UNITED STATES

DEPARTMENT OF INTERIOR

GEOLOGICAL SURVEY

COLLECTION, REDUCTION and INTERPRETATION of MARINE SEISMIC SONOBUOY DATA

by

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OPEN FILE REPORT

78-442

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I. INTRODUCTION

Over the past three years the U.S. Geological Survey has been developing a program for the collection of sonobuoy seismic data aboard the U.S.G.S. research vessel S.P. LEE, and for the subsequent reduction and analysis of those data. The sonobuoy seismic studies have been conducted primarily over the Alaskan continental shelf and the contiguous deep water basins, often in conjunction with multichannel seismic reflection surveys. In this report, we wish to describe in detail the present sonobuoy program, covering both the collection of data at sea and the reduction and interpretation of data back in the office.

The report is divided into three sections. The first is a review of the main principles of seismic refraction and wide angle reflection theory, including background information for the specific techniques referred to in the report. The second section describes the equipment currently available on the S.P. LEE and contains an outline of the procedures that have been developed for data collection. In the last section, the procedures and computer program for digitizing, editing, reducing and interpreting the sonobuoy field records are described, and instructions for their use included. Following this section are numerous appendices containing program listings, derivations, examples and other useful information.

In designing the current sonobuoy program, we are indebted to investigators at Lamont-Doherty Geological Observatory and Woods Hole Oceanographic Institute who laid the groundwork in this field of study. In particular, we have adopted several procedures, especially in the area of data reduction, from a report by S.T. Knott and Hartley Hoskins (1975). Their technical report, which describes the sonobuoy program at Woods Hole, has proved invaluable in our work.

II. THE SONOBUOY METHOD

General Technique

The routine use of sonobuoys in marine geophysical studies was developed by Lamont-Doherty Geological Observatory in the 1960's, following the initial development of the technique by Hill (1963) in the post-war years. The method proved to be an economical, dependable, and relatively quick technique to determine velocity-depth variations within the sediments of marine basins. Since that time, the sonobuoy profiling method has come into much greater use in marine geophysics for the study of velocity distribution within not only sedimentary basins, but within the oceanic crust as well. The sonobuoy method enhances other standard vertical incidence seismic profiling techniques, by providing velocity information which can be used to convert reflection time on the vertical incidence record to true depth. The methods originally developed at Lamont to record, reduce and interpret sonobuoy data are still the primary basis for more recent work. Recent improvements in equipment and technology have been responsible for increased interest in the method.

Basically, a sonobuoy is a free floating buoy that contains a battery powered radio transmitter and a hydrophone. When the sonobuoy is dropped into the water from a seismic ship, the hydrophone is released and sinks to a predetermined depth. As the ship moves away, the seismic energy from the ship-towed source (usually air guns or arcer) is detected by the hydrophone and is relayed back to the ship by the radio transmitter for recording and display (see Fig. 1). The sonobuoy is usually left to scuttle itself after several hours, because retrieval is unfeasible. Sonobuoys are used to increase the range over which seismic energy is normally collected (e.g. the length of a towed hydrophone), thereby producing better reflection velocity information

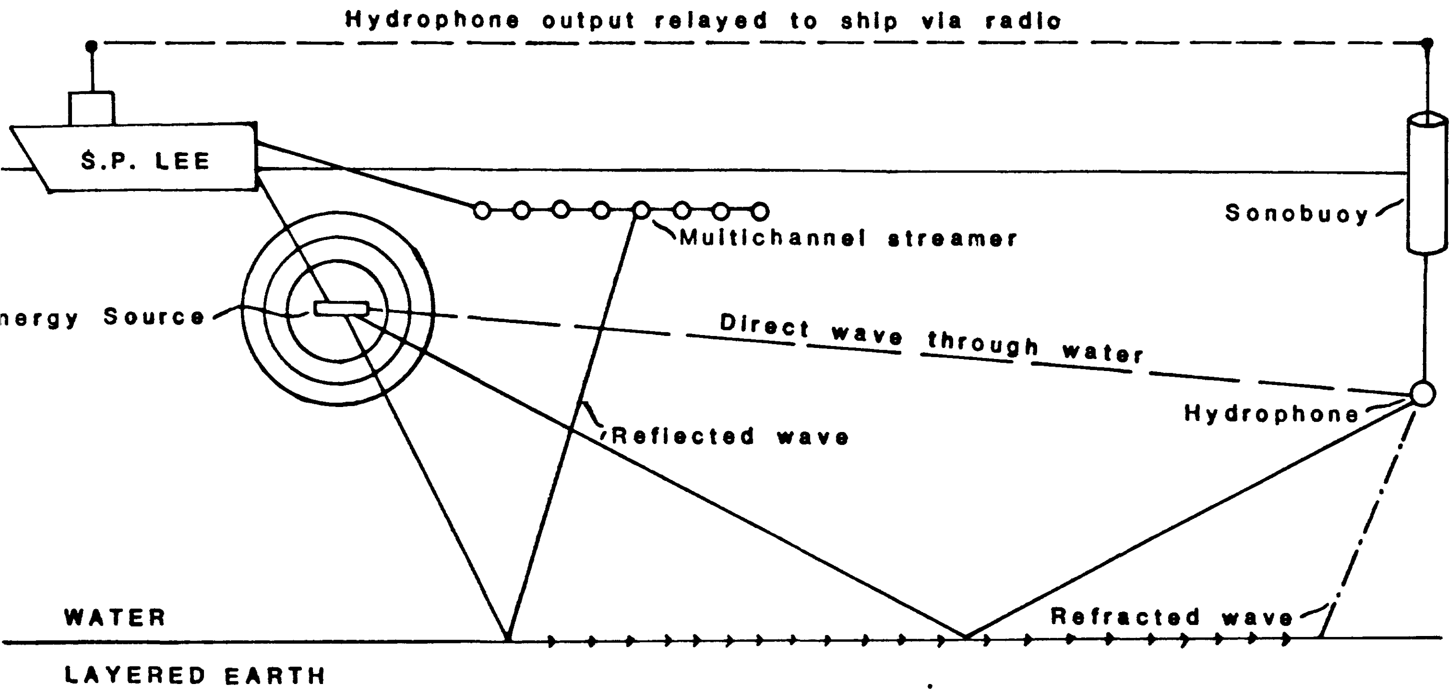


Figure 1 Schematic illustration of sonobuoy data collection, with various seismic travel paths indicated. Only one interface (the seafloor) is shown. Compare with subsequent figures (2-5) to see how these paths are displayed graphically

from deep sedimentary and crustal layers, as well as detecting refracted energy from these same deep layers. Before the development of sonobuoy methods, refraction studies were limited to two ship operations, involving high, often prohibitive costs. Now, these refraction surveys can be done concurrently with other geophysical studies by using the relatively inexpensive, expendable sonobuoys. Appendix A illustrates the types of research problems for which the sonobuoy technique is well suited.

The use of high energy, rapidly firing, seismic sources, initially developed for multichannel seismic reflection work, has dramatically improved the quality of sonobuoy data. These sources provide a highly consistent and coherent outgoing pulse. Consequently, the reflected and refracted arrivals from deep as well as shallow sedimentary and crustal layers can easily be identified when displayed on high density (40 shot traces per inch) graphic recorders, often out to distances exceeding 40 kilometers. Figures 2 and 3 illustrate graphically recorded sonobuoy data using a large airgun source (1326 cu in. - 5 gun array) in shallow and deep water areas respectively. At the deep water station (Fig. 3), the large source provided sufficient energy to penetrate the entire sedimentary section and refractions were observed from sub-basement (crustal) layers down to and including the mantle.

Methods of Analysis

The analysis of wide-angle reflection and refraction seismic data is normally based on standard ray tracing theory, which can be found in any text on applied geophysics (Dobrin, 1960, ch 5, 6; Telford et al., 1976, ch 3, 4; Officer, 1958, ch 2). LePichon et al. (1968) have applied the generalized theory to the specific case of wide angle reflection data from sonobuoys. Computer programs for analyzing both the sonobuoy wide angle reflection data

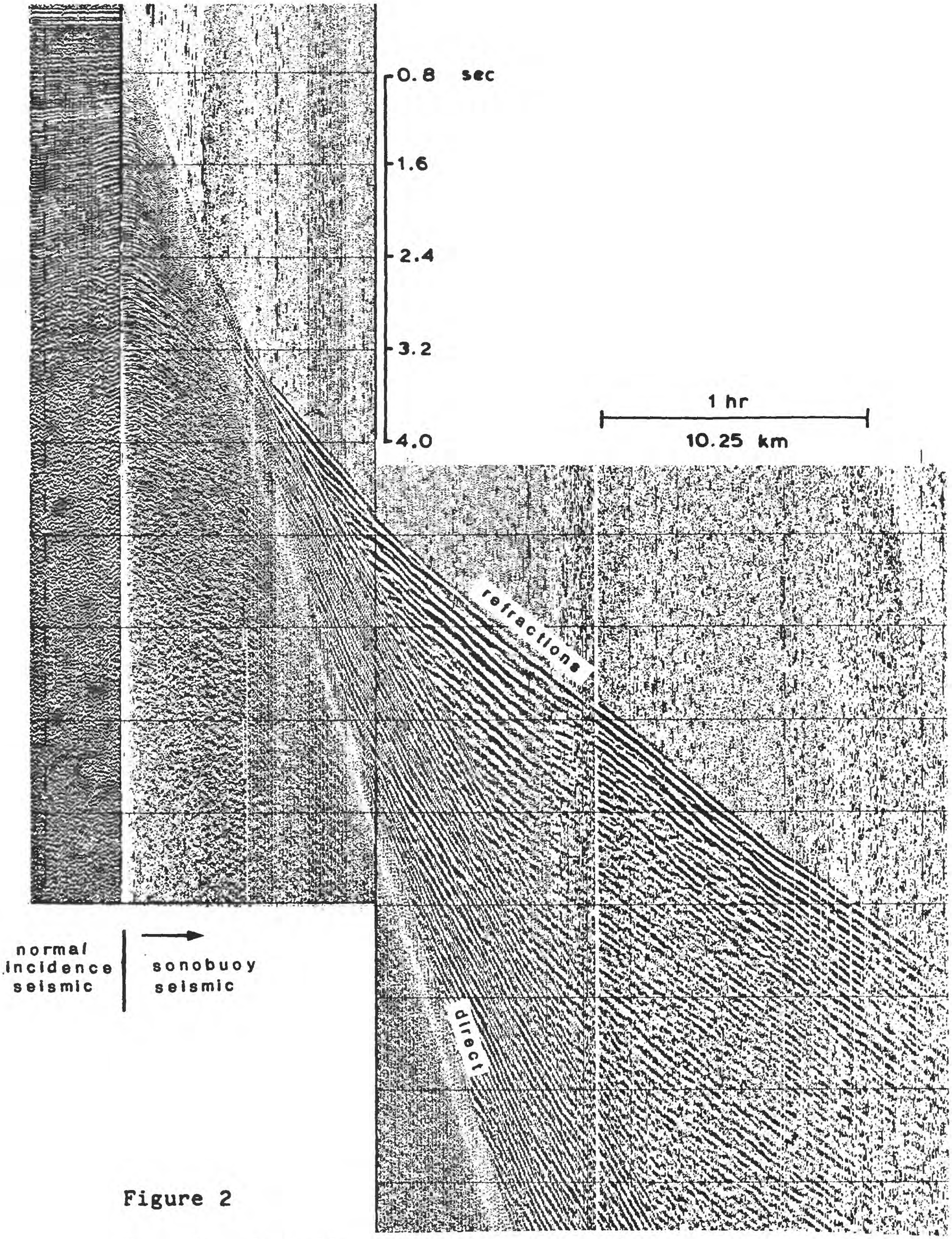


Figure 2

Example of shallow water (150 meters) sonobuoy record. (Recording 0 - 8 seconds.) Several minutes of vertical incidence seismic were recorded just prior to the launch of the sonobuoy. Observe that all refractors come in a as first arrivals. (Compare with Figure 5.)

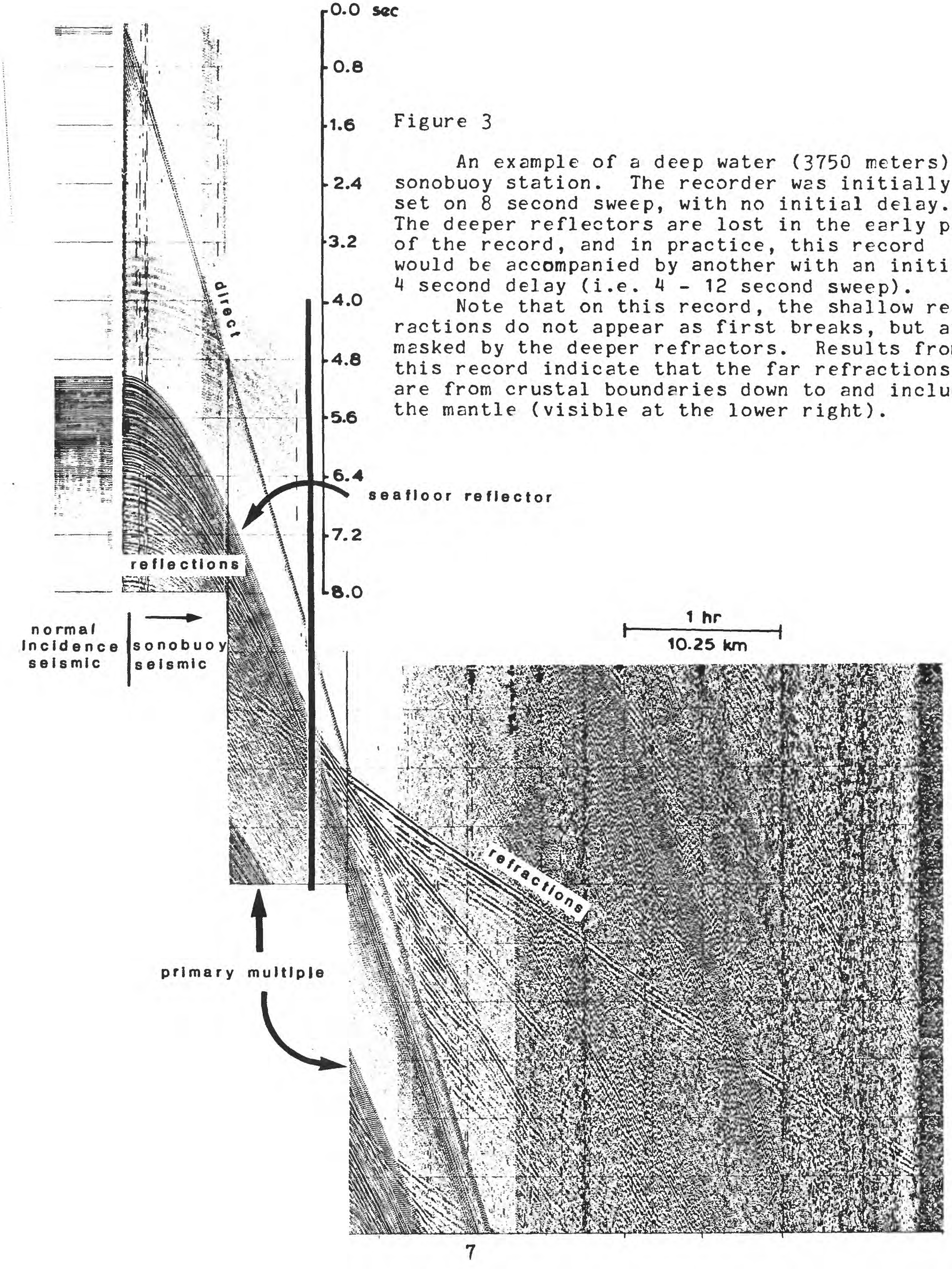


Figure 3

An example of a deep water (3750 meters) sonobuoy station. The recorder was initially set on 8 second sweep, with no initial delay. The deeper reflectors are lost in the early part of the record, and in practice, this record would be accompanied by another with an initial 4 second delay (i.e. 4 - 12 second sweep).

Note that on this record, the shallow refractions do not appear as first breaks, but are masked by the deeper refractors. Results from this record indicate that the far refractions are from crustal boundaries down to and including the mantle (visible at the lower right).

(LePichon's method) and the sonobuoy refraction data (general method) are given by Knott and Hoskins (1975). We will summarize briefly the basis for these methods.

The ray paths and the time-distance plots for seismic waves in a simple two layer model (water overlying sediment) are shown in Figure 4. Three basic travel paths are involved; the direct, the variable angle (wide angle) reflections, and the refractions. The direct arrival is the energy that travels through the water from the sound source directly to the hydrophone. On the time-distance plot the direct arrival is a straight line; the slope of this line is the reciprocal of the horizontal velocity of sound through the water near the sea surface. The direct arrival can, therefore, be used to determine the distance from the ship to the sonobuoy (the product of the direct arrival time, T_d, and the horizontal velocity, v_H). In practice, it is assumed that the horizontal water velocity, rather than the separation distance, is known, primarily because navigational uncertainties and sonobuoy drift introduce unknown errors into the separation distance. Once the horizontal velocity is determined, through Matthew's Tables (Mathew, 1939; also in Handbook of Oceanographic Tables, 1966), or similar tables (National Ocean Data Center, 1968), or through surface temperature and salinity measurements (including expendable bathythermographs: XBT's), then careful recording of the direct arrival times obviates the requirements that both ship navigation (course and speed) and buoy position remain constant during the sonobuoy station. Small deviations in these parameters (ship course, speed, and buoy position) will cause small changes in the slope of the direct arrival trace, but these changes are irrelevant if the proper data reduction method is used. See Appendix B for a discussion of sound velocity in water.

Seismic energy travels through the earth with a velocity which is dependent not only upon the material through which it is travelling, but also upon the manner in which it is propagating (e.g. compressional waves, shear waves, etc.). Sonobuoy data can be used to determine: rms (for root mean square) velocity from wide angle reflections and head wave (also called refraction) velocity from refractions.

The rms velocity is an "average" velocity for all the material (water and rock) lying between the sea surface and the reflecting interface. This is the same velocity that is determined through analysis of multichannel data, but sonobuoy reflection data is collected over a considerably greater distance (typically 6 km for a sonobuoy station in 300 meters of water). The theory and geometry for determining rms velocity from wide angle reflections is presented in Appendix D. Briefly, the curve on a time-distance plot(as shown in Fig. 4) that results from a flat reflecting plane (boundary) is a hyperbola:

$$T^2 = T_o^2 + \frac{1}{V_{rms}^2} X^2 \qquad (1)$$

This equation is linear in X^2 and T^2. Therefore, if we measure the values of X and T along an experimental reflection hyperbola and plot X^2 versus T^2, the X^2, T^2 points will lie along a straight line. The slope of this line, $(1/v_{rms}^2)$ is the reciprocal of the square of the rms velocity (v_{rms}), while the intercept of the line with the T^2 axis is the square of the minimum reflection time (T_o) to the horizon. This plot is referred to as an $X^2 - T^2$ plot, and this type of analysis referred to as an $X^2 - T^2$ velocity determination. The rms velocities from two reflecting horizons can be used to determine the interval velocity (V_{int}) between those two horizons. The interval velocity, which is the seismic wave velocity over a specific depth interval, can be computed in either of two ways: the first employs an approximate method

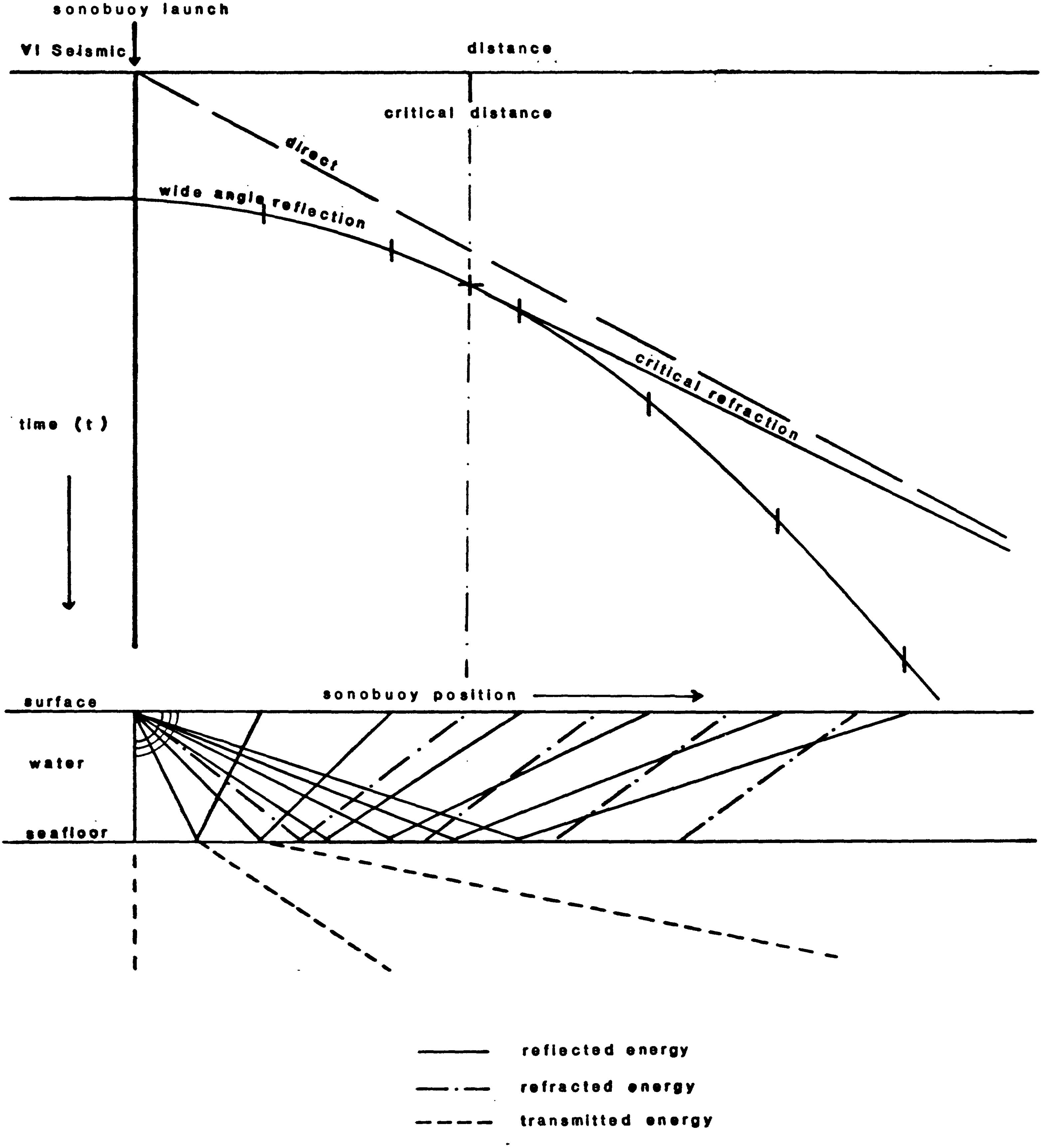


Figure 4 Schematic diagram illustrating the relationship between the seismic travel paths as seen on the graphic record of a sonobuoy. Note that in this representation, we've shown the source as stationary and the sonobuoy position as variable. In practice just the reverse is true, but the two cases are completely symmetric.

described by Dix (1955) while the second uses a more sophisticated ray tracing technique described by Le Pichon, et al. (1968). The latter method is described in detail in Appendix D, Part III, and is the basis for the computer program SLOWI described later in this report (Section IV).

