH WATER(M/S)
C          (MACKENZIE, 1981)
10     C1=1448.96+4.591*T-5.304*1.0D-2*T**2+2.374*1.0D-4*T**3
       C2=1.340*(S-35)+1.630*1.0D-2*D+1.675*1.0D-7*D**2
       C3=-1.025*1.0D-2*T*(S-35)-7.139*1.0D-13*T*D**3
       C=C1+C2+C3
C  CONSTANTS
       PI=3.1415926
       RAD=1.74533E-2
C
C  SIDE SCAN SONAR SPECIFICATIONS
C
```

```
C    FREQUENCY   (KHZ)
      IF(ITYPE.GT.1.5) GO TO 11
C       KLEIN SYSTEM
      FKHZ=100.0
      GO TO 12
C       EG&G SYSTEM
11    FKHZ=105.0
C
C    HORIZONTAL BEAMWIDTH (DEGREES)
12    BEAMH=1.0
C
C    VERTICAL BEAMWIDTH (DEGREES)
      IF(ITYPE.LT.1.5) GO TO 19
C  EG&G SYSTEM
      BEAMV=20.0
      GO TO 18
C  KLEIN SYSTEM
19    BEAMV=40.0
C
C    PULSE LENGTH (MILLISECONDS)
18    PULSE=0.1
C
C    DEGREES DOWN FROM THE HORIZONTAL (INCLINATION)
      DEGINC=10.0
C
C    ACOUSTIC OUTPUT(DB REF 1 MICRO PASCAL)
      SL=228.0
C
C
C  CHANGE DEGREES TO RADIANS, MILLISECONDS TO SECONDS
      PULSE=PULSE*1.0E-3
      BEAMH=BEAMH*RAD
      BEAMV=BEAMV*RAD
```

```
C-----------------------------------------------------------
C    ---- REVERBERATION LIMITED----
C                    (KINSLER, 1982: P.422)
C-----------------------------------------------------------
C  RL = SL - 2TL + TS(R)
C     TS ≥ TS(R)+DT
C
C        DT - DETECTION THRESHOLD
      DT=00.0
C        TS(R)=S+10LOG R +10LOG (BEAMH*C*PULSE/2)
C                    (KINSLER, 1982: P.425)
C            S - SCATTERING STRENGTH FOR SAND
C                  DEPENDING ON GRAZING ANGLE
C            GA - GRAZING ANGLE (COMPUTED FROM
C                   TOWING HEIGHT AND RANGE)
C
C  FIND TARGET STRENGTHS FOR GIVEN RANGES
C        RJ - HORIZONTAL RANGE
C        R - SLANT RANGE
      ICOUNT=0
      DO 25 J=1,301
C
C  COMPUTE "WHITE GAP" TARGET STRENGTH FOR EG&G
C
      IF(HTOW.GT.18.0) GO TO 13
      IF(J.NE.26) GO TO 15
      RJ=16.0/TAN(33.08085*RAD)
      GO TO 9
13    IF(J.NE.44) GO TO 15
      RJ=28.0/TAN(33.08085*RAD)
9     KK=20
      GO TO 14
15    RJ=J-1
      KK=0
14    R = ((RJ**2+HTOW**2)**0.5)
```

```
C
C    REVERBERATION LIMITED
C        DETERMINE GRAZING ANGLE
      GA = ARSIN(HTOW/R)
C        USING GRAPH FIND BOTTOM BACKSCATTERING STRENGTH
C        FROM FIGURE 3.4 (MCKINNEY, 1964: P.161)
      GA=GA/RAD
      IF(GA.LT.2.0) GO TO 666
      IF(GA.GT.60.0) GO TO 25
      ICOUNT=ICOUNT+1
      RANGE(ICOUNT)=RJ
C
C   BACKSCATTER COEFFICIENTS OVER SAND BOTTOM
C
C   FOR SOLID ROCK BOTTOM COMMENT OUT THIS SECTION AND
C   INSERT OTHER COEFFICIENTS
      S=-41.5
      IF(GA.LT.2.0) GO TO 86
      IF (GA.GT.6.0) GO TO 520
      S=GA-43.5
      GO TO 86
520   IF(GA.GT.7.2) GO TO 521
      S=0.833*GA-42.498
      GO TO 86
521   IF(GA.GT.8.6) GO TO 522
      S=0.714*GA-41.641
      GO TO 86
522   IF(GA.GT.9.4) GO TO 523
      S=0.625*GA-40.875
      GO TO 86
523   IF(GA.GT.17.4) GO TO 524
      S=0.5*GA-39.7
      GO TO 86
524   IF (GA.GT.18.6) GO TO 525
      S=0.417*GA-38.256
```