The refraction velocity is the speed at which seismic energy propagates along an acoustic interface. With homogeneous layers, as in the model of Figure 4, the refraction velocity is equivalent to the interval velocity in the layer beneath the interface. In reality, however, an interval velocity usually encompasses several discrete rock layers, and the refraction velocity represents the "fastest" of those layers near the top of the interval. Therefore, the refraction velocity tends to be higher than the associated interval velocity. Furthermore, as pointed out by Knott & Hoskins (1975, p. 6) "sediments frequently display velocity anisotropy, in which the velocity of propagation along the bedding is significantly higher than the velocity transverse to the bedding in the same material". Refractions only occur when the interval velocity in the underlying layer is greater than the overlying layer, and are not detected until the distance between the ship and the sonobuoy exceeds the "critical distance", as determined by Snell's Law. On the time-distance plot (Figure 4), refractions appear as straight lines; the slope of the refraction ($1/v_{ref}$) is the reciprocal of the refraction velocity. When an acoustic interface produces both a reflection and a refraction, the refraction appears as a tangent to the corresponding reflection on the time-distance plot, and "peels off" from the reflector as a straight line. The point of tangency is the critical point. Since the critical distance is the point beyond which total internal reflection occurs (i.e. beyond which there is no transmitted energy), the amplitude of the reflected arrival increases at this point. This amplitude increase often helps identify the point at which the refraction arrivals should start to appear.

Figures 5 and 6 are synthetic plots of sonobuoy records in shallow and deep water respectively illustrating these travel time curves and their relationship.

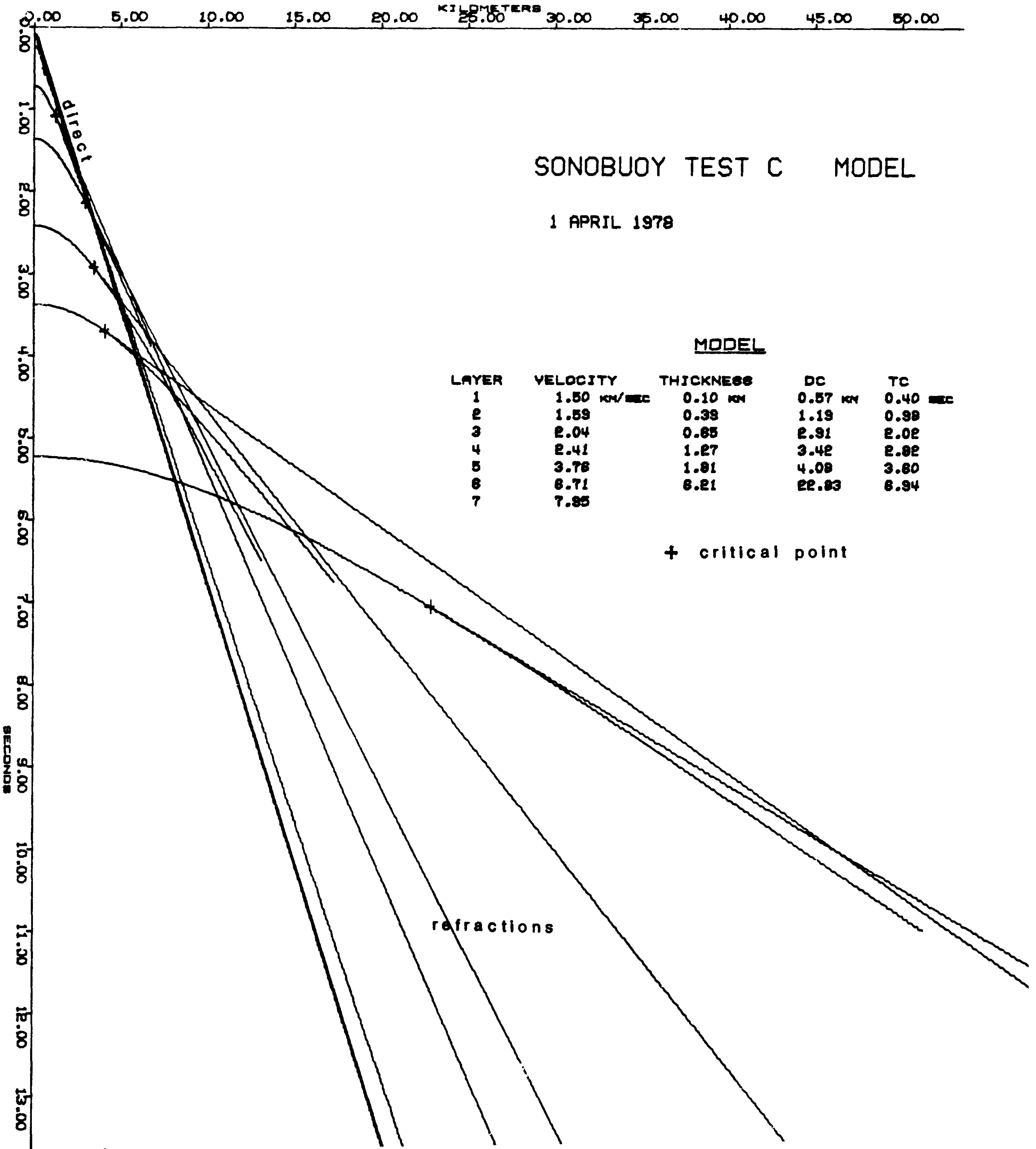


Figure 5 Artificial sonobuoy record based on a shallow water (100 meters) model. The table indicates the velocity and thickness of each layer in the input model, as well as the critical distance (DC) and critical time (TC) calculated by the program. The model assumes flat lying layers. The finite extent of the wide angle reflections is a result of the mathematical equations used to calculate them. (Compare with Figure 3. This plot produced by the program SONOMODEL.)

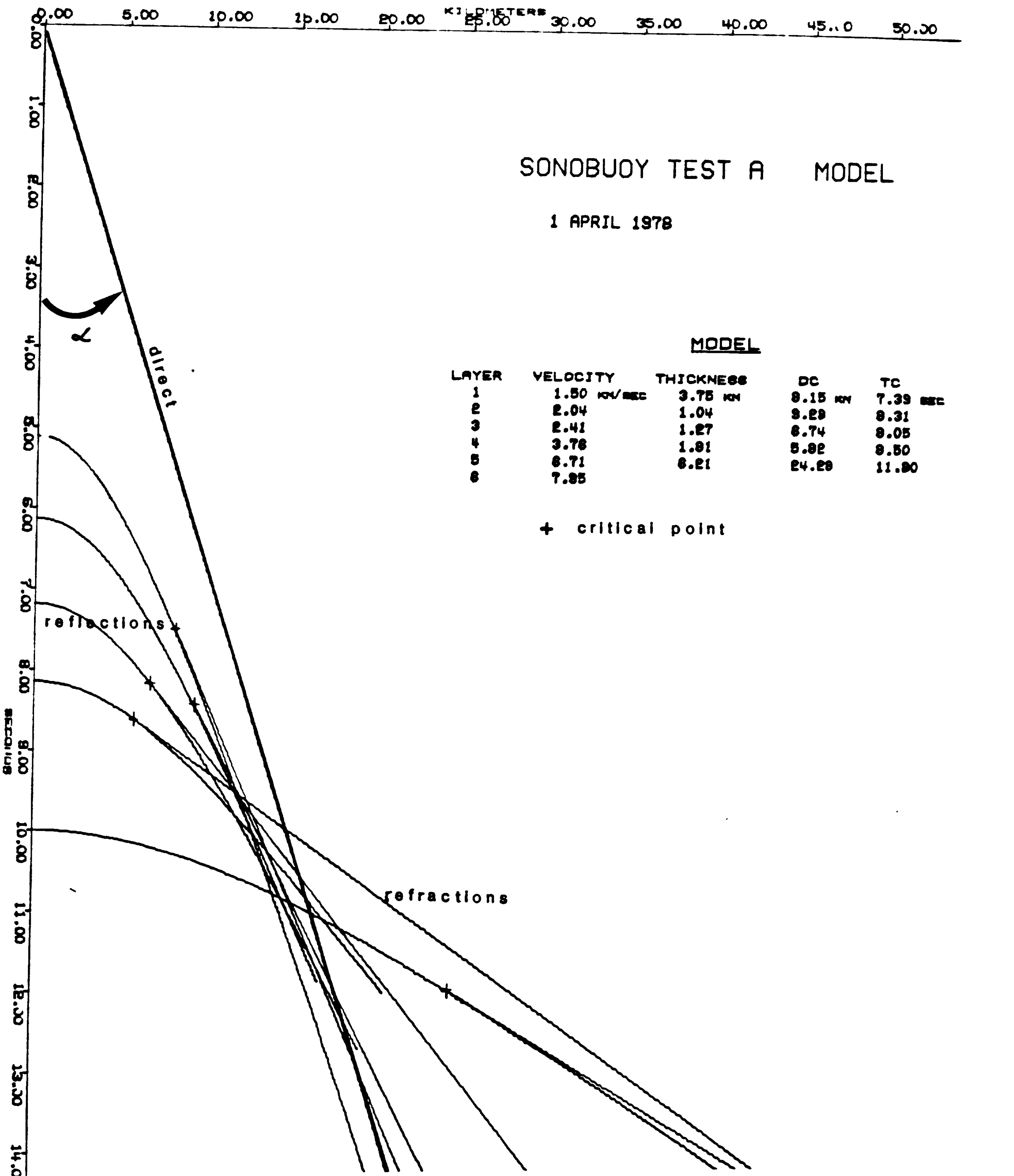


Figure 6 Artificial sonobuoy record based on a deep water (3750 meters) model. See Figure 5 for description. Note how the shallow refractors are masked by the deeper arrivals. (Compare with Figure 4.)

III. FIELD OPERATIONS

General Information

Knott & Hoskins (1975) note that there are three possible modes for recording sonobuoys. The first is to have a free running source and a shot actuated recorder; the second is to use a continuously running recorder (controlled by a time base), which keys the source; and the third is to use triggered recorders and triggered sources controlled by an independent timer. The first system is used primarily by Lamont-Doherty (Knott & Hoskins, 1975, p. 7), while Woods Hole relies exclusively on the second method. Because much of our sonobuoy work on the S.P. LEE is concommitant with multichannel operations, we use the third method almost exclusively. (In a few instances during high resolution seismic surveys, the second method has been used.) In standard operation, the navigation system generates a trigger pulse at 50 meter intervals that simultaneously fires the air gun array and starts the graphic recorders for the sonobuoy. At normal operating speeds of 5.5 knots, the airguns fire every 17 seconds. The airgun array used for our sonobuoy and multichannel operations is a five gun tuned array with a total volume of 1326 cu. in., which is fired at a pressure of approximately 1800 psi. The individual airgun sizes are 94, 148, 195, 309, and 580 cu in.

During field recording, the sonobuoy data is displayed in real time on one or more graphic recorders and is simultaneously recorded on analog magnetic tape. Figure 7 shows a schematic diagram of the current sonobuoy system aboard the S.P. LEE and indicates the signal path for the seismic information during recording of a sonobuoy.

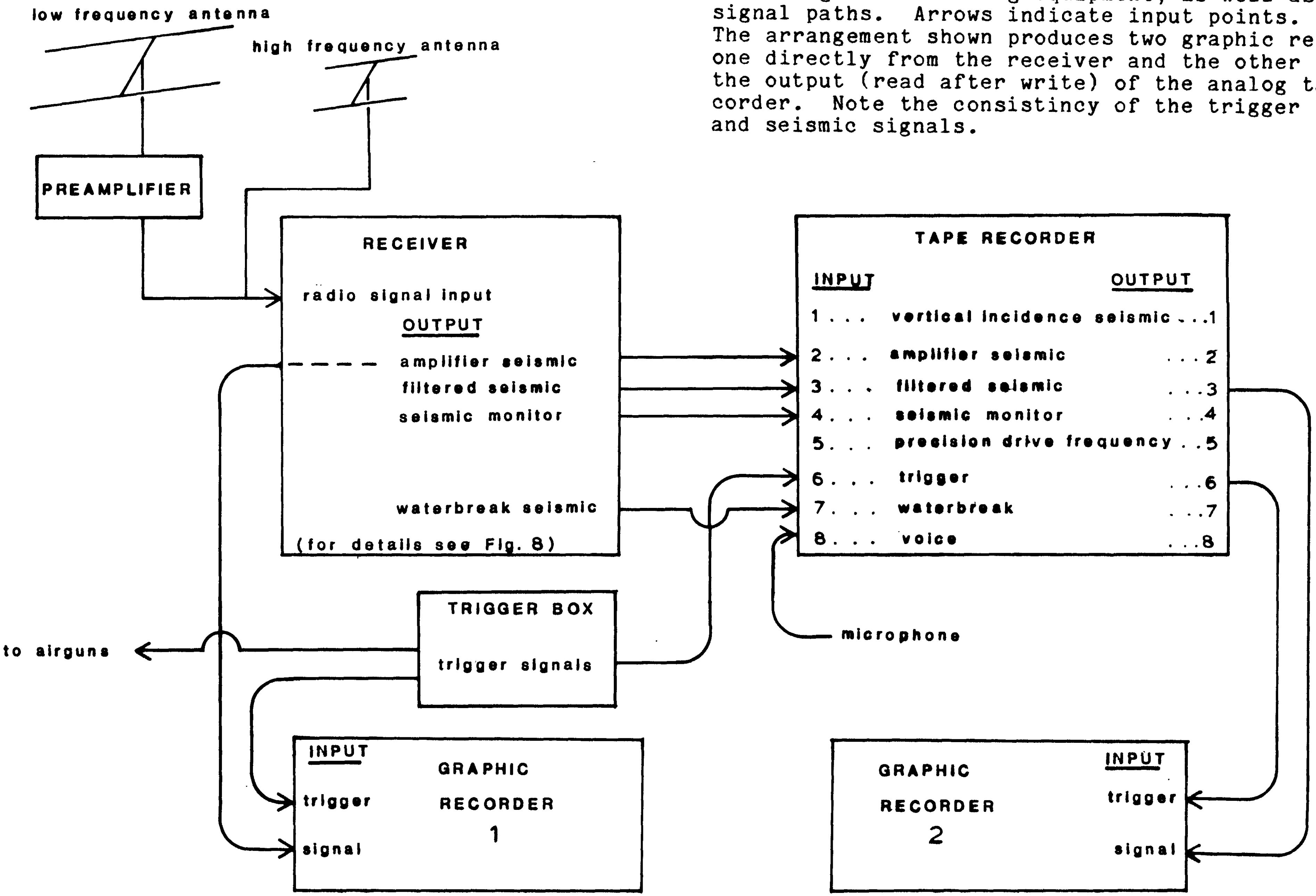


Figure 7 Schematic diagram indicating the juxtaposition of receiving and recording equipment, as well as the signal paths. Arrows indicate input points. The arrangement shown produces two graphic records, one directly from the receiver and the other from the output (read after write) of the analog tape recorder. Note the consistincy of the trigger signals and seismic signals.

Equipment Description

Sonobuoys

The sonobuoys used aboard the S.P. LEE are of two basic types: those purchased from private industry and those procurred from the U.S. Navy (see Appendix A for criteria in deciding which type of sonobuoy to use). The commercial seismic sonobuoys are available from Fairfield Industries, Inc., Fairfield Select Division, of Houston, Texas, and from Refraction Technology, Inc. of Irving, Texas. Sonobuoys produced by the two companies are very similar electronically, but differ in the design of the hydrophone suspension system. Both companies provide the same options with buoys.

1. Radio frequency band

Each sonobuoy transmits on a specific channel, in either the low frequency range (74-76 MHz) or the high frequency range (170 MHz). The lower frequency range generally allows for longer broadcasting distances and requires a larger antenna.

2. Hydrophone suspension

The sonobuoys are generally equipped with variable length hydrophone suspensions ranging from 30 to 240 foot depths. The longer suspensions (i.e. deeper hydrophones) generally give better isolation from surface noise. However, the thermal density (velocity) stratification in the upper part of the water column can cause the direct arrival to be totally reflected away from a very deep hydrophone (refer to App. B).

3. Delayed hydrophone release

When sonobuoys are deployed during multichannel operations, a delay mechanism for the sonobuoy hydrophone release is used to avoid fouling the sonobuoy on the multichannel streamer. A 20 minute delayed hydrophone release timer is provided with each sonobuoy to allow sufficient time for the sonobuoy to clear the end of the multichannel streamer. The timer may be disabled for sonobuoy deployment during single channel operations.

4. Amplifier gains

Commercial sonobuoys are available with either fixed gain or automatic gain control amplifiers. Most buoys now in use on the S.P. LEE are fixed gain type, which allow greater control of recording gains on both the graphic and tape recorders.

The Navy sonobuoys used on the LEE have been either SSQ-41A or SSQ-41B. The SSQ-41A sonobuoys have a higher frequency response and shorter antennas than the commercial seismic buoys. Consequently, the seismic range of the 41A buoys is less than the commercial buoys and low frequency seismic information from deep interfaces is lost. The SSQ-41B sonobuoy is basically a 41A that has a lower frequency response, roughly equivalent to the commercial buoy. Because both types of the Navy sonobuoys have a high frequency bandpass filter, they generally provide a strong direct arrival signal, as well as excellent resolution at shallow depths. The poor low frequency response of the SSQ-41A sonobuoys make them less suitable for studying deeper reflections and refractions. All Navy sonobuoys are equipped with standard 300 foot hydrophone lower and have no delayed hydrophone release timer. However, since the hydrophone assembly is readily accessible, if necessary it can be tied off at a shallower depth, or a "lifesaver" delayed hydrophone release can be installed. Great care should be exercised when using the Navy sonobuoys concurrently with multichannel operation, because of the risk of damaging the multichannel streamer with the sonobuoy hydrophone cable.

Receivers

The signal transmitted from the sonobuoy is received on ship by one of two Yagi antennas mounted on the aft mast; separate antennas are required for

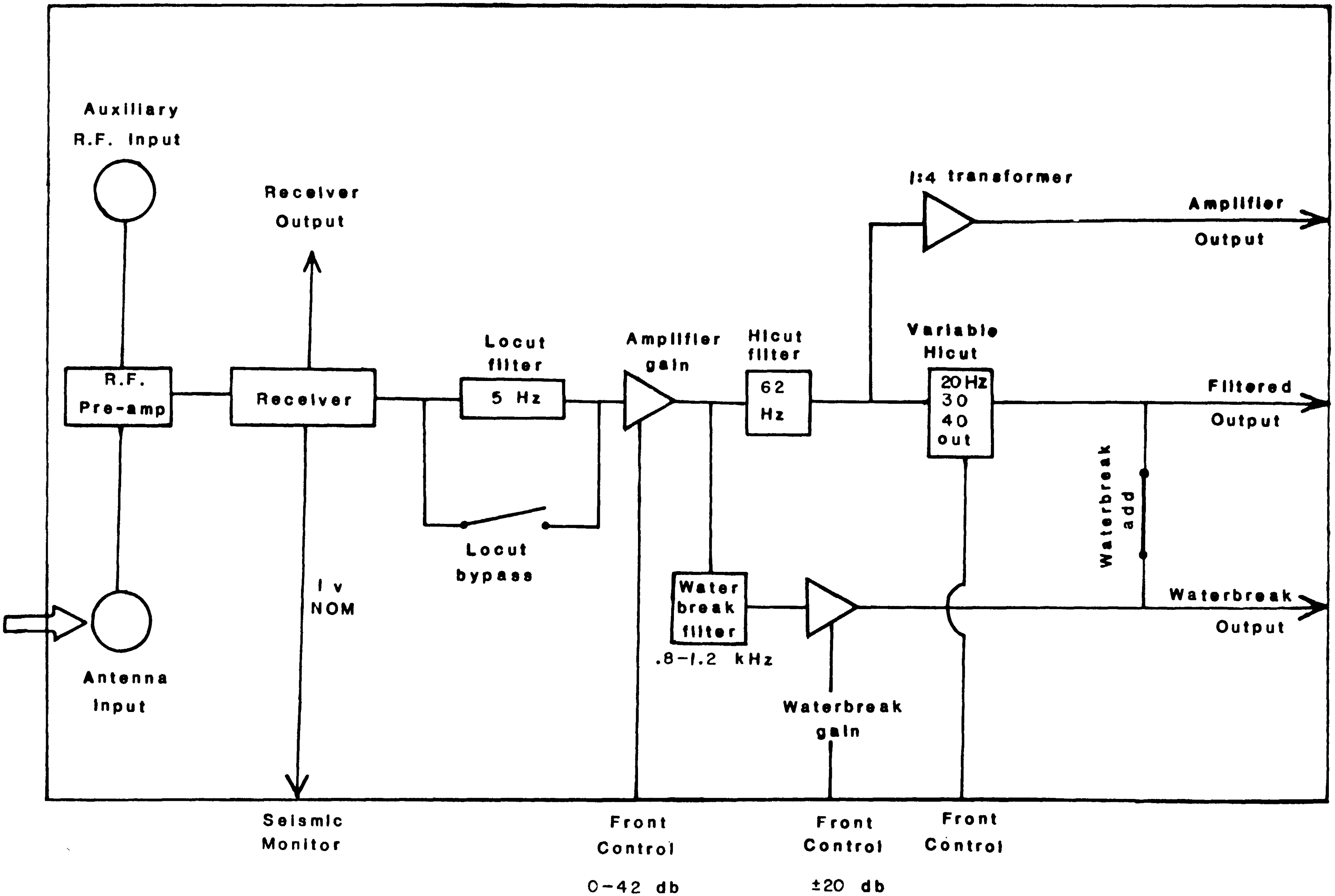


Figure 8 Schematic diagram of signal splitting and filtering circuitry of the Aquatronix receiver. Large arrows indicate input, small arrows output. Compare with Figure 7 for relationship with recording apparatus.

low and high frequency sonobuoys. The high frequency signal passes directly to the receiver, while the low frequency signal is preamplified before entering the receiver.

Two Aquatronix (now Fairfield Select, Inc.) mainframe receivers, each containing two separate crystal controlled receiving modules can be used to receive either commercial or Navy sonobuoys. Since sonobuoys with different transmitting frequencies can be received simultaneously by the two modules in both receivers, four separate sonobuoys can be received simultaneously with this equipment.

Within the receiver, the unprocessed sonobuoy signal is passed through a series of filters and amplifiers. The radio signal is first passed through a 5 Hz lo-cut filter and gain amplified. The signal is then split into two components: the seismic signal, 5-62 Hz, and the waterbreak signal, 800-1200 Hz. The seismic component is passed through a variable hi-cut filter, while the waterbreak component is amplified $\pm$ 20 db with respect to the incoming signal. The two components are then recombined and output to the recorders, and are also output separately as amplified output and waterbreak output. Figure 8 shows the receiver circuit schematically.

A third receiver, made by Nems-Clarke, Inc., which can be selectively tuned to any sonobuoy transmitting frequency, is used primarily as a backup unit. The demultiplexed signal from the Nems-Clarke receiver is fed into the filter-amplifier circuitry of the Aquatronix receiver through the auxiliary RF input to take advantage of the bandpass filtering and mixing capabilities of the Aquatronix receiver (see Figure 8).

Analog Tape Recorder

All sonobuoy data is recorded both on graphic recorders and analog magnetic tape. The tape recorder used is the Hewlett-Packard 3968A, a quarter-inch eight track instrumentation tape recorder capable of recording either FM or Direct (AM) modes. In single buoy operations, the channels are generally assigned in the following manner:

Channel 1 (FM): vertical incidence single channel seismic, from either single channel system and Teledyne amplifier, or a monitor channel from the multisystem

Channel 2 (FM): unfiltered sonobuoy seismic; from the seismic monitor of the sonobuoy receiver (see Fig. 8)

Channel 3 (FM): filtered sonobuoy seismic; from the filtered output of the sonobuoy reciever (see Fig. 8)

Channel 4 (FM): amplified sonobuoy seismic; from the amplifier output of the sonobuoy receiver (see Fig. 8)

Channel 5 (FM): tape recorder precision drive frequency; an internally derived crystal frequency for playback control (see page 22)

Channel 6 (FM): airgun trigger; trigger pulse from the multichannel trigger box, which also triggers the graphic recorders

Channel 7 (Direct): waterbreak output; filtered (800-1200 Hz) output from the sonobuoy receiver (see Fig. 8)

Channel 8 (Direct): voice channel and WWV time record

The magnetic tape used for sonobuoy recording is 1/4 inch, 1/2 mil thick instrumentation magnetic tape. The tape is intermediate band (DC-20 kHz), which is completely satisfactory for sonobuoy recording and a fraction of the cost of wide band instrumentation tape. The tape recorder requires 7 inch tape reels, which will accommodate 3500 feet of 1/2 mil tape.

The 3968A is a six speed recorder, with a range from 15/32 to 15 inches per second. We generally record all sonobuoys at 3 3/4 ips. This, is the lowest tape speed which will allow seismic information (5-62 Hz) as well as the waterbreak signal (800-1200 Hz) to be recorded on a single FM tape channel. At this speed, a 3500 foot tape (7 inch reel) will last for about 3 hours, usually long enough for one sonobuoy station, especially in shallow water. However, longer range sonobuoys may require two tapes to record the distant refractors. The problem of switching tapes can be avoided by reducing tape speed to 1-7/8 ips. In order to preserve the direct arrival (waterbreak) at the lower tape speed (FM bandpass at 1-7/8 ips is DC-625 Hz), the waterbreak (Channel 7) must be mixed with the sonobuoy seismic (Channel 3) when the tape is replayed.

To insure accurate replay of recorded sonobuoys, it is necessary to devote one channel (FM or Direct) to record the precision drive frequency generated by the tape recorder. The precision drive frequency is used to phase lock the capstan motor during replay, thereby compensating for small deviations in tape speed that occurred during recording. A channel near the center of the tape (track 4 or 5) should be used for this purpose, and if an FM channel is used, the board must be modified slightly. Instructions for recording the precision drive frequency are found on pages 64-67 of the Operating and Service Manual.

Since the 3968A recorder can record and playback simultaneously, the data going onto tape can be monitored in real time if the seismic channel (Channel 4) and the trigger pulse channel (Channel 6) are input to a graphic recorder. The disadvantages of this procedure are that the recorded signal may be slightly inferior to the original signal, and that a malfunction in the tape recorder will result in complete loss of information. We normally make two records, one using output directly from the receiver and the other using output from the tape recorder.

The tape recorder should be maintenanced periodically, particularly when undergoing heavy use. Routine maintenance is covered on pages 50-55 of the Operating and Service Manual. The most critical maintenance function is careful cleaning of the tape heads and drive capstan after every sonobuoy station. Oxide buildup on the record heads can seriously degrade the record quality, while oxide buildup on the capstan drive will cause tape slippage. The problem of capstan slippage may become so serious that the tape will stop completely while the capstan continues to spin. Another advisable procedure is to periodically degauss the tape heads.

Graphic Recorders and Recording Techniques

The filtered output (5-62 + 800-1200 Hz) from the sonobuoy receivers is displayed in real time on one or more Raytheon Universal Graphic Recorders (UGR's). These dry paper, fascimile recorders are capable of operating in either a continuous mode or a start/stop mode, at sweep speeds ranging from 1/4 to 8 seconds. Normally, sonobuoys are recorded in the start/stop mode with sweep speed of either 6 or 8 seconds. The recorder sweep is initiated by a trigger pulse from the navigation system, which also triggers the airguns. Because of mechanical delays in firing the airguns, there is usually a small time delay between the air gun fire and the sweep trigger.

When recording sonobuoys in deep water areas, a sweep start delay of between 0.1 and 9.9 seconds is used to eliminate recording the water path travel time. This delay option is only possible in the start/stop mode, and makes it possible to record continuously a "full page" of seismic information. Whenever the seismic data approaches the bottom of the record, an additional delay is added and the seismic data is shifted up the record. This procedure allows us to obtain a complete and continuous record of both the seismic and direct traces which is free from having an overprinted multiple trace. Such a record is not possible in a "continuous" record mode.

There are two limitations to the start/stop recording technique. The first is that the total time (delay plus sweep) cannot exceed the fire rate, otherwise the recorder will miss every other shot and the vertical exaggeration of the record will change. For example, with an eight second sweep and a 17 second fire rate, the maximum allowable delay (for removing the water travel time) would be 8.9 seconds (.1 second must be allowed for the recorder to stop and prepare for the next trigger. The second limitation is encountered on very long sonobuoys, when the direct trace goes off the bottom of the record because an additional delay would either exceed the fire rate and cause missed shots or would shift seismic information up and off the top of the record.

The resolution and vertical exaggeration of the graphic sonobuoy record depend on three parameters: recorder sweep speed, recorder paper feed and the seismic shot interval. These factors must be optimized to obtain a record that has low vertical exaggeration, provides good resolution of reflectors, and contains all the seismic data of interest. Often, two records with different parameters must be made to satisfy this objective.

The resolution of the sonobuoy record depends on the sweep speed of the graphic recorder. Knott & Hoskins maintain (p. 18) that a sweep speed of at least 7 cm (2.7 in.) per second is necessary to obtain measurements to $\pm$ 3 m sec required for reliable analysis. With our digitizing system, a slightly smaller scale appears to be sufficient. The paper for the UGR recorder is 48 cm. (19 in.) wide, so a six second sweep is 8 cm/sec, while an eight second sweep is 6 cm/sec. With normal sonobuoy operations, either one of these two sweep speeds will provide adequate resolution. The eight second sweep speed is preferable in deep crustal velocity studies because of the longer recording period that is possible.

The vertical exaggeration of the sonobuoy record depends on both the recorder paper feed and the seismic shot interval. A lower vertical exaggeration makes it easier to correlate events from one sweep of the recorder to the next. During multichannel operation, the seismic shot interval is fixed by the multichannel system, usually at 50 meters. With the single channel system, however, almost any shot interval can be used subject only to the recharge capability of the air gun compressors. In the start/stop mode, the optimal shot interval is the shortest time between shots that will give a complete record of the seismic section at large distances from the buoy. This interval depends on water depth, sediment thickness, anticipated sub-crustal seismic penetration, etc. In the continuous record mode, the optimal shot interval is the shortest possible time between shots (see Knott & Hoskins, 1975, pp. 16-24). The paper feed on the UGR recorders, which ranges from 40 to 120 lines per inch, is coupled to the pen sweep, so that whenever the pen sweeps, the paper feeds. The maximum feed rate, 40 lines per inch, is advisable when recording sonobuoys because it gives the lowest vertical exaggeration and it will facilitate the counting of individual seismic traces during the data reduction.

Vertical exaggeration is an important consideration when dealing with wide angle reflection records. Refractions are easily correlated at even high vertical exaggeration, but wide angle reflections become difficult to distinguish and pick when the curvature of the reflectors becomes too steep. Vertical exaggeration can be expressed as the angle that the direct arrival makes with the edge of the paper ('α', Fig. 6). For reasons relevant to their own processing technique, Knott & Hoskins (1975, p. 18) suggest that this angle be less than 45°. We have found that an angle of 18° is quite satisfactory. The 18° angle is obtained on our records using an eight second sweep speed, a feed rate of 40 lines per inch, and a 50 meter fire interval. An angle of as little as 13° is also satisfactory, but anything less make correlation of successive sweep difficult. To determine what this angle will be for different recording parameters, use the equation

$$\alpha = \arctan\left[\frac{sw}{n * r * ss * 0.006477}\right] \qquad (2)$$

where

α = angle of direct trace

sw = sweep speed

n = number of lines per inch

r = fire rate (in seconds)

ss = ship speed (in knots)

Sonbuoy Preparation and Launch

A number of steps must be completed in preparation for the launch of a sonobuoy. These steps are summarized in the accompanying checklist, Table 1, and it is advisable to follow such a checklist when preparing to deploy a sonobuoy.

TABLE 1

Checklist for sonobuoy preparation and launch

1. Prelaunch check of sonobuoy
   a. If possible, start transmitting on deck to ensure that sonobuoy batteries are working and that the selected crystal frequency is correct.
   b. Check the hydrophone lower depth and delayed release timer
2. Notify radio officer and bridge of intent to deploy buoy
3. Fill out log forms
4. Prepare analog tape recording system
   a. Voice introduction, including date, time, identification, etc.
   b. Set footage counter
   c. Check input levels on each channel
5. Start recording vertical incidence seismic on tape and graphic recorders
6. Prelaunch lab check
   a. Ensure that the correct crystal is being used in the receiver and that all recorder inputs are coming from the receiver module used
   b. Ensure that the correct initial settings (gain, hicut filter, waterbreak gain) have been set on the receiver
   c. Ensure that antenna preamp gain has been turned down (for low frequency sonobuoys)
   d. Check signal paths (seismic signal and triggers) to both graphic and analog tape recorders
7. Proceed with countdown to launch
   a. Radio operator on deck counts down airgun shots, and reports when the sonobuoy is in the water and adjacent to the airguns
   b. Lab procedure:
      1. Record start of countdown on tape
      2. Set correct feed rates on recorders
      3. Set proper display mode on recorders
      4. Switch recorder input from vertical incidence seismic to sonobuoy seismic
      5. Mark the first trace (when sonobuoy at airguns) on the recorders
      6. Record time and footage reading in log and on tape recorder
      7. Retune the sonobuoy on the receiver
      8. Adjust the graphic recorders for optimum display

(1) Prelaunch check of the sonobuoy

In preparing commercial sonobuoys for launching, it is advisable to attach the antenna securely to the sonobouy case with fiber tape and seal the base with polyvinyl chloride (PVC) glue to avoid antenna breakage or water leakage. The hydrophone release should be set to the desired depth (refer to App. B for criteria) and the timer activated or deactivated as required. If possible, the sonobuoy should be activated on the deck, to allow checking the sonobuoy batteries, receiver crystal, etc. If anything appears to be wrong with the sonobuoy, it is advisable to stop the entire operation until the problem is corrected or the sonobuoy is replaced.

(2) Notify radio officer and bridge

Both the radio officer and the bridge should be notified at least 10 minutes prior to the deployment of a sonobuoy. Some types of radio transmission will interfere drastically with the sonobuoy signal, and the notification will allow the radio officer time either to complete the transmission or to postpone it until after the sonobuoy station. Since a sonobuoy station may last for several hours, it is courteous to give the radio officer up to several hours warning of a sonobuoy station so that the transmitting schedule can be altered accordingly. The bridge should be notified before any activity on the fantail, especially deployment of equipment. In addition, the bridge should be notified prior to a station so that speed and course changes will be avoided if at all possible. In this regard, it is also helpful to notify the navigation watch so that course or speed changes will not be requested from the lab.

(3) Fill out log forms

Log forms, as shown in Figure 9, should be prepared for each sonobuoy prior to launch. These forms contain all information essential for later

Figure 9 Example of sonobuoy station log. Sonobuoy recorded on two recorders (0-6 and 4-12 seconds) with underway multichannel operations.

SONOBUOY STATION LOG

I SHIP R/V S.P. LEE

CHIEF SCI. A. Cooper

GENERAL AREA N Aleutian Basin

APPROXIMATE LATITUDE 58°5' / 58°25'

LONGITUDE 176° 51' / 177° 32' E

WATER DEPTH 5.052 sec (2-way) V_H 1.485 km/sec

SURFACE WATER TEMP 10 °C METHOD velocimeter

WEATHER: (CLEAR) DRIZZLE HEAVY RAIN

DATE

LOCATOR L8 77 BS

ARCHIVE SONO 46 (Sta. No.)

LINE # 7 COURSE 054 NE

SPEED 5.0 KTS

SEA STATE 2-3' swells ; calm

WIND: VELOCITY 12 kts DIRECTION ESE (from)

II. ACOUSTIC SYSTEMS

DEPTH BELOW SEA SURFACE

A. 3.5/12 kHz TRANSDUCER ______ ft

B. SEISMIC SOURCE: AIRGUNS 40 ft

ARCERS ______ ft

C. SINGLE CHANNEL STREAMER ______ ft

POWER: BATHYMETRY 3.5 kHz (12 kHz)

AIRGUNS 1326 cu. in.

ARCER ______ kJ

FIRE SEQUENCE:

(DISTANCE BASIS) TIME BASIS

DISTANCE 50 m TIME ______ sec

FIRE SEQUENCE DIAGRAM

air guns only

TRIGGER TIMES:

SEISMIC(t_0) - GRAPHIC RECORDER(t_1) ______ msec

SEISMIC(t_0) - MAG TAPE RECORDER(t_2) ______ msec

III. RECORDERS

1. GRAPHIC RECORDER: RECORDER NO. D & E

MODE: (Start/Stop) Continuous

SCALE: ______ m

SWEEP 6 & 8 sec

TRIGGER: Edge 1/4 1/2 3/4

PAPER FEED 40 & 40 lines/inch

INITIAL RECORDER DELAY (thumbwheel) 0 & 4 sec

SEISMIC ROLL NUMBER(S) UNIB #3 & BA35 #2

2. MAGNETIC TAPE RECORDER

TYPE H·P 3968A - 8 TRK - 1/4 in

TAPE SPEED 3 3/4 in/sec

TAPE/TACH SERVO (On) Off

FOOTAGE COUNTER: 1404 start run

3048 end run

CHANNEL	FM/DIR	INFORMATION
1	(FM) ~~DIR~~	vertical incidence seismic - Teledyne amp
2	(FM) ~~DIR~~	Right unfiltered sonobuoy seismic
3	(FM) ~~DIR~~	Left filtered sonobuoy seismic
4	(FM) ~~DIR~~	Right filtered sonobuoy seismic
5	(FM) ~~DIR~~	H·P precision drive frequency
6	(FM) ~~DIR~~	Waterbreak - right channel
7	~~FM~~ (DIR)	Trigger
8	~~FM~~ (DIR)	Voice & WWV

IV. SONOBUOY GEAR

1. SONOBUOY TYPE SB-76 SER. NO. 11971

CHANNEL 20 L AMPS: (Fixed gain) AGC

PHONE DEPTH 120 ft DELAY RELEASE 20 min ~~sec~~

FREQUENCY BAND 76 MHz 171 MHz (74 MHz)

2. RECEIVER (Initial)

FRONT FILTERS HI OUT LOW 5

GAIN 12 dB

BACK 5 Hz LOCUT SWITCH (Off) On

WATER BREAK ADD Off (On)

MDIG 1/77

U.S.G.S. STATION OPERATIONS LOG

STATION # 46

SHIP/LEG S.P. LEE AREA BERING SEA LAT (ST/ED) 58° 5' / 58° 25'

CHIEF SCI. MARLOW/COOPER CRUISE LOCATOR (COL. 73-78) L8 (ID) - 77 (YR) AREA CODE (COL. 79-80) BS LONG (ST/ED) 176° 51' E / 177° 32' E

PUNCH FLAG	TIME & POSITION * JULIAN DAY	GMT TIME HR-MIN	LINE NO	STA NO OR SHOT POINT	SPEC CODE 3 LET.	EQUIP. CODE 4 LETTERS	SAMPLE ** ATTEMPT NO 8 LET/NO	X IN ONE BOX ONLY — SAMPLING LOCATION: DISCRETE (E.G. DART CORE)	VARIABLE (E.G. DREDGE) STRT	VARIABLE END	FOOTAGE COUNTER	OPERATIONS, COMMENTS, OR DATA MEASUREMENTS	STATION DATA ONLY: RECOVERY? Y/N	WATER DEPTH 4 NO	DEPTH UNIT LET
X	220	1800	7		MAG	SONO	46		X		0000	Start tape #46		3698	M
X	↓	1800	7		PAP	SONO	E 46		X			Start eight sec record (4-12 sec)			
X	↓	1800	7		PAP	SONO	S 46		X			start six sec record (0-6 sec)			
X	↓	1906	7		OBS	SONO	46		X		1404	sonobuoy at air guns			
	↓	1920	7			↓	S				1625	Change scale 1.2-7.2 sec			
	↓	1928	7			↓					1761	Phones drop			
	↓	1935	7			↓	S					Change scale 3.0-9.0 sec			
	↓	2001	7			↓					2208	Routine			
	↓	2027	7			↓						Gain increased to 30 db			
	↓	2101	7			↓					2920	Routine			
	↓	2111	7		MAG	SONO	46			X	3048	End tape 46			
	↓	2112	7			"						4 shots lost on tape			
	↓	2113	7		MAG	SONO	46A		X		0000	Start tape 46A			
	↓	2124	7			"						Radio			
	↓	2148	7			"						interference			
	1-3	5-8	12-15	16-18	21-23	25-28	29-33	36	37	38	41-64		66	67-70	71

REMARKS: EQUIP., OPERATION, WEATHER, ETC.

Phones drop after 22 min !! Early radio interference due to antenna preamp too low

* PLEASE RIGHT JUSTIFY THESE ENTRIES ** FORMAT FOR SAMPLE LABEL IS CRUISE LOCATOR SAMPLE ATTEMPT # (E.G. S2 76 103)

MDIG 1/77

U.S.G.S. STATION OPERATIONS LOG

STATION # 46

SHIP/LEG S.P. LEE   AREA BERING SEA   LAT (ST/ED) ______

CHIEF SCI. MARLOW/COOPER   CRUISE LOCATOR (COL. 73-78) L8 (ID) - 77 (YR)   AREA CODE (COL. 79-80) BS   LONG (ST/ED) ______

PUNCH FLAG	TIME & POSITION * JULIAN DAY (1-3)	GMT TIME HR-MIN (5-8)	LINE NO (12-15)	STA NO OR SHOT POINT (16-19)	SPEC CODE 3 LET (21-23)	EQUIP CODE 4 LETTERS (25-28)	SAMPLE ** ATTEMPT NO 5 LET/NO (29-33) *	X IN ONE BOX ONLY — SAMPLING LOCATION: DISCRETE E.G. DART CORE (36)	VARIABLE E.G. DREDGE STRT (37)	END (38)	FOOTAGE COUNTER (41-64)	OPERATIONS, COMMENTS, OR DATA MEASUREMENTS	STATION DATA ONLY: RECOVERY? Y/N (66)	WATER DEPTH 4 NO (67-70) *	DEPTH UNIT LET (71)
	220	2149	7			SONO					907	Hicut filter down to 30 Hz			
X	↓	2300	7		PAP	SONO	E 46			X	2070	Buoy disappearing			
X	↓	2310	7		MAG	SONO	46A			X	2208	Tape off			
X	↓	2327	7		PAP	SONO	S 46			X					
X	↓	2330	7		OBS	SONO	46			X		Radio signal gone			

REMARKS: EQUIP., OPERATION, WEATHER, ETC.