```
      GO TO 86
525   IF(GA.GT.20.0) GO TO 526
      S=0.357*GA-37.140
      GO TO 86
526   IF(GA.GT.21.8) GO TO 527
      S=0.278*GA-35.56
      GO TO 86
527   IF(GA.GT.23.8) GO TO 528
      S=0.25*GA-34.95
      GO TO 86
528   IF(GA.GT.26.5) GO TO 529
      S=0.185*GA-33.403
      GO TO 86
529   IF(GA.GT.31.0) GO TO 530
      S=0.111*GA-31.441
      GO TO 86
530   IF(GA.GT.40.0) GO TO 531
      S=0.0555*GA-29.72
      GO TO 86
531   S=-27.5
      GO TO 86
C
C          SOLID ROCK BACKSCATTER COEFFICIENTS
C
C     S=-27.5
C     IF(GA.LE.2.0) GO TO 86
C     IF (GA.GT.3.0) GO TO 620
C     S=GA-29.0
C     GO TO 86
C620  IF(GA.GT.3.8) GO TO 621
C     S=0.625*GA-27.875
C     GO TO 86
C621  IF(GA.GT.4.8) GO TO 622
C     S=0.5*GA-27.4
C     GO TO 86
```

```
C622  IF(GA.GT.5.9) GO TO 623
C     S=0.4545*GA-27.182
C     GO TO 86
C623  IF(GA.GT.7.3) GO TO 624
C     S=0.357*GA-26.606
C     GO TO 86
C624  IF(GA.GT.9.4) GO TO 625
C     S=0.238*GA-25.737
C     GO TO 86
C625  IF(GA.GT.11.7) GO TO 626
C     S=0.217*GA-25.540
C     GO TO 86
C626  IF(GA.GT.14.2) GO TO 627
C     S=0.2*GA-25.34
C     GO TO 86
C627  IF(GA.GT.16.8) GO TO 628
C     S=0.192*GA-25.226
C     GO TO 86
C628  IF(GA.GT.19.7) GO TO 629
C     S=0.172*GA-24.890
C     GO TO 86
C629  IF(GA.GT.28.1) GO TO 630
C     S=0.0595*GA-22.672
C     GO TO 86
C630  IF(GA.GT.40.0) GO TO 631
C     S=0.042*GA-22.18
C     GO TO 86
C631  IF(GA.GT.57.0) GO TO 632
C     S=0.029*GA-21.66
C     GO TO 86
C632  S=-20.0
C
C  TO CHANGE SCATTERING STRENGTH TO BEING AT 1 METER
C  (MCKINNEY STATES THE VALUES AT YARDS)
86    S=S+0.7
```

```
C
C
C  CALCULATE INSONIFIED DISTANCE IN TRANSVERSE DIRECTION
C  FOR BOTTOM (AB = AREA INSONIFIED)
C
      H1=RJ-((R-C*PULSE/2)**2-HTOW**2)**0.5
      AB=BEAMH*H1
C        SEA SURFACE IS NOT INSONIFIED IF DEPTH OF FISH IS
C        GREATER THAN TOW HEIGHT
      IF(D.GE.R) GO TO 413
C
C  CALCULATE INSONIFIED DISTANCE IN TRANSVERSE DIRECTION
C  FOR SEA SURFACE  (AS = AREA INSONIFIED)
C
      RSUR=(R**2-D**2)**0.5
      RCHEK=R-C*PULSE/2
C  CHECK FOR LARGE GRAZING ANGLE
      IF(RCHEK.LT.D) GO TO 781
      H2=RSUR-(RCHEK**2-D**2)**0.5
      GO TO 782
781   H2=2*RSUR
782   AS=BEAMH*H2
C
C  CALCULATING SOURCE LEVEL DEPENDENT ON
C  ANGLE OFF ACOUSTIC AXIS
C
C    CALCULATE SURFACE GRAZING ANGLE
      GAS=ARSIN(D/R)/RAD
C    CALCULATE ANGLE FROM MAIN AXIS IN RADIANS
C       (S-SURFACE, B-BOTTOM)
      SANG=(GAS+DEGINC)*RAD
      BANG=(GA-DEGINC)*RAD
      IF(BANG.NE.0.0) GO TO 95
      HB=1.0
      GO TO 98
```