Good, long buoy; noisy at times

** FORMAT FOR SAMPLE LABEL IS CRUISE LOCATOR SAMPLE ATTEMPT # (E.G. S2-76-103) reduction and interpretation of the sonobuoy. In addition, the logs serve the very important function of verifying claims in the event of a sonobuoy failure. The entries on the log forms are all straightforward. Two entries worth mentioning are the water depth, which should be noted in two way time from the bathymetry record, and the horizontal velocity of sound in water, v_H, which appears on the satellite navigation terminal output.

(4) Prepare analog tape recording system

First, tape heads and drive capston should be cleaned, if necessary (see p. 23). Then, a new, properly labeled tape should be mounted on the recorder to record vertical incidence seismic prior to the launch of a sonobuoy. It is advisable to record pertinent information on the voice channel, i.e. information such as cruise identification, sonobuoy station number, time, tape recorder channel designations and area. The footage counter on the recorder should also be set to zero and noted on the tape. Finally, the tape speed should be checked, usually 3 3/4 ips.

When vertical incidence seismic recording is underway, the input levels for each tape recorder channel should be measured with an oscilloscope and reset if necessary. Most important are the seismic channels and the trigger channel. The seismic channels should be adjusted for maximum gain without clipping the signal, while the trigger pulse should be adjusted so that at least a 2 volt signal is recorded. The Raytheon recorders require a two volt trigger. Having set the input gains, you should then look at the output signals (the recorder can record and playback simultaneously). This will insure that the signal being recorded will be useable for playback at a later date.

(5) Preparation of Graphic recorders

In most operations, when not recording sonobuoys, the graphic recorders are being utilized for display of other seismic data. Therefore, prior to a sonobuoy station, the seismic data being recorded should be interrupted, the paper advanced several inches, and the start of the sonobuoy station clearly marked, along with time, scale, and filters or source, if necessary. The recorder should then be set up to record vertical incidence seismic, preferrably using the same initial delay and sweep rate that will be used to record the sonobuoy.

The input for the UGR will come either directly from the sonobuoy receiver, or will come from the output of the tape recorder. Make certain that the trigger pulse to initiate the recorder sweep is consistent with the signal, i.e. if the signal is coming from the tape recorder, then the trigger input to the UGR should also be the output from the trigger channel of the tape recorder. Failure to match the signal and trigger pulse will create a recording offset because of the finite distance between the write and read heads of the tape recorder.

In shallow water, one graphic record is sufficient to record all data. If one recorder is being used to display the tape recorder output, it is advisable to make two graphic records, to protect against complete loss of data in the event of tape recorder malfunction. In deep water areas, it is usually necessary to record the sonobuoy on two separate graphic recorders. This is due to the long water path. In 5 seconds of water, even an 8 second record will provide only 3 seconds sub-seafloor. This problem can be circumvented by introducing a deep water delay, and recording from 4-12 seconds. Therefore, two recorders are necessary: one to record the direct arrival and seafloor (0-8 sec or 0-6 sec) and a second to record the complete sedimentary section.

Generally, we make a 0-6 second record and a 4-12 second record in deep water areas. Both records are used in subsequent digitizing of the wide angle reflections, so it is essential that both are correctly marked, particularly that the zero trace (the closest approach of the sonobuoy to the airguns) is marked on both records. It is also helpful to periodically make simultaneous marks on both records to insure correct correlation of seismic traces during the data reduction.

(6) Lab prelaunch and launch

Proper preparation of all equipment prior to the actual launch of a sonobuoy is the key to success! While the sonobuoy is on the deck the receiver in the lab should be tuned to the transmitting frequency of the sonobuoy to verify that the buoy is transmitting properly at the crystal frequency or channel marked on the sonobuoy (the channel markings are occasionally incorrect). The controls on the front panel of the receiver (gain and filter settings) should be initialized (see Log form, Figure 9, for example) and the antenna preamp (if using a low frequency sonobuoy) should be adjusted to a low gain setting. It is advisable also to check all signal paths, to ensure that the correct receiver and module are being recorded, and that the trigger pulse is correct. All input signals going onto tape should be checked with an oscilloscope. This ensures that the recording levels are in the proper range (maximum gain without clipping of the signal) and that the proper signals are actually being recorded.

If possible, launching the sonobuoy should be a three person operation; two people on the fantail and one person in the lab. Radio contact is desirable, but careful planning and coordination may suffice. The two people on the fantail should wear survival gear, and the person who actually launches the sonobuoy should be secured by a safety harness. The second person on the fantail coordinates the launch by radio. Once everyone in the lab and on the fantail are ready, a countdown of airgun shots can commence. This countdown enables the person in the lab to prepare for and determine the precise time that the sonobuoy will be in the water and adjacent to the airguns.

During the countdown period, several actions must be completed by the lab person. A countdown of the shots on the voice channel of the tape during this time will prove invaluable upon later replay of the tape. Two airgun shots before the launch, the feed rate on the recorders should be increased (to 40 lines per inch) and the input signal to the graphic recorders switched to display the sonobuoy seismic rather than the vertical incidence seismic. When the sonobuoy is in the water and at the airguns, event marks should be placed on the graphic recorders and simultaneously a voice annotation made on the voice channel of the tape recorder that "the sonobuoy is at the guns". As soon as possible thereafter, the reading of the footage counter on the tape recorder and the launch time should be noted in the logs. Next, the graphic recorders should be adjusted for the sonobuoy signal; the receiver should be checked to ensure that the sonobuoy is properly tuned and that the AFT is tracking the radio signal; and the tape recorder output signals again checked with the oscilloscope to guarantee that all signals are being recorded properly (without clipping) on the tape recorder.

Underway operations

While the sonobuoy station is underway, there are several items that require monitoring. Initially, one must watch the RF signal strength carefully and keep the antenna preamplifier as high as possible without overdriving the reciever (for low frequency sonobuoy only). The signal levels being recorded on tape should also be rechecked periodically and adjusted if necessary. As the station progresses, the gain on the receiver should be increased as the signal strength diminishes, and the hicut filter can be lowered to enhance the lower frequencies in the seismic signal. All changes should be noted on the log sheet as well as on the voice channel of the tape. If more than one recorder is being used, it is important to periodically (every 10 or 15 minutes) mark the same trace on all records with the event mark.

After 20-30 minutes, it may be necessary to introduce a sweep delay to the record. Generally, it is important to keep the direct arrival on the record, as well as all the seismic information. Continue to increase the delay until either the maximum allowable delay (dictated by the fire rate) is used, or until the direct trace and the seismic traces can no longer be kept on the record at the same time. A change in the amount of delay should always be accompanied by an event mark on the record. This will facilitate later preparation of the record, when it must be cut at these delay changes. This preparation will also be greatly facilitated if the amount of delay is a fraction of the integral number of time lines. (For example, on a six second record, time lines are generated by the UGR every 0.6 seconds. Therefore, successive delays should be integral multiples of this: 0.6, 1.2, 1.8, etc.) Using these fractional delay times will make it easier to align the section when constructing the complete sonobuoy record.

If the sonobuoy is deployed during multichannel operations, particularly for sonobuoys on the shelf, it is helpful to obtain wiggly trace camera records from the GUS 24 channel system. These records enable the identification of shallow reflectors and the definition of reflectors which may be obscured at the beginning of the sonobuoy station.

Generally, all sonobuoys are recorded until radio signal is lost, or until it is clear that no additional seismic information is forthcoming. It is always advisable to continue recording until long after the buoy appears to have stopped sending useful information. We have found that atmospheric "skipping" of the radio signal often will provide small windows of seismic information well beyond the normal range of the sonobuoy. Later replay or processing may illuminate previously obscure information. In the course of very long sonobuoys, more than one reel of magnetic tape will be required for a single station. The tape change should be accomplished as quickly as possible to avoid obvious loss of information. The number of shots missed in changing reels should be accurately counted and noted in the log.

When the sonobuoy station is completed, the radio room and bridge should be notified so that the may resume their normal operations. The navigation watch should also be notified, so that necessary speed or course changes can be ordered. Upon completion, it is also useful to mark the start and end times of the station on the vertical incidence records. This will help locate the station later when the vertical incidence record must be referred to for dip information.

Replaying analog tapes

Replaying sonobuoy tapes is most easily done during the cruise while the necessary equipment is available and operational. The playback time can be reduced considerably if the sonobuoy tapes are replayed at higher speeds than those at which they were recorded. We normally replay our buoys at 15 ips, which is 4 times faster than the recording speed of 3 3/4 ips. To produce an equivalent sonobuoy record at the higher playback speeds, both the filter settings on the external Krohn-Hite filter and the sweep speed on the UGR must be changed by the appropriate fraction: playback speed/recording speed. On playback, the filter settings should always be higher and the UGR sweep speed should be lower than the equivalent original sonobuoy record. At 15 ips we use Khron-Hite filter settings of 20-240 Hz to get a 5-60 Hz record and we use a sweep speed of 2 seconds to get an 8 second record.

Since the reason for making replays is to recover information that may have been lost or obscured on the original record, it may not be necessary to replay the sonobuoy if the original record is good. Some enhancement of the seismic data is possible by using different filter settings during replay. We routinely make one replay that is filtered to contain only the waterbreak channel (600-1200 Hz) so that the accurate direct times, often not available on the original record, can be determined.

For accurate replays, insure that the tape recorder is using the precision drive frequency that was recorded on the tape during the sonobuoy station.

III. REDUCTION AND INTERPRETATION OF FIELD RECORDS

Shipboard Interpretation

Preliminary analysis and interpretation of sonobuoy records may be done onboard ship with a few drawing supplies (Mylar, straight edge, pencil) and a hand calculator. Refraction records are straightforward since velocities can easily be determined from the ratio of the slope of the refractor to the slope of the direct arrival. The depths to the refractors can then be computed using the refraction velocities and the refractor intercepts at x = 0 (nearest approach of the sonobuoy to the sound source). An approximate technique for determining interval velocities from the wide angle reflection records can also be done onboard ship. Velocities (rms) for successively deeper reflecting horizons are first determined by a graphical method, and are then used in Dix's equation for computing the interval velocities. Detailed procedures for shipboard analysis of refraction and wide angle reflection data are given in Appendix C.

Office Procedures

Careful analysis of the sonobuoy records can be done only in the office where special digitizing and computer facilities are available. The analysis procedure involves five basic steps:

Processing Step	System/Procedures Used	Pages/Appendix
1. preparing the records	done by hand	41-42
2. choosing and tracing seismic horizons	done by hand	42-44

3. digitizing and editing seismic horizons	TEKTRONIX 4051: interactive BASIC programs REFRACT LINDIGIT and SlODIGIT	44-61/F,J
4. processing the digitized data on MULTICS (to determine velocities and depths)	HONEYWELL 68/80 MULTICS System: FORTRAN Programs LINFT and SLOWI	62-65/H,K
5. interpreting the computer results	done manually and with FORTRAN programs POLYFIT and SONOMODEL	66-68/I,L

A complete sequential listing of all the computational steps is given in Appendix E.

Preparing the Records

Once the sonobuoy records have been excised from the seismic reflection rolls (easily done onboard ship) they should be mounted on a stable backing (48" wide, heavy brown wrapping paper works well). Records that contain time shifted data must be carefully cut along a single vertical trace at the time shift. Use a good pair of scissors and a steady hand, or a straight edge and an exacto knife. The cut sections are then time shifted, aligned so that timing lines are parallel, and taped to the backing. The sections must be shifted and aligned very carefully because the digitizing and computer processing techniques are highly sensitive to discrete shifts in the reflecting, refracting, or direct arrival traces. The record is then covered with a sheet of clear mylar acetate (3 mil thick), that has been "cured" for shrinkage. (Leave the unrolled sheet of mylar on a flat surface for a few days before using.)

All interpretatons and reference lines should be drawn on this overlay with drafting pens (point 00 or smaller). The horizontal timing lines, the initial trace (the closest approach of the sonobuoy to the source) and a reference dot on each corner of the record should be drawn on the overlay for later orientation. The UGR recorders do not draw either the uppermost of lowermost horizontal time lines, so these must be determined using a Gerber scale or ten point dividers.

Choosing & Tracing Seismic Horizons

Next, the seismic traces should be marked on the overlay. The seismic arrivals generally consist of a complex wave train, and it is important to pick the same phase of the wave on successive recorder sweeps. The use of transparent colored inks (red, blue, violet) leaves the phase clearly discernable beneath the inked line. Because the ink tends to spread on the acetate, it is advisable to use the narrowest drawing pen available.

The direct trace should be drawn and extended back through the initial sweep trace. The intersection of these two lines (the initial sweep and direct tract) is the time origin of the sonobuoy record. If the sonobuoy hydrophone had been precisely adjacent to the airguns on the first sweep, and if the air guns and the recorder had been triggered simultaneously, this intersection would correspnd exactly to the time origin of the graphic recorder. Thus, any difference in zero times results from delays in the timing and recording circuitry and from a difference between the depth of the sonobuoy hydrophone and the airgun. When drawing the direct trace, be aware that slope changes in the direct arrival trace may occur; these result from small relative course or speed changes during the sonobuoy station.

The refractors can be drawn next. In shallow water (less than 300 meters), this is a relatively straightforward process, because all refractors appear as first breaks on the record (see Figs.2 and 5). On records from stations in deeper water, however, shallow refractions do not always come in as first breaks, but may be masked by refractions from deeper horizons, (Figs. 3 and 6). Therefore, care must be exercised when picking the deep water records to guarantee that all possible refractors have been marked.

Generally, shallow water sonobuoy stations (less than 300 meters) produce good refraction records, but do not yield useable wide angle reflection records. Because the moveout of a reflection hyperbola occurs rapidly for shallow reflectors, the reflection information is usually impossible to read from the high vertical exaggeration sonobuoy records. As a general rule, the horizontal distance over which useful wide angle reflection information can be collected is equal to twice the water depth. With a 50 meter sample interval, measurement of wide angle reflections does not become feasible on the sonobuoy records until the water depth exceeds 1000-15000 meters, and is best done in the deep ocean basins (greater than 3000 meters of water).

Even on a good quality sonobuoy record, there may be a multitude of possible reflection traces to pick, primarily because the reflection section is often complicated by multiples and artificial "bubble pulse" reflectors. In the absence of other information, it is permissable to pick all possible reflections and rely on later editing to identify and remove the questionable traces. This is a time consuming process, however, and a preferable method is to establish initial criteria to determine which reflection traces should be picked.

The first criteria involves choosing those reflection traces which have associated refractors. A refractor, once identified, usually can be traced back to the reflection to which it is tangent. As mentioned earlier (p. 11), assignment of the refraction to the correct reflection hyperbola may be aided by noting which reflection hyperbola undergoes an abrupt increase in reflection amplitude near the point of tangency. Computer results from the refraction data, if available, can also be used as a guide in determining the normal incidence time to the refracting horizon. The normal incidence times to the refractor (from the refraction solutions) should be compared to the vertical incidence seismic reflection profile recorded just prior to launching the sonobuoy to locate the correct reflecting horizon.

A second criteria is that all prominent reflectors observed on the reflection profile (ideally a processed multichannel record) over the sonobuoy station should be picked on the sonobuoy record. Artificial reflections are sometimes suppressed on the vertical incidence record, making it easier to pick out the real reflections. The real reflections can be identified on the early traces of the sonobuoy record.

A final criteria can be employed if there are several sonobuoy stations that are close together. Reflectors can often be correlated from one station to another, assuming that reflectors in the region are continuous. Correlating reflectors between stations will not only aid in picking the records, but will benefit the interpretation by producing a more realistic picture of the sub-surface velocity structure.

Digitizing and Editing Seismic Horizons

Once the sonobuoy record is prepared and marked, the interactive computer programs for the TEXTRONIX 4051 System are used to digitize the sonobuoy record. Refractions and wide angle reflections are digitized separately, using two different programs LINDIGIT and SLODIGIT. In the following sections, we first describe the machine on which the digitizing is done (the hardware) and then describe the computer programs which have been written to perform the digitizing (the software). Appendix G contains examples of the digitizing programs, while Appendix J contains program listings.

In the past, digitizing the sonobuoy records was a time consuming process that had to be done manually. The time pairs were measured off the record using a Gerber scale, then recorded on computer coding forms, keypunched, and read into the computer. Now the process is semi-automated and relatively fast. The individual points are picked by hand using a cross-hair cursor and a digitizing tablet. The position of the digitized point on the sonobuoy record is automatically input to the minicomputer program and is stored in the memory. The minicomputer program also allows interactive editing of the data points before the program writes a final data set on magnetic tape. The final data set is, in turn, transferred to and used by the U.S.G.S. Honeywell computer (MULTICS) to complete the data reduction. Simplification of the numerous intermediate steps (coding, keypunching, card reading, etc.) has substantially decreased the time necessary for processing a sonobuoy record.

The computer programs for digitizing the sonobuoy records are written in a modified BASIC language for a Tektronix 4051 Graphics System. Two pieces of peripheral equipment, a Graphics Tablet (Tektronix 4956) and a Digital Cartridge Tape Drive (Tektronix 4924) are used by the Graphic System during the digitization process. A third peripheral device, a Hard Copy Unit (Tektronix 4631) is useful, but not required, for copying information from the CRT screen. The 4051 Graphic System must be equipped with 16k bytes of memory, a binary program loader, and a data communications interface in order to run the programs and communicate with the MULTICS computer.

General Notes on the Tektronix System

Before using the sonobuoy digitizing programs, it is helpful to become acquainted with the Tektronix 4051 through the Graphics System Tutorial, available on the Plot 50 Systems Software Tape. To get started, turn the 4051 on (the switch is under the console on the right) and allow the machine a few seconds to warm up. (The screen will become bright, and can be cleared with the "HOME PAGE" at the upper left of the keyboard). Insert the Systems Software Tape and press "AUTOLOAD" (at the upper right of the keyboard). The program will enter an interactive mode. To the first question reply "4" and press "RETURN". This will initiate the tutorial.

During the tutorial, you may wish to retain a copy of the information on the screen. This requires that the hard copy unit be on and warmed up (5-10 minutes in advance). Then, the screen image may be copied by pressing "MAKE COPY" (at the upper right of the keyboard) or the button on the hard copy unit. The "light-dark" control adjusts the intensity of the copied image.

Digitizing Programs

The digitizing programs written for the 4051 are completely interactive. All input is requested through the program, and is entered from either the terminal console or the Graphics Tablet. All console input is free format. Program output is sent either to the terminal CRT screen or, if requested, to magnetic tape through the auxiliary tape cartridge drive. Permanent record of output to the CRT screen is possible only with the hard copy unit.

The final output data set is written to and stored on the data tape in the auxiliary tape drive. This data set is subsequently transferred to the MULTICS computer system for reduction. Each data set is written on a separate tape file, which must be marked prior to writing. The digitizing programs will mark the tape file automatically if requested. Previously marked tape files may be overwritten without disturbing the data on the rest of the tape. MARKING A NEW TAPE FILE, HOWEVER, WILL DESTROY ALL SUCCEEDING TAPE FILES!! Therefore, care must be taken to maintain a record of the tape files previously used, if several data sets are written on the same tape before they are transferred to MULTICS for permanent storage.

The magnetic tape cartridges contain a write protect mechanism. This is a small slot at one corner of the cartridge, with a black triangle inscribed next to it. The slot can be turned with a screwdriver or even a strong thumb nail. When the trangle points to "SAFE", the magnetic tape cannot be written on, and is write protected. When the triangle points the other way, the tape is "write enabled", and data can be written to tape.

To initiate either digitizing program, the sonobuoy program tape should be inserted into the 4051 internal tape drive, and the data tape, write enabled, should be inserted into the peripheral tape drive. The user starts the program by pressing the "AUTOLOAD" button and, when queried, by indicating which type of data (refraction or reflection) is to be digitized. This will direct the program to the correct starting point, and the interactive process will begin.

The operation of the program can be monitored in several ways: by the questions or statements written on the CRT screen, by the status lights at the upper righthand side of the console, and by the cursor (the blinking signal on the screen). While the program is operating, the "BUSY" status light will be illuminated. When user input is required, the I/O status light will also be illuminated, and the cursor will either be blinking "?" (indicating console input) or will have disappeared (indicating digitized input from the Graphics Tablet). When the program has reached a stopping point, all lights (except "POWER") will be dark, and the cursor will display a blinking rectangle. At this point, the program is awaiting direction via the user definable keys.

The user definable keys (referred to later in the text by UD #) are located at the upper left of the terminal console, and serve as a nerve network, directing program flow and providing user commmand control. Generally, the user definable keys either branch to a subroutine which, upon completion, returns to the program point at which the branch requested; or they link to subsequent program sections and continue execution. The specific function of each user definable key is indicated on a plastic overlay which can be placed over the keys for easy reference.

Whenever the CRT screen becomes full with input data, the "page full" condition will be indicated by a blinking "F" in the upper left corner of the screen. The "HOME PAGE" button at the upper left of the keyboard will erase the screen and allow the program to continue. If a copy of the information on the screen is desired, it can be made at any time by pressing "MAKE COPY". Any input from the keyboard is terminated by a keyboard "RETURN". An input error can be corrected before the "RETURN" by either erasing (with the "RUBOUT" key) and retyping, or by pressing the "CLEAR" key (at the top center of the console) and reentering the data.

Digitized data values are input to the program through the Graphics Tablet, which must be powered up before the digitizing program has been started. The toggle switch to turn the power on is located at the back of the control box, on the right. There are two digitizing cursors available, a pen cursor and a cross-hair cursor. To digitize a point with the pen, place it directly on the point and press slightly. With the cross-hair cursor, align the hairs over the point and press the white button in the middle of the cursor. The pen cursor is easier to use, while the cross hair cursor is more accurate. Most sonobuoy digitizing should be done with the cross hair cursor.

Whenever a point is digitized, the 4051 will emit a short, high pitched tone. If this tone is not forthcoming, then something is wrong. It may be necessary to quit the program (by pressing the "BREAK" key twice), turn the digitizing table off and on again, and restart the program. Before the program is started, later trouble may be avoided by pressing the white button on the cursor (or by pressing the pen point) and observing the red lights at the left of the control box. Before the program is operating, the "Z-AXIS" light should go on when the button is pressed, but the "PROX" light should remain off. When the program is operating, both lights should go on, and the "PROX" button will generally stay on.

Each of the digitizing programs requires that the origin of the record be set before the other points are digitized. The program will direct the user when this step is required. To set the origin, press the "ORIGIN" button on the control box, and digitize the origin point, with the origin button depressed. After hearing the tone, release the the origin button.

The sonobuoy record should be placed on the digitizing table with the time axis aligned approximately parallel to the long edge of the table. Therefore, the origin will usually lie near the lower left corner of the table. The record need not be aligned exactly parallel with the table, however, because the program performs a coordinate transformation on each point to correct for misalignment.

In order to process the sonobuoy reflection or refraction data, the computer program must be provided with both the distance from the ship to the sonobuoy as well as the total reflection or refraction time required for the energy to travel from the airguns through the water and subsurface rocks to the sonobuoy. The distance is computed from the direct arrival time and the total travel time is read directly from the sonobuoy record. Consequently, the digitized input required for the processing programs consists of time:time pairs (e.g. direct arrival time:total reflection time).

Refraction traces are easier to pick than reflection traces. Five point are usually sufficient to define a refraction, whereas at least 15, and commonly 30 or more points are required to reliably determine a reflection hyperbola. Refraction traces are most easily picked by digitizing a direct time and a refraction time for each data point. Therefore, five points along a refractor will require 10 time picks. Because successive reflectors on a record underly one another, digitizing reflection points is facilitated by picking a direct time and then all the reflection times along the same recorder trace. Therefore, if 8 reflecting horizons are to be measured, then 9 data points (one direct and 8 reflection) will be picked along a given recorder trace.

Digitizing Refractions (Textronix Program LINDIGIT)

The program for digitizing refraction records is straightforward and self-explanatory. All the input data required is available on the record itself or on the log sheets. The following procedure describes the basic steps in the program, and a complete example may be found in Appendix D.

1. Place the sonobuoy record on the Graphics Tablet and secure it in place.
2. Initialize the program by following the instructions given.
3. Set the Origin and determine the scale factor.
4. Check the reference marks and reset the origin, if necessary.
5. Digitize the data points (direct arrival: total travel time pairs).

6. Write out the parameters to the screen for copying.

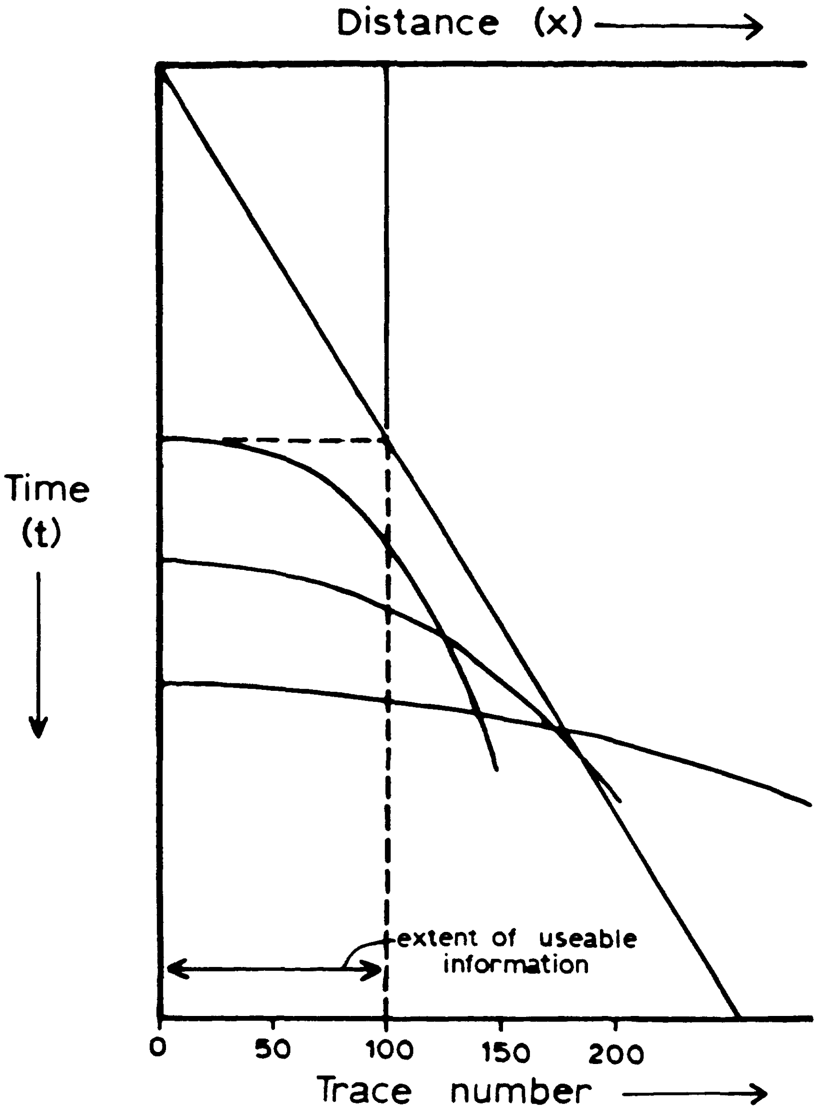
7. Write and output data set to tape for transmittal to Multics.

The program is controlled interactively; there are no user definable functions available, with the exception of the MULTICS login procedure (UD 14).

Two options are available in the program. The first is the number of points per refractor that are to be picked. We have found that in general, five points are sufficient to determine refractions accurately. However, in some situations it may be preferrable to pick more points. The program will also provide a hypothetical seafloor refractor (given the depth of the seafloor and an assumed velocity of 1.55 km/sec). This option is probably not necessary in shallow water, but is required on deep water buoys where the seafloor refraction is probably not visible on the record.

Digitizing Reflections (Textronix Program SLODIGIT)

The reflection digitizing program is completely interactive and prompts the user for all necessary input information. A good rule to follow in choosing the horizontal distance over which the wide-angle reflection traces can be used for the velocity analyses is that the total reflection angle from seismic source to sonobuoy should not exceed 90^o (incidence angle of 45^o; Knott and Hoskins, 1975). The 90^o reflection angle is reached for the seafloor roughly at the vertical trace on the sonobuoy record at which the direct arrival time is equal to the normal incidence time for the seafloor (see Figure 10). All reflection picks should be made prior to this vertical trace. Thirty data points are sufficient to determine the wide angle reflection, although as few as fifteen and as many as forty may be used.



TOTAL NUMBER OF TRACES = 100

NUMBER OF SAMPLES = 25

$$\Delta x^2 = (100)^2/25 = 400$$

Δx^2	Δx	Trace
0	0	0
400	20	20
800	28.3	28
1200	34.6	35
1600	40	40
⋮	⋮	⋮
10000	100	100

Figure 10 Method for picking wide angle reflections in deep water to ensure even distribution of samples in x-squared.

TABLE 2

Function of User Definable Keys - Reflection Digitizing Program

UD #	UD Key Name	Function	Program Section
1	Repick point	Repick point - correction while digitizing	DIGIT
2	Skip layer	Skip layer - correction while digitizing	DIGIT
3	Stop on trace	Skip rest of vertical trace-correction while digitizing	DIGIT
4	STOP digitizer	Stop digitizing	DIGIT
5	List parms	List input parameters	DIGIT
6	Delete layer	Delete layer	EDIT
7	Delete trace	Delete vertical trace	EDIT
8	EDIT points	Edit (remove/reinsert) points	EDIT
9	Residual table	Print residual table	EDIT
10	SLOWI list	List SLOWI formatted data set	EDIT
11	X2T2	Branch to $X^2 - T^2$	DIGIT, EDIT
12	DHRC	Branch to DHRC	DIGIT EDIT X2T2
13	Reference check	Verify record alignment	DIGIT
14	MULTICS login	Login to MULTICS	EDIT
15	List picks	List digitized picks	DIGIT
16	EDIT	Branch to EDIT	X2T2
17			
18	DUMP to tape	Dump digitized data to tape	DIGIT
19	RECYCLE from tape	Read data from tape	DIGIT
20	SLOWI to tape	Write SLOWI formatted data set to tape	EDIT

Because the reflection time versus distance equation is linear in X^2, the digitizing interval should also be equal increments of X^2. If instead, equal increments in X are used, the least squares solution for the $X^2 - T^2$ line will be too heavily weighted near the origin. Therefore, the digitizing intervals should get closer together with increasing values of X. The digitizing process is considerably facilitated by counting and marking the recorder traces before they are digitized. Figure 10 illustrates which traces would be picked if we wished to make 25 picks over 100 traces of the seismic record.

If the digitizing is done from two records (one containing the direct arrival and the other containing the seismic information) it is essential that the traces on each record be accurately counted and that identical traces on both records be marked before digitizing. The direct time and reflection times must be measured along the same trace or significant errors will result. (It is for this reason that emphasis was placed in the operation section on carefully marking the intitial trace on both sonobuoy records, and on placing simultaneous even marks on both records at periodic intervals).

The program for digitizing wide angle reflection records is a more complicated program than the refraction digitizing program, since it performs several functions in addition to simply digitizing the record and writing an output data set to tape. The program is broken into five subprograms; these subprograms are linked together through the user definable keys. An example of the reflection digitizing program is given in Appendix F, and the BASIC program in Appendix J. Table 2 indicates the user definable functions available, with descriptions of their use and the program sections under which the functions operate. Table 3 lists the procedure to be followed for digitizing and editing a wide-angle reflection record. The five program sections are:

I. Initializing and digitizing: DIGIT

II. Delayed hydrophone release correction: DHRC

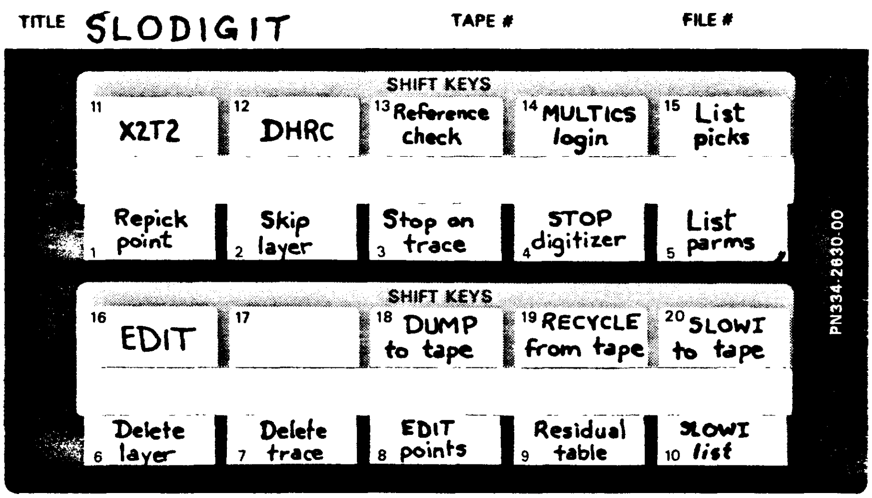
III. X^2-T^2 calculation: X2T2

IV. Data editing: EDIT

V. Dump to tape and recycle from tape: DUMP

I. Initializing and digitizing

This section interactively queries the user for all required input information. It asks the user to digitize all relevant points on the record (e.g. the origin, the zero point, the point at which the hydrophone was released, the seafloor, etc.) The program allows for data points to be digitized from a single record, or for the direct times to be digitized from a second record. Generally, the direct time is digitized first, followed by the reflection times along the same recorder sweep for all the reflecting layers. (If two records are used, all the direct times are digitized first, then the same recorder traces are located on the second record and the successive reflectors digitized.) While digitizing, the user is capable of making minor corrections or changes in the digitizing order through the user definable keys. If a user definable key is used while digitizing, it must be "activated" by digitizing a random point on the table. (The point digitized to activate the UD function is discarded, so its position is irrelevant.) These allow a point to be repicked, if done before the succeeding point is picked (UD 1), for a single layer to be skipped along a trace (UD 2), and for all succeeding layers to be skipped along a trace (UD 3). When all points have been picked, the digitizing is halted with a user definable key (UD 4). A final step in this section is to write out a table of



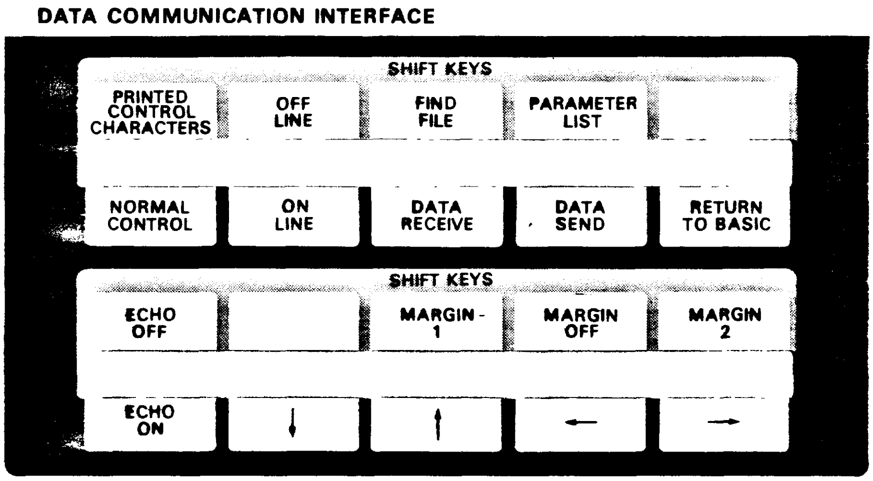


Figure 11 Overlays for user definable keys for the reflection digitizing program and data communication interface (MULTICS interface). UD 14 (MULTICS login) on the reflection digitizer also works from the refraction digitizer. The only user definable functions required for MULTICS operation are UD 13 (find file), UD 4 (data send) and UD 5 (return to BASIC).

input parameters (UD 5), as well as a table of raw data picks (UD 15).

II. Delayed hydrophone release correction: DHRC-(UD 12)

This section is optional, and corrects all points prior to the time of the hydrophone release by an amount proportional to the hydrophone depth. This adjustment is explained in Appendix F.2 on corrections concerning the hydrophone lower. This program section automatically transfers program execution to the next section $X^2 - T^2$.

III. $X^2 - T^2$ calculation (UD 11)

First, this section converts the direct times to true distance and squares the distance:time pairs. Then the program performs a linear least squares fit to the squared values and calculates the slope and intercept of the least squares line. From these results, the velocity and depth to the reflecting horizon are determined, and the interval velocity calculated from Dix's equation (see Dix, 1955 and Appendix B). For each layer, a table is produced listing the input times, the converted distance, squared distance and time, and the residual (observed T^2 value minus least square T^2 value). These listings are optional. A second table lists the rms velocity, reflection time, interval velocity, depth, and coefficient of determination ("FIT") for each layer. Finally, the program plots the $X^2 - T^2$ values with the linear fit line. This plot may be reproduced at different scales.

IV. Data Editing: EDIT (UD 16)

Program control is next transferred to the Edit portion of the program, which allows the user to remove horizontal layers, vertical traces or individual points from the data set (UD 6, 7, and 8 respectively). Editing is performed on the basis of the table and plot produced by the $X^2 - T^2$ section, and by a "residual table" which the editing section also produces (UD 9). This residual table lists the same residuals that were listed in $X^2 - T^2$, but the tabular form makes the identification of poorly picked reflectors and erroneous direct picks much easier. The criteria for editing points is discussed in the subsequent section on Editing Reflection Data. The final function of the Edit section is to write a formatted output data set to magnetic tape so that it can subsequently be transferred to MULTICS. However, this need not be done after the first call to Edit, because $X^2 - T^2$ can be called up again from the Edit section, and the two sections iteratively invoked until a satisfactory data set is produced.

V. Dump to tape and recycle from tape

This section dumps the digitized data (after completion of section I) onto a magnetic tape file for later retrieval and use. Since the digitizing of the data is the most time consuming part of the process, dumping to tape immediately after completing the digitizing will protect against complete loss of data if something goes awry later in the process. This feature is also useful if it is necessary to interrupt the program before reaching the final editing step.

Section V also allows the user to read the digitized data from tape and to reenter the program as though the initial digitizing section (I) had just been completed. To recover this data, respond affirmatively to the first question asked by the program ("Do you wish to recover data from tape?"), and when queried, specify to which tape-file the data you wish to recover has been dumped. After the data read is completed, the "Parameter List" key can be pressed to verify that the correct data has been recovered, and then the HDRC or $X^2 - T^2$ button can be pressed to continue.

Table 3

Procedure for digitizing and editing wide-angle reflection data

1. Digitize record (Part I)

2. Dump raw digitized data to tape (Part V). This step protects against later error or interruption in the process.

3. Delayed hydrophone release correction (Part II). The Delayed hydrophone correction can be called directly after the digitizing step, or can be made after X^2-T^2 and/or Edit have been called. It is sometimes helpful to see the X^2-T^2 plot before and after the correction to determine whether the data was improved. This correction is reversible, that is the correction can be removed if it appears detrimental. This subprogram branches directly to $X^2 - T^2$. See Appendix F.1 for a more complete explanation of this correction.

4. $X^2 - T^2$ (Part III). This is the first pass at $X^2 - T^2$.

5. Edit (Part IV). First print out a residual table, and use it in conjunction with the $X^2 - T^2$ table and plot to edit traces and points through the user definable keys.

6. $X^2 - T^2$ (Part III). With the edited data set, return to $X^2 - T^2$ and reevaluate preliminary velocities and depths.

7. Edit (Part IV). Return to Edit. The iterative process between $X^2 - T^2$ and Edit can continue until satisfactory data set is produced. EDIT allows previously removed points, layers or traces to be reinserted. When a final data set is reached, it should be dumped to tape (V) for later transmittal to MULTICS, and it should be recorded on paper by pressing the "MAKE COPY" button.

Editing Reflection Data

After the reflection traces are digitized, they must be checked carefully for digitization errors. Two principal sub-programs for editing the data are available. These sub-programs, which must be used sequentially, are $X^2 - T^2$ (UD 11) and EDIT (UD 16). Several criteria, based on numbers generated by these sub-programs help the user decide which traces or data points are questionable and should be discarded. The criteria include:

1. $X^2 - T^2$: The parameter "FIT" (e.g. coefficient of determination) is a number between 0.0 and 1.0 that indicates the "goodness of fit" between the X^2, T^2 points and the least square line that passes through these points. Our experience has shown that "FIT" should not be smaller than either 0.99990 for shallow layers (0.0-1.0 sec sub-bottom) or 0.99900 for deep layers (greater than 1.0 sec sub-bottom).

2. $X^2 - T^2$: The RMS VELOCITY should increase with depth. A reflector that has an RMS VELOCITY, which is the smaller than that of the overlying layer, is probably a multiple reflection event and should, therefore, be removed.

3. $X^2 - T^2$: The INTERVAL VELOCITY normally increases with depth, therefore, any decrease in the INTERVAL VELOCITY (less than 80% of the overlying layer) should be examined carefully. The interval velocity is calculated with the Dix equation (Dix, 1955), so a decrease may be caused by a computational, rather than a real geologic, effect. Normally, computational instabilities (e.g. velocity inversions) are found when reflectors are too close to one another. The "resolution" of the sonobuoy technique is generally no better than a layer thickness that is 1/12 of the water depth (LePichon et al., 1968). If a velocity inversion in the INTERVAL VELOCITY occurs in a layer, try discarding that layer (or discard the next deeper layer if the deeper layer is thinner).

4. EDIT: The residual values ($T^2_{observed} - T^2_{calculated}$) which are tabulated for all data points, should generally be smaller than 300. Omit points with larger values. The residual table also shows bad traces (high residuals for every point along the trace) as well as traces that have a high, but acceptable, degree of scatter (this is also reflected in the parameter FIT in the $X^2 - T^2$ section). Often the pattern of the residuals for a trace (negative at both ends of the trace but positive in the middle) indicates curvature in the $X^2 - T^2$ line, which is caused by dip in the reflector.

Once the initial $X^2 - T^2$ and EDIT steps have been completed and the erroneous data removed, another iteration of the process is usually advisable. The $X^2 - T^2$ section can be recalled and calculations made with the corrected data set. Then editing routine can be entered a second time, and additional data removed, or previously edited data reinserted, if desired. When the data has been satisfactorily edited, the final function of the editor is to write a SLOWI formatted data set to tape. This data set is then suitable for transferral to MULTICS and input directly to SLOWI.

Processing The Digitized Data on MULTICS

The two programs for processing the digitized sonobuoy records are called LINFT (for LINear FiT) and SLOWI (for SLOping WIde angle). These programs were obtained from Woods Hole Oceanogaphic Institute, and are described in detail in Knott and Hoskins (1975). Program LINFT is used to process the digitized refraction data, while SLOWI is used to process wide angle reflection data. A theoretical basis for SLOWI is given in Appendix D. When these programs were converted for use on the U.S.G.S. computer system, some significant errors were found and the necessary corrections were included. Both SLOWI and LINFT are available on the U.S.G.S. Honeywell Multics system in Menlo Park, California. Complete descriptions of the input required for each program, as well as an example data set, are included in the introductory comments to each program (see the FORTRAN listings in Appendix K). Examples of the output from these programs are shown in Appendix H.