```
C
C     CALCULATE SOURCE LEVEL FOR SURFACE AND
C     BOTTOM GRAZING ANGLES
      IF(ITYPE.LT.1.5) GO TO 96
C          FOR EG&G
95    XS=8.0136600*SIN(SANG)
      XB=8.0136600*SIN(BANG)
      GO TO 97
C          FOR KLEIN
96    XS=4.0686420*SIN(SANG)
      XB=4.0686420*SIN(BANG)
97    HB=ABS(SIN(XB)/XB)
      HS=ABS(SIN(XS)/XS)
98    SLS=20*DLOG10(HS)+SL
      SLB=20*DLOG10(HB)+SL
C
C
C    ASSIGN SURFACE BACKSCATTERING VALUES FROM FIGURE 3.5
C          (URICK,1956)
C
      SUR=-53.5
      IF (GAS.GT.19.4) GO TO 720
      SUR=0.072*GAS-53.5
      GO TO 76
720   IF(GAS.GT.25.8) GO TO 721
      SUR=0.125*GAS-54.525
      GO TO 76
721   IF(GAS.GT.36.9) GO TO 722
      SUR=0.180*GAS-55.944
      GO TO 76
722   IF(GAS.GT.45.8) GO TO 723
      SUR=0.225*GAS-57.603
      GO TO 76
723   IF(GAS.GT.50.7) GO TO 724
      SUR=0.265*GAS-59.437
```

```
      GO TO 76
724   IF (GAS.GT.54.5) GO TO 725
      SUR=0.342*GAS-63.339
      GO TO 76
725   IF(GAS.GT.58.8) GO TO 726
      SUR=0.419*GA-67.536
      GO TO 76
726   IF(GA.GT.61.6) GO TO 727
      SUR=0.571*GA-76.475
      GO TO 76
727   IF(GA.GT.64.0) GO TO 728
      SUR=0.667*GA-82.387
      GO TO 76
728   IF(GA.GT.66.3) GO TO 729
      SUR=0.957*GA-100.948
      GO TO 76
729   IF(GA.GT.71.1) GO TO 730
      SUR=1.083*GA-109.303
      GO TO 76
730   IF(GA.GT.73.1) GO TO 731
      SUR=1.45*GA-135.395
      GO TO 76
731   IF(GAS.GT.74.3) GO TO 732
      SUR=2.00*GA-175.6
      GO TO 76
732   IF(GA.GT.76.8) GO TO 733
      SUR=2.04*GA-178.572
      GO TO 76
733   IF(GA.GT.81.0) GO TO 734
      SUR=3.405*GA-283.404
      GO TO 76
734   IF(GA.GT.83.0) GO TO 735
      SUR=1.9*GA-161.5
      GO TO 76
735   IF(GA.GT.85.3) GO TO 736
```

```
      SUR=1.349*GA-115.767
      GO TO 76
736   IF(GA.GT.87.7) GO TO 737
      SUR=0.708*GA-61.092
      GO TO 76
737   IF(GA.GT.89.2) GO TO 738
      SUR=0.667*GA-59.496
      GO TO 76
738   IF(GA.GT.91.1) GO TO 739
      SUR=0.316*GA-30.187
      GO TO 76
739   WRITE(6,914)
914   FORMAT(1X,'PROBLEM')
      STOP
C
C  TO CHANGE SCATTERING STRENGTH TO BEING AT 1 METER
C  (URICK STATES THE VALUES AT YARDS)
76    SUR=SUR+0.7
C
C-----------------------------------------------------------
C CALCULATE TARGET STRENGTH FOR REVERBERATION LIMITED CASE
C-----------------------------------------------------------
C
C   SURFACE REVERBERATION INVOLVED
C
      RX=-SLB+SLS+10*DLOG10(AS)+SUR
      RY=S+10*DLOG10(AB)+SLB-SLS-10*DLOG10(AS)-SUR
      RY=10**(RY/10.0)
      RCOM=RX+10.0*DLOG10(1.0+RY)
      RLTS(ICOUNT)=10*ALOG(R)+DT+RCOM
      GO TO 24
C
C   NO SURFACE REVERBERATION
C
413   RLTS(ICOUNT) =S+ 10*ALOG10(R)+10*DLOG10(AB)+DT
```

```
C
24     IF(KK.GT.10) GO TO 15
25     CONTINUE
C
C  DISPLAY RANGE AND MINIMUM TARGET STRENGTH
666    DO 50 J=1,ICOUNT
       WRITE(6,800) RANGE(J),RLTS(J)
800    FORMAT(1X,F5.0,5X,F15.1)
50     CONTINUE
       IF(ITYPE.GT.1.5) GO TO 75
C
C   COMPUTE OTHER KLEIN TOW HEIGHTS
C
       IF(HTOW.GT.12) GO TO 432
       HTOW=15.0
       GO TO 4
432    IF(HTOW.GT.17) GO TO 433
       HTOW=20.0
       GO TO 4
C
C   COMPUTE OTHER EG&G TOW HEIGHTS
C
75     IF(HTOW.GT.20) GO TO 433
       HTOW=28.0
       GO TO 4
433    STOP
       END
```

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