The Honeywell Multics System is rather formidable, and the inexperienced user is advised to obtain some assistance before attempting to use it. The procedure below outlines the basic sequence of commands necessary to access and execute the programs, but these will be given without further explanation. Communication with MULTICS computer, through the Data Communication Interface of the Tek 4051, is initialized by calling a BASIC program, which is available through UD 14 from either digitizing program. (Warning: by calling this program, all digitizing program information is lost. Therfore, the MULTICS login must not be called before all the digitized information has been written to tape.)

The following sections describe the method by which the MULTICS programs are accessed and executed. Within the text are the commands and replies from an actual terminal session, during which links to the sonobuoy programs were created. The digitized data were transferred from magnetic cassette tape to MULTICS, and the reduction program (in this example SLOWI) executed. The terminal session is shaded in the text, and the arrows (⟶) indicate commands or information entered by the user.

When the MULTICS system has been called up with UD 14, the user is ready to login:

```
⟶ l ASmith
  Password:
⟶ [redacted]
  You are protected from preemption until 2252.
  ASmith  Marine logged in 04/05/78  2252.5 pst Wed from ASCII termina
  Last login 04/05/78  2154.7 pst Wed from TN300 terminal "none".
  check_info_segs: No change.
  No memos.
  - Wed 04/05 2252.6
```

The terminal parameters necessary for the Tektronix are initialized by:

```
⟶ stty -modes ^lfecho,pl34,ll72
```

where ^lfecho disables the line feed echo by the carriage return (assuming that the user has enable lfecho, perhaps through a start_up.ec). The pl34 parameter sets the page length to 34 lines and ll72 specifies that the Tektronix CRT is 72 characters wide. The stty command can be imbedded in a start_up.ec for convenience. With the page length set, MULTICS will stop sending data to the terminal after every 34 lines printed, and issue an EOP (for End of Page). To continue, press "HOME PAGE" and then "control L". (The control key works like the shift key.)

All the segment links necessary to access the programs mentioned here are provided through an exec_com entitled sonobuoy.ec. This exec_com need only be linked to and invoked one time. The procedure is:

```
→ link >udd>Marine>JChilds>sonobuoy.ec
  - Tue 03/21 1750.7

→ ec sonobuoy
  link >udd>Marine>JChilds>sonobuoy>slowi.fortran
  link >udd>Marine>JChilds>sonobuoy>slowi
  link >udd>Marine>JChilds>sonobuoy>linft.fortran
  link >udd>Marine>JChilds>sonobuoy>linft
  link >udd>Marine>JChilds>sonobuoy>sonomodel.fortran
  link >udd>Marine>JChilds>sonobuoy>sonomodel
  link >udd>Marine>JChilds>sonobuoy>io.ec
  link >udd>Marine>JChilds>sonobuoy>asr.ec
  link >udd>Marine>JChilds>sonobuoy>plot.ec
  - Tue 03/21 1750.8
```

All data stored on the tape cassettes is transferred to MULTICS through a text editor. We always use "ted", but "qedx" can be used in an identical manner:

```
→ ted
→ a
      (find file)          (User definable key 13)
      (data send)          (User definable key 4)
→ \f
      (edit with ted)
→ w testa.data
→ q

→ ls

  Segments = 1, Lengths = 3.

  r w    3  testa.data

  - Tue 03/21 1753.6
```

To execute a sonobuoy program (we have here used SLOWI as an example) it is first necessary to specify the segments for data input and output. This is done with io.ec, which requires two arguments: the input data segment and the target segment for output.

```
——► ec io testa.data  testa.result
    io attach file05 vfile_ testa.data -no_trunc
    io attach file06 vfile_ testa.result -no_trunc
    - Tue 03/21 1754.0
```

Finally, the program itself is executed:

```
——► slowi

    STOP

    fortran_io_: Close files?   yes ◄——
    - Tue 03/21 1754.7

——► ls

    Segments = 2, Lengths = 20.

    r w   17  testa.result
    r w    3  testa.data

    - Tue 03/21 1755.2
```

The results are either printed out at the terminal (with the print command), e.g.

pr testa.result

or printed offline with daemon_print

dp testa.result

When entirely finished, the user should logout, and return the Tektronix to BASIC control, with UD 5 (see Fig. 11).

Sonobuoy Interpretation Programs

Two interpretive programs are available. The first, called SONOMODEL, produces a Benson-Lehner pen plot of an artificial sonobuoy record. The program requires as input a layered model, with specified velocities and thicknesses for the layers. Based on ray tracing theory and assuming flat lying layers, the program produces a pen plot, which is scaled to match an actual sonobuoy record. This plot includes wide angle reflections, refractions, direct arrival, and indicates the critical point for each layer. Also produced by the program is an output table listing which includes critical distance and critical time for each layer.

Before executing the modelling program, an input segment must be created, generally through a text editor. The required information and format are specified in the introductory comments prefacing the fortran listing of the program (sonomodel.fortran). This listing is included in Appendix K.

The terminal session which follows was used to run the SONOMODEL example in Appendix I. We assume that this model data set has already been entered as a segment called testc.model.data . We ask that the output from SONOMODEL be directed to a segment called testc.model . The plot produced by the program is contained in the segment called bl_plot. When the plot is produced, the U.S.G.S. project account to which the plotting should be billed must be furnished. This is a nine digit number and is referred to below as "account#".

```
——► ls

    Segments = 1, Lengths = 1.

    rew     1  testc.model.data

    - Wed 03/22 2114.8

——► ec asr
    asr >udd>bl_lib -after working_dir
    - Wed 03/22 2114.9

——► ec io testc.model.data  testc.model
    io attach file05 vfile_ testc.model.data -no_trunc
    io attach file06 vfile_ testc.model -no_trunc
    - Wed 03/22 2115.1

——► sonomodel

    STOP

    fortran_io : Close files?   yes ◄——
    - Wed 03/22 2115.9

——► ls

    Segments = 3, Lengths = 24.

    r w    21  bl_plot
    r w     2  testc.model
    rew     1  testc.model.data

    - Wed 03/22 2116.1



——► ec plot account#
    ec >udd>bl_lib>plotter "bl_plot" "30" "1" "account#"
    Tape bl_plot_Marine,7track,den=556 will be mounted with a write ring.
    Tape plot.parm_Marine,7track,den=556 mounted on drive 5 with a write r
    TAPE: plot.parm_JChilds written at 03/22  2123.8 Wed
    io detach plot
    - Wed 03/22 1217.9

——► dp testc.model
    1 request signalled, 3 already in printer queue 3
    - Wed 03/22 2203.8
```

The sonomodel program also contains the option to produce page size illustrations of sonobuoy records. A comment in the program listing notes which lines must be changed to enable page size plots. To do this, the user must copy the fortran listing (sonomodel.fortran) into their own directory, make the changes through the text editor, and recompile the program. Figures 5 and 6 were produced in this manner.

The other interpretive program called POLYFIT, performs polynomial regressions and operates on the Tektronix 4051. The polynomial regression can be used to determine the relationship between travel time and sediment depth from the sonobuoy results, and hence provides excellent use of the sonobuoy data in the analysis of vertical incidence seismic records. See Appendix I for further details. The regression program itself is available on the Statistics package of the Tek 4051, and is fully cocumented in the Statistical package manual. Examples of both SONOMODEL and POLYFIT are contained in Appendix I.

REFERENCES CITED:

Bialek, E. L. (editor), 1966, Handbook of oceanographic tables: Special Publication SP-68, U.S. Naval Oceanographic Office, Washington, D. C., Section III, Table II, p. 63-95.

Dobrin, M. B., 1976, Introduction to geophysical prospecting (3rd ed.). McGraw-Hill Book Company, San Francisco, 630 pp.

Hamilton, E. L., Bachman, R. T., Curray, J. R., and Moore, D. G., 1977, Sediment velocities from sonobuoys: Bengal Fan, Sunda Trench, Andaman Basin, and Nicobar Fan: Jour. Geophys. Research, v. 82, p. 3003-3012.

Hamilton, E. L., Moore, D. G., Buffington, E. C., Sherrer, P. L., and Curray, J. R., 1974, Sediment velocities from sonobuoys: Bay of Bengal, Bering Sea, Japan Sea, and North Pacific: Jour. Geophys. Research, v. 79, p. 2653-2668.

Hill, M. N., 1963, Single-Ship Seismic Refraction Shooting, in The Sea, vol. 3. M. N. Hill ed., John Wiley & Sons, New York, 963 p.

Houtz, R. E., Ewing, J., and Buhl, P., 1970, Seismic data from sonobuoy stations in the northern and equatorial Pacific: Jour. Geophys. Research, v. 75, p. 5093-5111.

Houtz, R. E., Ewing, J. I., and Le Pichon, X., 1968, Velocity of deep-sea sediments from sonobuoy data: Jour. Geophys. Research, v. 73, p. 2615-2641.

Knott, S. T., and Hoskins, H., 1975, Collection and analysis of seismic wide angle reflection and refraction data using radio sonobuoys: Technical Report 75-33, Woods Hole Oceanographic Institute, 86 pp.

Le Pichon, X., Ewing, J., and Houtz, R. E., 1968, Deep-sea sediment velocity determination made while reflection profiling: Jour. Geophys. Research, v. 73, p. 2597-2614.

Levin, S. (editor), 1968, Velocity profile atlas of the North Pacific (Composite profiles): National Oceanographic Data Center, Washington, D. C. 20390.

Matthews, D. J., 1939, Tables of the velocity of sound in pure water and sea water for use in echo sounding and sound ranging: Hydrographic Dept., Admiralty, London.

Nettleton, L. L., 1940, Geophysical prospecting for oil. McGraw-Hill Book Company, New York, 444 pp.

Officer, C. B., 1974, Introduction to theoretical geophysics. Springer-Verlag, New York, 385 pp.

Telford, W. M., Geldart, L. P., Sheriff, R. E., and Keys, D. A., 1976, Applied geophysics. Cambridge Univ. Press, Cambridge, chapter 4.

Appendix A: Range and Penetration of Sonobuoys

(excerpted from an internal memo dated 12/14/77)

Subject: What type of sonobuoy do I need to get the job done?
NAVY or Commercial?

The answer to the above question depends on where you will be working, deep or shallow water. After talking to many of you about your sonobuoy results from 1976 and 1977, and after considering our work in the Bering Sea, we have put together a rather complicated diagram (attached) of a typical continental margin. The diagram is intended to illustrate how much crustal penetration we can expect to attain using either the Navy 41B or commercial sonobuoys with the 1326 cu.in. airgun array.

Three important observations have been made after examining the '75, '76, '77 records from sonobuoys that functioned properly:

A. On the shelf (200 m), an acoustic basement refractor (v=4.5-5.5) is seen on all sonobuoy records; however, this is the deepest refractor that can be identified on either the Navy or commercial buoy records. Insufficient seismic energy, rather than buoy transmitting range, is the limiting factor.

B. At intermediate depths (200-3000 m), a sub-basement refractor (v=6.0-6.7) is often seen with commercial buoys; the deepest refractor on Navy records is from acoustic basement.

C. In deep water (3000 m), a mantle refractor (v=7.9-8.4) can sometimes be identified with commercial buoys; Navy buoys normally only show a refractor from oceanic layer 3.

The type of buoy that will get the job done for you, based on our previous experiences on the LEE, is shown in the table:

Type of study \ Area	Shelf (200m)	Intermediated (200-3000m)	Deep water (3000m)
Sediment and Basement velocity	Navy	Navy	Navy
Deep crustal structure	Need Explosives	Explosives or Commercial	Commercial

TYPICAL CONTINENTAL MARGIN

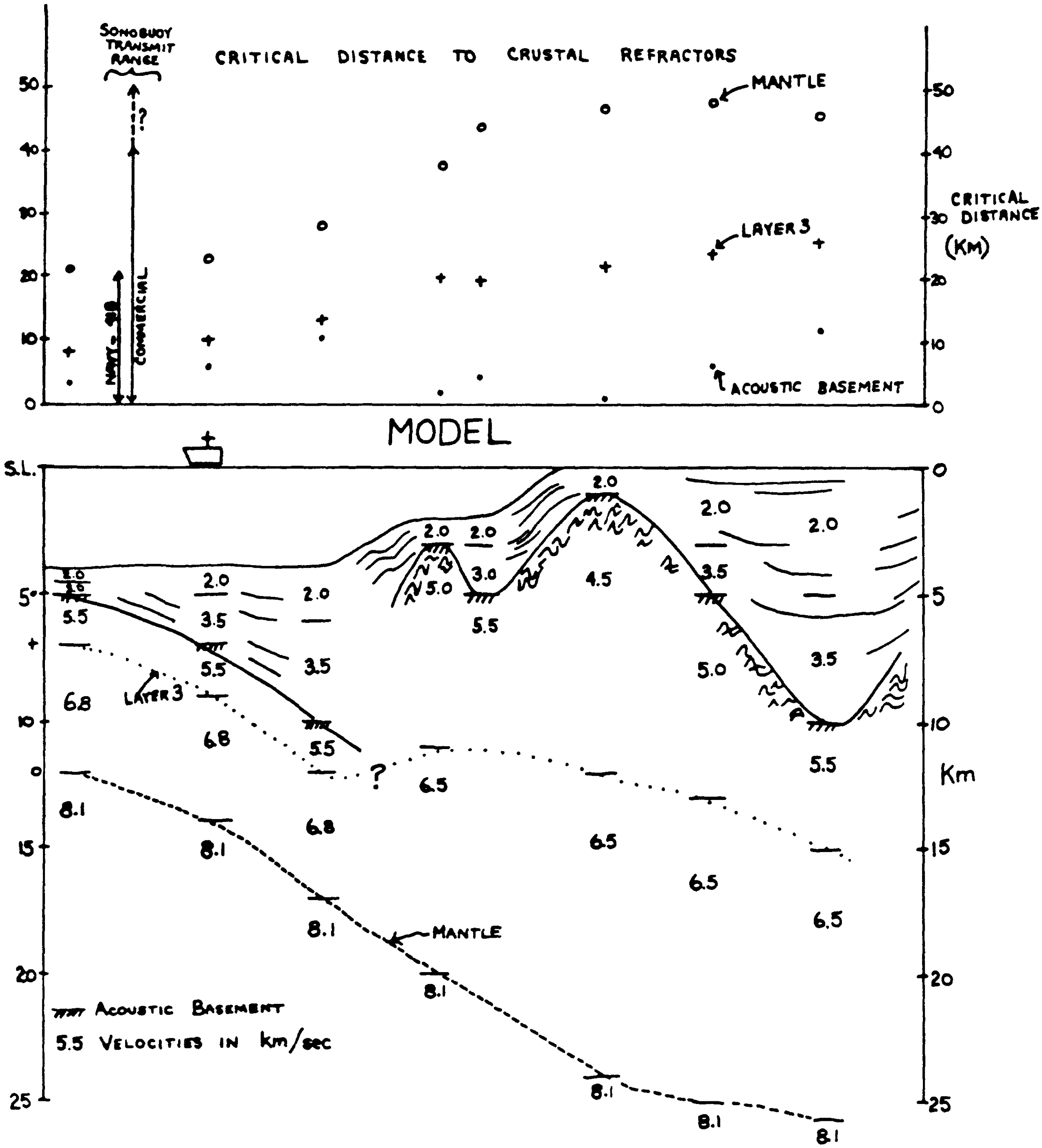


Figure 12 Sonobuoy penetration and range as a function of tectoni province. All results indicated in this diagram are strictly hypothetical, based upon sonobuoy models. The limits shown are approximate depths of penetration for commercial and military sonobuoys.

Appendix B

Velocity of sound in sea water

Velocity of sound in water is a function of several variables, primarily water temperature, pressure, and salinity. For a given area and time of year, however, the velocity of sound may be expressed simply as a function of water depth. Figure 14 illustrates this variation for the Southern Bering Sea during the summer months of July through September. The diagram is taken from Levin (1968, vol. II, p. 393). The plot shows sound velocity in meters/second versus water depth in meters. Also shown in the diagram are the hydrophone depths for sonobuoys equipped with 60, 120, and 240 foot lowers.

From the plot, we can see that the velocity at the sea surface, v_h, is about 1485 m/s. There is a sharp negative velocity gradient to a depth of 100 meters, at which point the velocity gradient reverses, and from there increases, almost linearly, to a depth of just less than 2000 meters (off the bottom of the graph). While this curve is not representative of all ocean waters, it does serve to point out some difficulties of which the sonobuoy user should be aware.

First, the marked velocity inversion, which results from the thermocline observed in most areas, should be considered when choosing the hydrophone lower depth. In the Southern Bering Sea, the inversion is quite deep, but in other areas it can occur at a much shallower depth. If the hydrophone is too deep and drops below this inversion, the velocity structure of the water may actually reflect the direct arrival energy away from the hydrophone, resulting in a very weak direct arrival. The deeper hydrophone may also result in less clearly defined seismic reflection arrivals. Each individual seismic wavelet recorded at the hydrophone consists of the primary wavelet and an accompanying

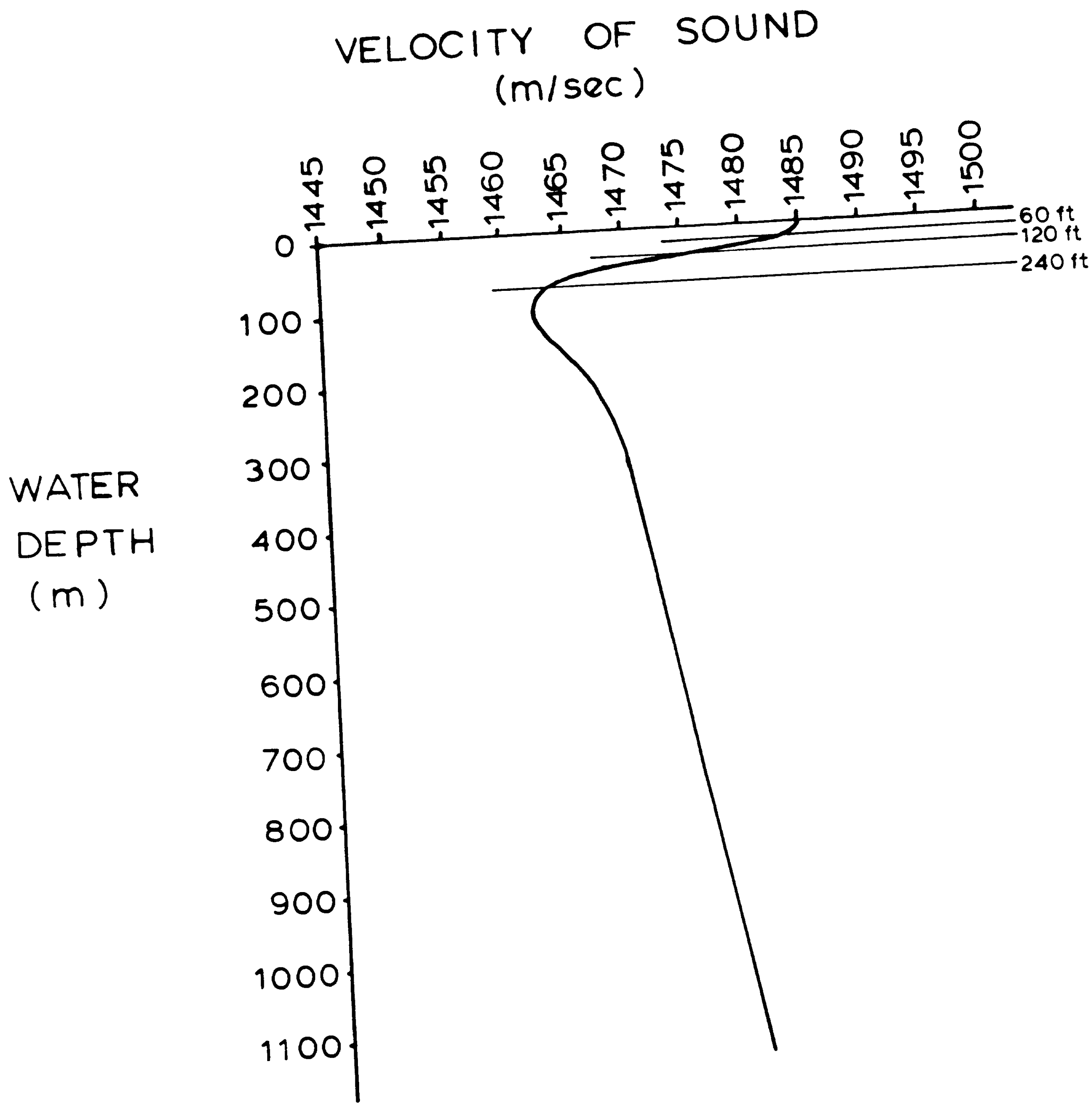


Figure 13 Variation of velocity of sound in sea water with depth for the Southern Bering Sea, summer months.

"ghost" wavelet from the sea surface (water-air interface). With a deeper hydrophone, the time delay between the primary arrival and its ghost will be greater, and the composite wavelet more diffuse. (Knott and Hoskins, 1975, p. 24). Errors may also be introduced into the wide angle reflecton and refraction solutions through incorrectly assumed values for the average vertical velocity of sound in water, v_v, and the horizontal velocity, v_h. Both velocities are input parameters to the reduction programs. In LINFT, the refraction velocity is determined directly from the ratio of the slope of the refractor to the slope of the direct arrival line. Therefore, the accuracy of the final refraction velocity results is directly proportional to the accuracy with which the horizontal velocity of sound is known. The horizontal velocity in Figure 14 is 1485 m/s, which is the default value in the digitizing programs. A variation of $\pm$ 10 m/s is less than a 1% error, but in other areas and at another time of year, the variation may be much greater.

The wide angle reflection program SLOWI, requires both v_h and v_v as input. However, these two variables are not independent. The program actually solves for v_h, based on the input value for v_v and the seafloor depth. The input value of v_h is used as a trial solution to the interative process. Therefore, it is critical to provide SLOWI with a reliable value for the average vertical of sound as some function of depth, f(z). For a given depth of water, z_1, the average vertical velocity is determined by integrating the curve f(z) from 0 to z_1:

$$\bar{V}_v = \frac{1}{z_1} \int_0^{z_1} f(z)\, dz$$

This integration can be done numerically. If we apply this technique to Figure 14 from 0 to 1100 meters, we arrive at a value for v_v of approximately

1472 m/s. The default value provided for v_v by the digitizing program is 1500 m/s, a difference of 2%. In other areas this difference could be greater. Since v_v is required for the determination of v_h, this error would effect both the solutions for reflection velocities, as well as the depth to the seafloor.

These problems illustrate the importance of having some independent information regarding the variation of velocity with depth. One of the most valuable tools is an XBT, or expendable bathythermograph. This is an expendable thermistor which is dropped into the water, attached to the ship by a slender copper wire. As the thermistor drops through the water, the resistance is measured and converted to temperature. Thus, a temperature-depth profile is obtained. The variation of velocity of sound is very nearly directly proportional to the temperature of the water, so this measurement may provide a very close approximation to the variation of velocity with depth. With underway multichannel operations, XBT's cannot be used. Therefore, tables similar to Mathew's and the velocity profile atlas must be relied upon. The S.P. Lee is also equipped with a velocimeter, which determines the horizontal velocity of water near the sea surface, and this value should be recorded in the logs during a sonomodel station. Any remarkable variation from the expected value (1485 m/s) should be investigated carefully noted.

APPENDIX C: Shipboard interpretation of Refraction and wide angle reflection data

Preliminary analysis of both refraction and reflection data can be done with reasonable accuracy (10-15%) using a hand calculator. The objective of these analyses is to determine velocities (refraction and interval) and layer thicknesses. The two following sections present all the equations necessary to achieve this goal. For brevity, the more complicated equations are given without derivation.

REFRACTION DATA

Interpretation of refraction data from shallow water areas is usually a straightforward process of:

1. identifying each successively deeper refracting horizon, which almost always occurs as a 'first arrival' with a distinct change in slope (see Fig. C.1);
2. determining the refraction velocity from the slope of the refractor (eq. 1);
3. computing the depth to the refractor at vertical incidence (eq. 2 and 3).

In deep water areas, the refraction data is often complicated by 'second arrival' refractions that are difficult, but important, to identify (see R_1, Fig. C.2).

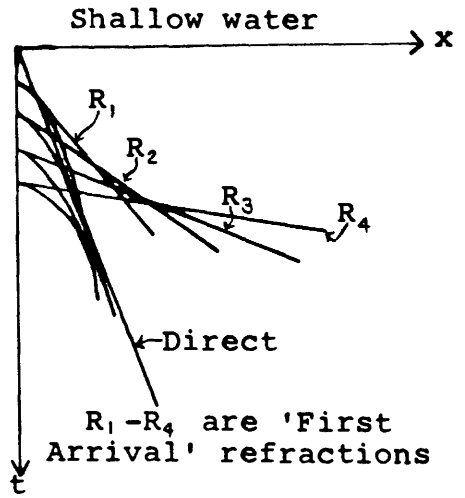


FIG. C.1

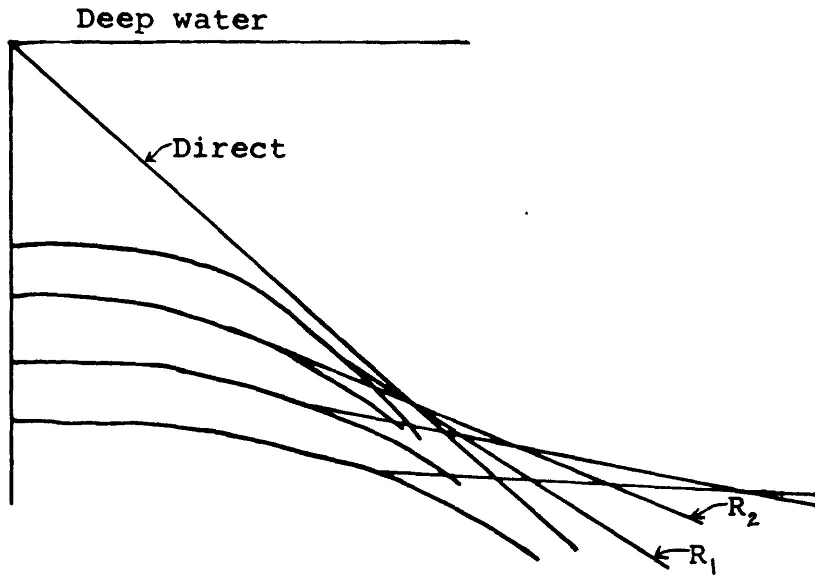


FIG. C.2

The velocity of the refractor (V_{REF}) can be determined from (assuming flat-lying layers):

$$V_{REF} = \frac{\Delta x}{\Delta T} = \frac{V_w T_{D2} - V_w T_{D1}}{T_{R2} - T_{R1}}$$

$$V_{REF} = \frac{1500\,(T_{D2} - T_{D1})}{(T_{R2} - T_{R1})} \qquad \text{(Eq. 1)}$$

V_{REF} in meters/sec

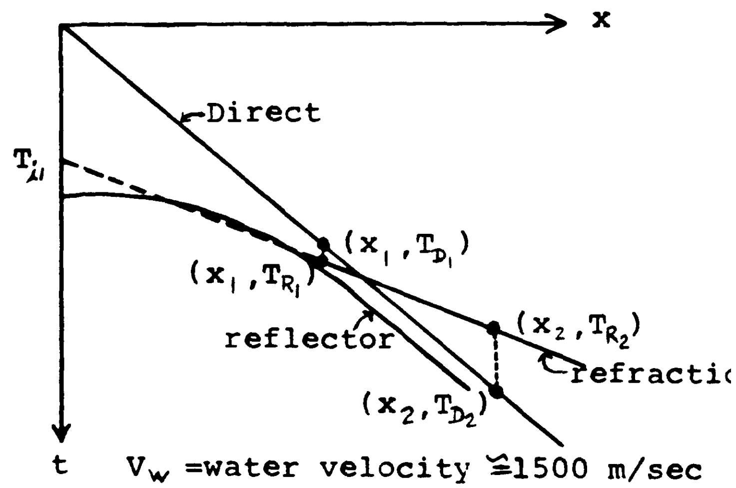


FIG. C.3

The depth to each refracting horizon involves a somewhat cumbersome set of calculations in which the thickness of the last penetrated layer (Z_{n-1}) is determined in terms of the thicknesses and velocities of the overlying layers. The generalized equation for determining the thickness of the (n-1)th layer is: (see Nettleton, 1940, p. 254)

$$Z_{(n-1)} = \frac{V_{n-1} V_n}{2\sqrt{V_n^2 - V_{n-1}^2}} \left[T_{in} - \frac{2Z_0\sqrt{V_n^2 - V_0^2}}{V_0 V_n} - \frac{2Z_1\sqrt{V_n^2 - V_1^2}}{V_1 V_n} \cdots - \frac{2Z_{n-2}\sqrt{V_n^2 - V_{n-2}^2}}{V_{n-2} V_n} \right] \quad \text{(Eq. 2)}$$

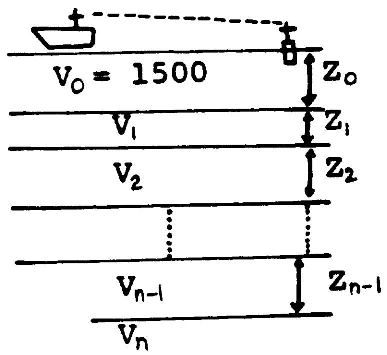


FIG. C.4

T_{in} is the intercept time for the nth layer (see Fig. C.3)

$V_o \cdots V_n$ are refraction velocities.

The thickness of the first four layers, in a format that is readily programable on a hand calculator is:

$$Z_0 = \frac{V_0}{\sqrt{V_1^2 - V_0^2}} \left(\frac{T_1 V_1}{2} \right)$$

$$Z_1 = \frac{V_1}{\sqrt{V_2^2 - V_1^2}} \left(\frac{T_2 V_2}{2} - \frac{Z_0\sqrt{V_2^2 - V_0^2}}{V_0} \right)$$

$$Z_2 = \frac{V_2}{\sqrt{V_3^2 - V_2^2}} \left(\frac{T_3 V_3}{2} - \frac{Z_0\sqrt{V_3^2 - V_0^2}}{V_0} - \frac{Z_1\sqrt{V_3^2 - V_1^2}}{V_1} \right)$$

$$Z_3 = \frac{V_3}{\sqrt{V_4^2 - V_3^2}} \left(\frac{T_4 V_4}{2} - \frac{Z_0\sqrt{V_4^2 - V_0^2}}{V_0} - \frac{Z_1\sqrt{V_4^2 - V_1^2}}{V_1} - \frac{Z_2\sqrt{V_4^2 - V_2^2}}{V_2} \right)$$

The depth to the top of the nth layer is given by:

$$D_n = \sum_{i=0}^{n-1} Z_i \quad \text{(Eq. 3)}$$

REFLECTION DATA

Constructing velocity versus depth sections from reflection data is generally done by:

1. determining the interval velocities between each of the prominent reflecting horizons (see steps I and II below);

2. converting the vertical incidence reflection times to depths using the interval velocities (eq. 11).

Procedure:

I. Determine the RMS velocities for each of the reflecting horizons using either (A) or (B):

(A). the Tangent method (eq. 7 or 8);

(B). the two point method (eq. 9).

II. Then use Dix's equation to compute the interval velocity between two reflecting horizons (eq. 10).

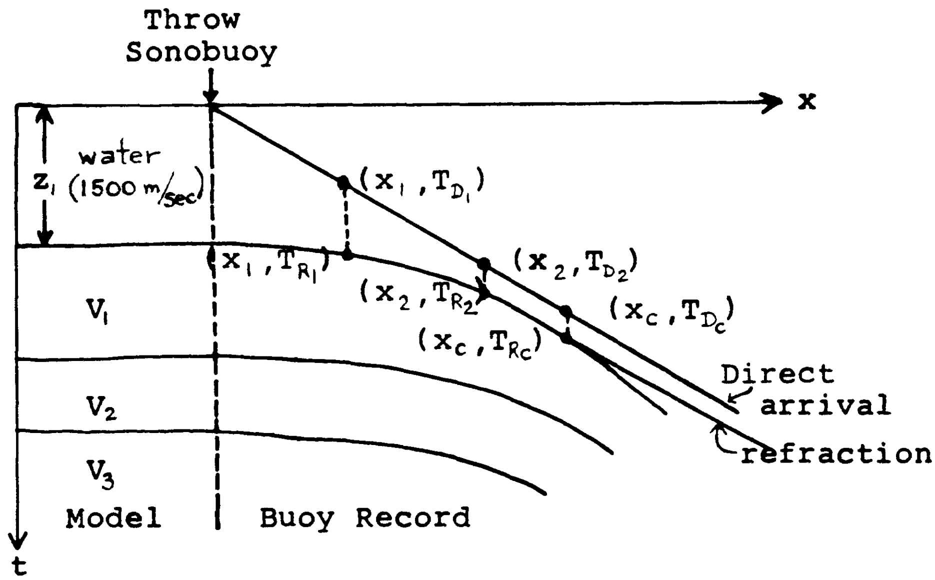


FIG. C.5

$$T^2 = T_D^2 + \frac{x^2}{V_{rms}^2}$$

$$= \left(\frac{2z}{V_{rms}}\right)^2 + \left(\frac{x}{V_{rms}}\right)^2 \qquad \text{(Eq. 4)}$$

$$\left(T V_{rms}\right)^2 = \left(2z\right)^2 + x^2 \qquad \text{(Eq. 5)}$$

I.A. RMS Velocity - Tangent method

Differentiate the travel time equation (5) with respect to x and at a constant depth z:

$$2V_{rms}^2 T \frac{\Delta T}{\Delta x} = 2x \qquad V_{rms}^2 = \left(\frac{x}{T\left(\frac{\Delta T}{\Delta x}\right)}\right)^{\frac{1}{2}} \qquad \text{(Eq. 6)}$$

Where $\frac{\Delta T}{\Delta x}$ is the slope of the travel time equation.

All terms in equations (2) and (6) can easily be determined from the sonobuoy record. The quickest method (see Fig. C.6) is to look for a region of good data along the reflection hyperbola of interest and to draw a tangent line to the hyperbola. The tangent point (x_1, T_{R1}), the direct arrival time (x_1, T_{D1}), and the slope of the line $(\Delta T/\Delta x)$ are used to determine the RMS velocity from equation (7).

$$x \cong 1500\, T_{D1}$$

$$\Delta T/\Delta x = (T_{R1} - T_I)/1500\, T_{D1}$$

$$V_{RMS} = \left(\frac{1500\, T_{D1}}{T_{R1}\left(\frac{T_{R1} - T_I}{1500\, T_{D1}}\right)}\right)^{\frac{1}{2}}$$

$$V_{RMS} = \frac{1500\, T_{D1}}{\left(T_{R1}\left(T_{R1} - T_I\right)\right)^{1/2}} \qquad \text{(Eq. 7)}$$

RMS VELOCITY IN METERS/SEC

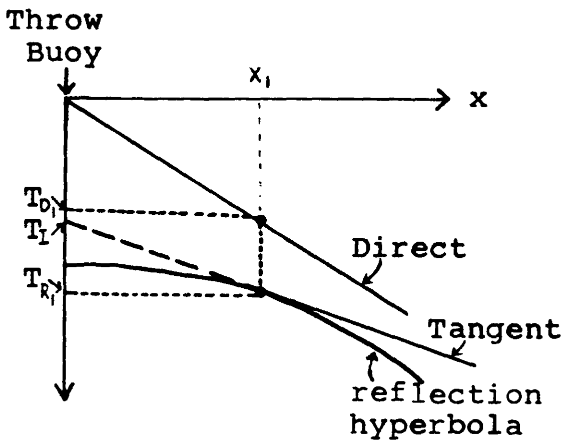


FIG. C.6

If the refraction velocity for a specific reflecting horizon has already been determined, then a simplified version of equation (6) can be used. Since refractions are always tangent to the reflection hyperbola, at the critical distance point (x_c, T_{RC}), the equation for RMS velocity becomes (see Fig. C.5):

$$V_{RMS} = \left(\frac{X_c}{T_{RC}(1/V_{REF})}\right)^{\frac{1}{2}}$$

$$\frac{\Delta T}{\Delta x} = \frac{1}{V_{REF}}$$

$$X_c \cong 1500\, T_{DC}$$

V_{REF} is the refraction velocity in meters/sec.

$$\boxed{V_{RMS} = \left(\frac{1500\, T_{DC}\, V_{REF}}{T_{RC}}\right)^{\frac{1}{2}}} \qquad \text{(Eq. 8)}$$

RMS VELOCITY IN meters/sec

I.B. RMS Velocity - Two point method

Using the travel time equation (4) for two different points (x_1, T_{R1}) and (x_2, T_{R2}) (see figure C.5) and eliminating the common T_o^2 term:

$$T_{R1}^2 - \frac{X_1^2}{V_{rms}^2} = T_{R2}^2 - \frac{X_2^2}{V_{rms}^2}$$

$$X_1 \cong 1500\, T_{D1}$$

$$V_{rms} = \left(\frac{X_2^2 - X_1^2}{T_{R2}^2 - T_{R1}^2}\right)^{1/2}$$

$$X_2 \cong 1500\, T_{D2}$$

$$\boxed{V_{rms} = 1500\left(\frac{T_{D2}^2 - T_{D1}^2}{T_{R2}^2 - T_{R1}^2}\right)^{\frac{1}{2}}} \qquad \text{(Eq. 9)}$$

rms velocity in meters/sec

II. Interval Velocity - Dix Equation

From Dix (1955), the interval velocity when $x \ll z$ is approximated by:

$$V_{INT} = \left(\frac{V_2^2 T_2 - V_1^2 T_1}{T_2 - T_1} \right)^{1/2} \qquad \text{(Eq. 10)}$$

where V_1 and V_2 are RMS velocities and T_1 and T_2 are zero offset (vertical incidence) times (see figure C.7).

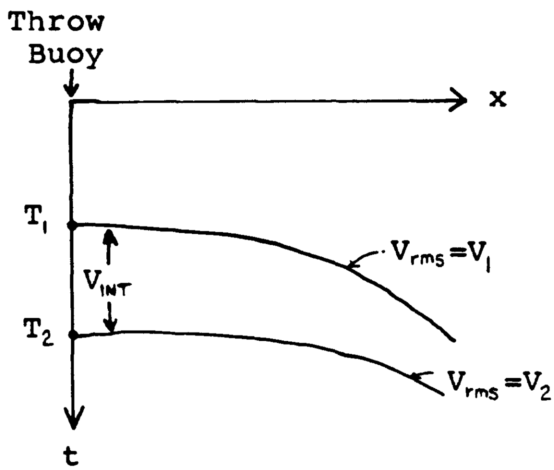


FIG. C.7

Once the interval velocities are known, the depths to each of the reflecting horizons can be determined from the vertical incidence reflection times. The depth (D) to the top of the N^{th} layer is:

$$D_n = \sum_{i=0}^{n-1} \frac{T_{vi}}{2} V_i \qquad \text{(Eq. 11)}$$

where T_{vi} is the vertical incidence reflection time (2-way) within the i^{th} layer (read from the reflection profile) and V_i is the interval velocity of the i^{th} layer.

APPENDIX D: Reflection ray tracing theory

In these derivations, the following notation is used:

1. All distances in lower case letters
2. All times in upper case letters

x - horizontal distance; source - receiver separation

h_1 - thickness of layer 1 (here the water layer)

h_2 - thickness of layer 2

r_1 - length of reflection path (2 way) to first reflecting horizon (here the water sediment interface)

r_2 - length of reflection path to second reflecting horizon

T_1 - reflection time (2 way) to first reflecting horizon (here the water-sediment interface)

$T_1(0)$ - minimum reflection time to first reflecting horizon

T_1' - reduced reflection times for T_1

T_2 - reflection time (2 way) to second reflecting horizon

$T_2(0)$ - minimum reflection time to second reflecting horizon

T_2' - reduced reflection times for T_2

T_d - time of direct water arrival

T_{con} - correction term to produce reduced times

V_h - horizontal velocity of propagation of sound at the water surface

V_1 - interval velocity of layer 1 (here the water layer)

V_2 - interval velocity of layer 2

V_{a2} - assumed interval velocity of layer 2

ω_1 - slope of first reflecting horizon

ω_2 - slope of second reflecting horizon (with respect to ω_1)

ω_{a2} - assumed slope of second reflecting horizon

D_1 - T_{d1}

D_2 - T_{d2}

I. Pythagorean Theorem for flat lying layers

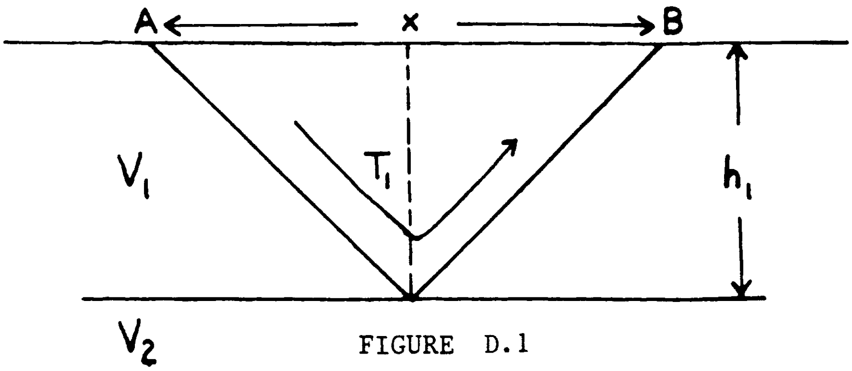


FIGURE D.1

By the Pythagorean Theorem:

$$\left(\tfrac{1}{2}x\right)^2 + \left(h_1\right)^2 = \left(\tfrac{1}{2}T_1 v_1\right)^2 \qquad (1)$$

$$x^2 + \left(2h_1\right)^2 = \left(T_1 v_1\right)^2 \qquad (2)$$

$$T_1^{\,2} = \left(1/v_1^2\right) x^2 + \left(2h_1/v_1\right)^2 \qquad (3)$$

This equation (3) is linear in x^2 and T^2. Therefore, a line fitted by least squares to the x^2-T^2 data points will have a slope inversely proportional to the square of the interval velocity (v_1)

of the layer. The intercept of this line is the square of the minimum reflection time ($T_1(0)$) to the reflecting interface. From $T_1(0)$ and v_1, the true depth to the interface can be determined.

II. Image method (law of cosines) for dipping interfaces

Using the image method to solve the wide angle reflection equation with dipping reflector interfaces (see Figure D.2):

By the law of cosines

$$r_1^2 = x^2 + (2h_1)^2 - 2(x)(2h_1)\cos(\alpha) \qquad (4)$$

where $\alpha = 90 - \omega_1$

Therefore

$$r_1^2 = x^2 + (2h_1)^2 - 4xh_1\cos(90 - \omega_1)$$

$$= x^2 + (2h_1)^2 - 4xh_1\sin\omega_1 \qquad (5)$$

Expressing the distances in terms of time and velocity:

$$(T_1 V_1)^2 = (T_d V_h)^2 + (T_1(0)\,V_1)^2 - 2(T_d V_h)(T_1(0)\,V_1)\sin\omega_1$$

Finally, the equation for travel times for dipping reflectors is:

$$T_1^2 = T_d^2 (v_h/v_1)^2 + T_1(0)^2 - 2T_d T_1(0)(v_h/v_1)\sin\omega_1 \qquad (6)$$

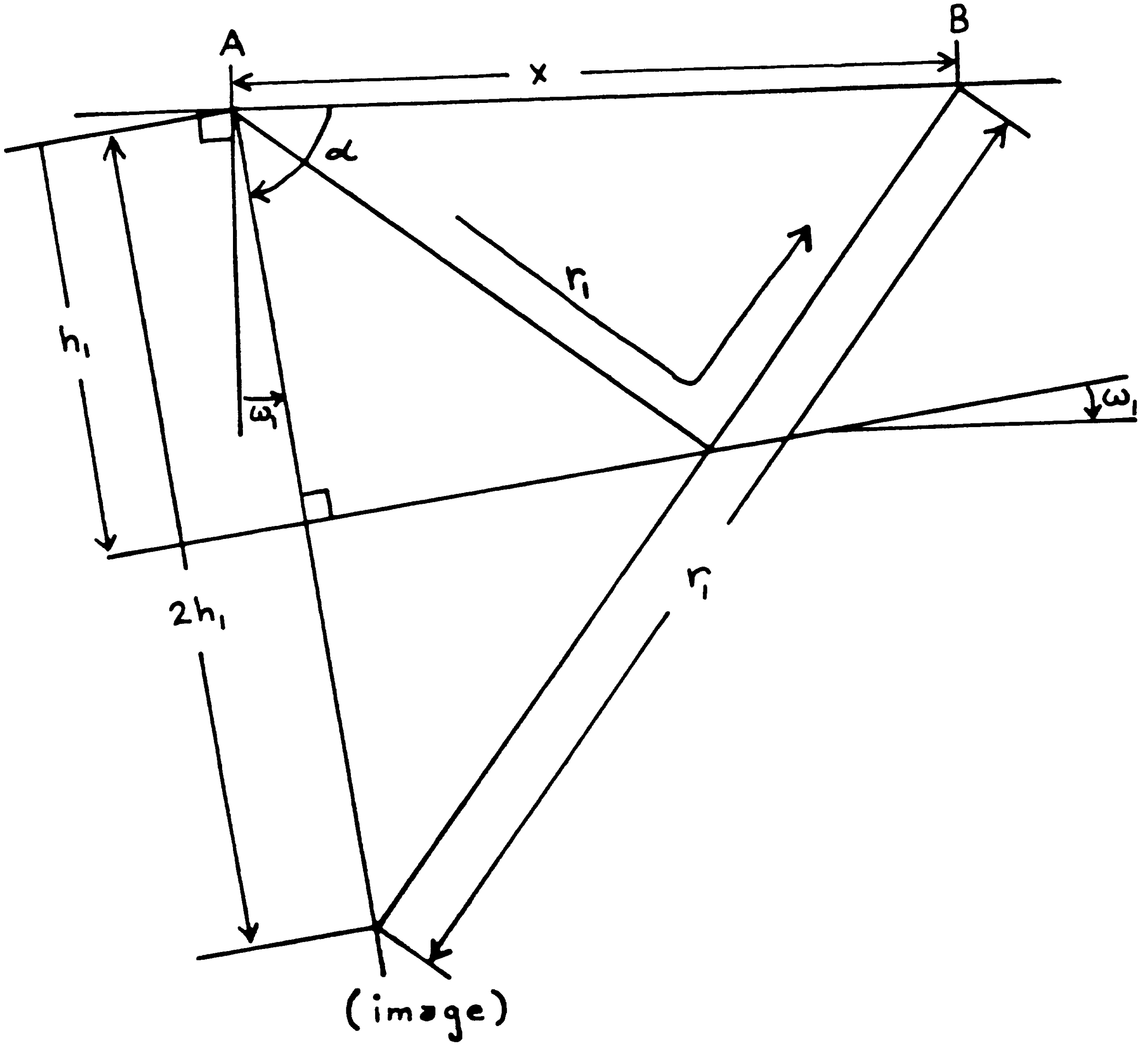


FIGURE D.2

(From Knott & Hoskins, p. 2-4)

III. SLOWI (SLOping WIde angle) reflection method

A. First (water) layer: Computation to iteratively determine a reliable value for the horizontal water velocity v_h

1. Assume that T_1, the total travel time, w_1, the slope of the first reflecting interface, and v_1, the interval velocity of the first layer, are known.
2. Find the minimum reflection time, $T_1(0)$:

   If the T/x curve starts close to the origin, (x=0), $T_1(0)$ is determined by a fourth order least squares fit to the time - distance curve:

$$T_1 = T_1(0) + C_1 T_d + C_2 T_d^2 + C_3 T_d^3 + C_4 T_d^4 \quad (7)$$

   where $T_d = x/v_h$

   If the T/x curve starts beyond the origin ($x > 0$), $T_1(0)$ is found by a linear least squares fit to:

$$T_1^2 = T_1(0)^2 + C_1(x/v_h)^2 = T_1(0)^2 + C_1 T_d^2 \quad (8)$$

   From $T_1(0)$, the minimum thickness, h_1, is found.
3. From the law of cosines solution (see equation 6, Part II):

$$T_1^2 = T_d^2\left(\frac{v_h}{v_1}\right)^2 + T_1(0)^2 - 2T_d T_1(0)\frac{v_h}{v_1}\sin\omega_1 \quad (9)$$

   Reduced times, T_1, are calculated from equation 9 by removing the normal incidence travel time within the layer, $T_1(0)$, as well as the difference in travel time resulting from the slope of the interface:

$$T_1'^2 = T_1^2 - T_{conl}$$

where

$$T_{conl} = T_1(0)^2 - 2T_d T_1(0) \frac{V_h}{V_1} \sin \omega_1$$

or

$$T_1'^2 = T_d^2 \frac{V_h^2}{V_1^2} \qquad (10)$$

This reduced travel time squared - distance squared equation is fit by linear least squares to determine v_h. (This value for v_h is compared to the input value for v_h and if the difference is large, another iteration is made from step 3 using the corrected value of v_h).

B. Second layer

1. Assume that T_2, the travel time to interface 2, ω_1, the slope of the first reflecting interface, and v_1, the interval velocity of the first layer, are known. Also, the apparent slope, ω_{a2}, determined from an assumed interval velocity, v_{a2}, for the second layer, must be known.

2. Determine by least squares the fourth order polynomial:

$$T_2 = T_2(0) + C_1 T_d + C_2 T_d^2 + C_3 T_d^3 + C_4 T_d^4$$

where $T_d = x/v_h$

3. Find $T_2(0)$, the normal incidence reflection time to the second interface, in the same manner as for the first layer (see section D.2), be either linear least squares or fourth order polynomial fit. Calculate h_2 from $T_2(0)$ and the assumed velocity v_{a2}.

4. Recall the ray parameter, p :

$$p = (\sin \theta_i)/v_i \tag{11}$$

where θ_i is the emergent angle of the ray for layer i and v_i is the interval velocity for the layer.
The ray parameter may be expressed as the derivation of the time - distance curve (see Officer, 1958, pp. 48 - 52):

$$p = \frac{dT}{dx} \tag{12}$$

Therefore, by differentiating the fourth order polynomial for T_2 above and substituting into equation (11) and (12):

$$\sin(\beta_1 - \omega_1) = v_1 \frac{dT_2}{dx} \tag{13}$$

where $(\beta_1 - \omega_1)$ is the emergent angle (see Figure D.3).

5. From Snell's Law and reflection geometry, we see from equations at the bottom of Fig. D.4, that the incident angle, β_1' can be calculated from the emergence angle $(\beta_1 - \omega_1)$ for each value of x.

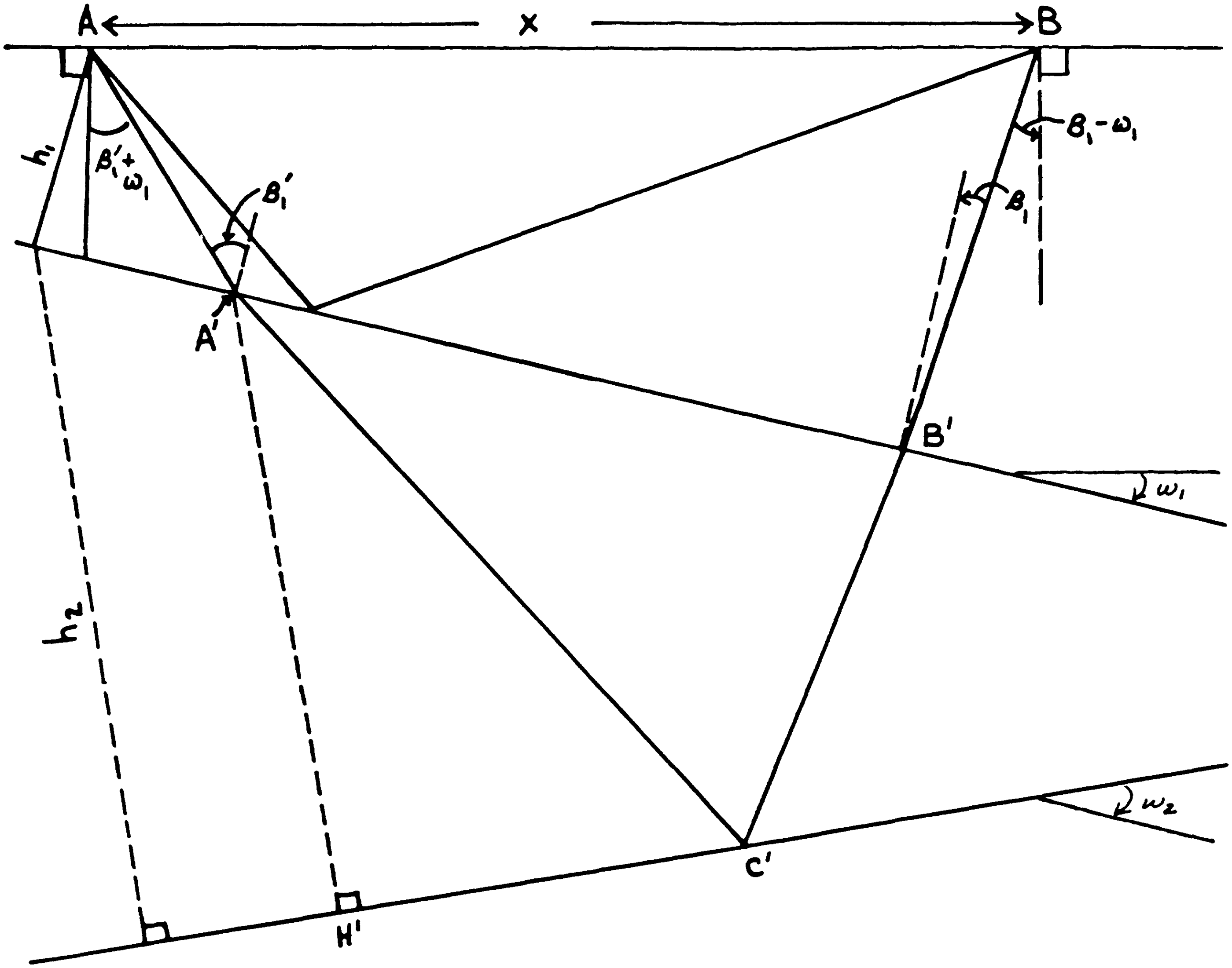

A
X
B
h_1
$\beta_1' + \omega_1$
β_1'
$\beta_1 - \omega_1$
β_1
A'
B'
ω_1
h_2
C'
ω_2
H'

FIGURE D.3

6. Knowing the incident and emergence angles, compute the one way travel times $T_{AA'}$, $T_{BB'}$, $T_{A'H'}$, and the distance A'B' .

7. With these travel times, "strip off" the upper layer and determine the travel time in the second layer alone:

$$T_{A'C'B'} = T_{AA'C'B'B} - T_{AA'} - T_{B'B} \tag{14}$$

8. This now is the one layer case. As before (Eq. 9), the travel times are expressed:

$$(T_2 V_{a2})^2 = (A'B')^2 + (2T_{A'H'} V_{a2})^2 - 2(A'B')(2T_{A'H'} V_{a2}) \sin \omega_{a2}$$

$$T_2^2 = (A'B'/v_2)^2 + (2T_{A'H'})^2 - \frac{2(A'B')(2T_{A'H'})}{V_2} \sin \omega_{a2} \tag{15}$$

The distance A'B' is known explicitly, and therefore it is not necessary to calculate a horizontal velocity along the interface as was done for the first layer.

9. These squared travel times are reduced by:

$$T_2'^2 = T_2^2 - T_{con2}^2 \tag{16}$$

where

$$T_{con2}^2 = (2T_{A'H'})^2 - \frac{2(A'B')(2T_{A'H'})}{V_{a2}^2} \sin \omega_{a2}$$

10. Any negative travel times are eliminated, and a least squares fit made to

$$T_2'^2 = \frac{(A'B')^2}{v_2^2} \qquad (17)$$

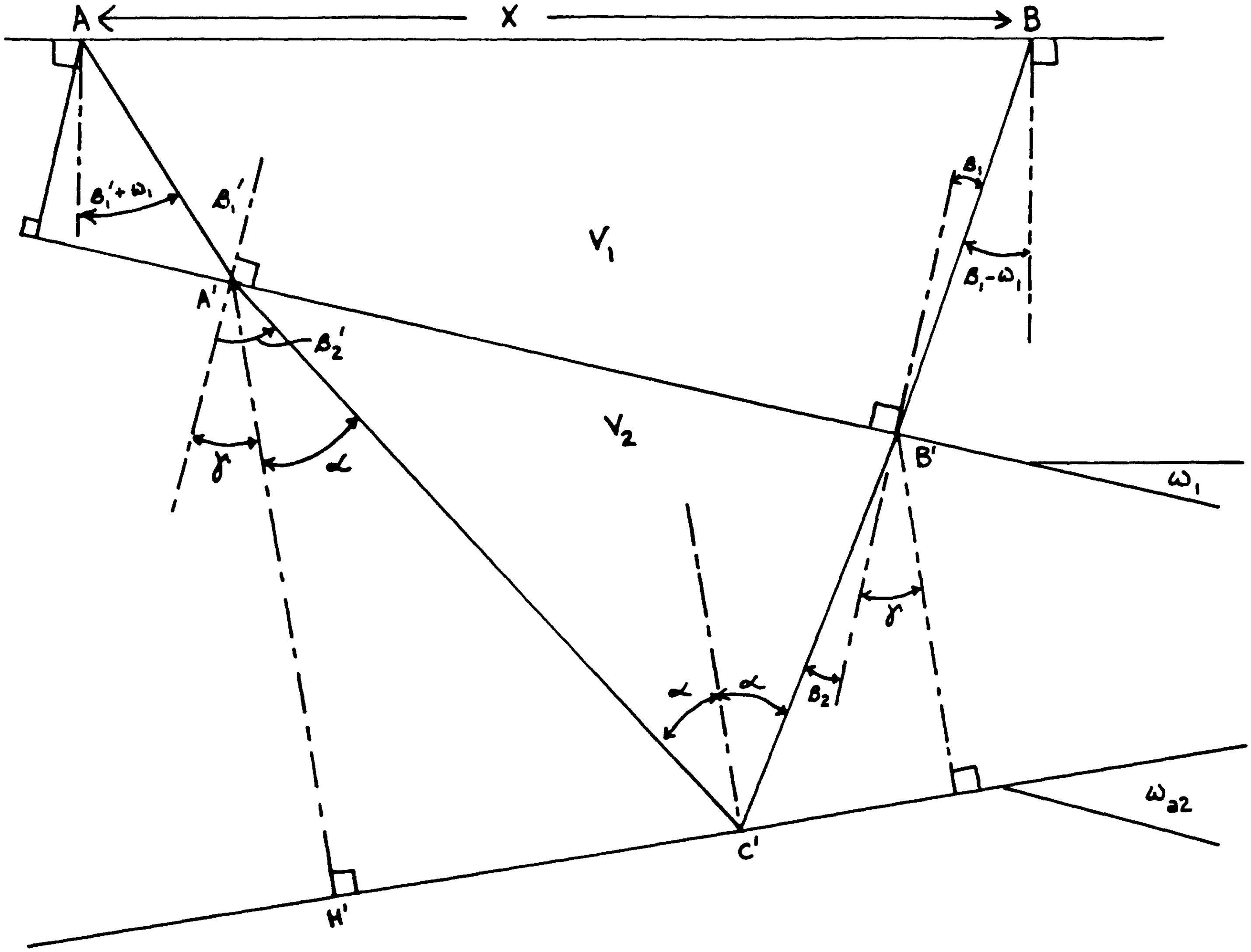
This fit provides a corrected value of v_2.

11. The apparent angle, ω_{a2} , is corrected according to

$$\tan \omega_2 = \tan \omega_{a2} \cdot \frac{v_2}{v_{a2}} \qquad (18)$$

12. With new values for ω_2 and v_2 , the program returns to step 3 and repeats. The same sequence of steps is then followed for each subsequent layer.

FIGURE D.4



$$\frac{\sin \beta_1'}{\sin \beta_2'} = \frac{V_1}{V_2}$$

$$\frac{\sin \beta_1}{\sin \beta_2} = \frac{V_1}{V_2}$$

$$\beta_2 = \arcsin\left(\frac{V_2}{V_1}\sin\beta_1\right)$$

$$\alpha = \beta_2 + \gamma$$

$$\beta_2' = \beta_2 + 2\gamma = \beta_2 + 2\omega_{a2}$$

$$\beta_1' = \arcsin\left(\frac{V_1}{V_2}\sin\beta_2'\right) = \arcsin\left(\frac{V_1}{V_2}\sin(\beta_2+2\omega_{a2})\right)$$

$$\beta_1' = \arcsin\left(\frac{V_1}{V_2}\sin\left[\arcsin\left(\frac{V_2}{V_1}\sin\beta_1\right) + 2\omega_{a2}\right]\right)$$

Appendix E

Procedure outline for digitizing and processing sonobuoy records

This appendix provides a suggested procedure for digitizing and processing sonobuoy records, from initial preparation of the record, through digitizing, reduction and interpretation.

Procedure outline for digitizing and processing sonobuoy records

I. Preparation of records prior to digitizing

1. Cut records and paste on a stable backing
2. Overlay record with "cured" mylar acetate overlay
3. Draw time lines and other reference points on mylar
4. Choose refractions and/or reflections and trace on the mylar

II. Refraction data

1. Load refraction digitizing program and execute

   The refraction digitizing program is interactive, and request all necessary information from the user. The digitizing is carried out one refraction trace at a time, and each data point requires two time picks: a direct time and a refraction time. Upon command, the program will automatically write an output data set to magnetic tape.

2. Transfer data set to MULTICS computer
3. Execute preliminary LINFT program

   LINFT performs a linear fit (least squares) to the refraction data and prints out velocity and depth solutions.

4. Determine the slopes of refracting surfaces from vertical incidence seismic reflection records, using the velocity solutions from preliminary LINFT.
5. Execute LINFT program again with slope corrections
6. Edit refraction results for spurious refractions and other errors
7. Execute final LINFT with corrected data set if necessary

III. Wide angle reflection data

1. Load reflection digitizing program and execute

   The reflection digitizing program is interactive, and requests all necessary information from the user. The order of digitizing data points is a direct time followed by "n" reflection times, where "n" is the number of reflection layers. The reflection digitizing program also provides preliminary analysis of the data in the form of $X^2 - T^2$ calculations, and allows editing of the data points before writing an output data set to magnetic tape. Therefore,the suggested order within the digitizing program is:

   a. Digitize the reflection recorde
   b. Execute $X^2 - T^2$ program
   c. Execute the Edit program to correct bad picks
   d. Execute $X^2 - T^2$ again with edited data set
   e. Execute the Edit program again, if necessary
   f. From Edit section, write an output data set to tape

2. Transfer data set to MULTICS computer

3. Determine apparent slopes of reflectors from vertical incidence seismic reflection records, using an assumed velocity of seawater for the sediments.

4. Execute SLOWI with program with assumed slope correction

   SLOWI performs a sophisticated variation of $X^2 - T^2$ analysis on the reflections and prints out velocity and depth solutions. The program also calculates true dips of the reflectors from the calculated velocities

5. Edit final SLOWI results

6. Execute SLOWI again with edited data set, if necessary

IV. Interpretation

1. Compile all refraction and reflection results

2. Determine the velocity - depth relationship

The velocity - depth relationship may be determined by a program that performs a polynomial fit to the sonobuoy results. Other relationships may be possible as well

3. Correct final reflection results according to the velocity - depth curve (optional). (Refer to Houtz et.al, 1968, pp2631-2632)

4. Construct velocity sections from the refraction results, and separate sections from the reflection results, if desired

Appendix F

Corrections to the reduction results

This appendix contains two sections:

1. Corrections for hydrophone lower
2. Corrections for dipping interfaces

The first part of this appendix describes correction factors which are necessitated by the hydrophone suspension system, and by the delayed release timer which activates the suspension.

The second section describes the manner in which sloping reflection and refraction interfaces are corrected for in the reduction programs. The digitizing programs do not require or accept slope corrections, and therefore these corrections must be included in the data sets after they have been transferred to MULTICS.

Correction for depth of the hydrophone

During normal operations, the sonobuoy hydrophone drops to depths of 60 to 300 feet beneath the sea surface as soon as the buoy is placed in the water. The error in the reflection times that is introduced by the depth of the hydrophone is corrected in program SLOWI, if the final hydrophone depth is input to the program and the "correct E/S depth" option is chosen.

If a sonobuoy station is conducted during multichannel seismic operations, it is necessary to delay the deployment of the sonobuoy hydrophone for 20 minutes, the time required for the buoy to clear the far end of the multichannel hydrophone cable. The delayed drop, from near the sea surface to depths of 60 to 240 feet, introduces two problems in the sonobuoy interpretation. First, the sudden increase in the distance from the hydrophone to the sea surface changes the general configuration of the reflectors in the sonobuoy record by increasing the time between the primary reflected arrival and the secondary sea surface reflection (from 4 msec to 48 msec with a 120 foot drop) (See also App. B). Secondly, the time difference resulting from the shortened travel path introduces an abrupt vertical shift in the reflectors (-25 m sec with a 120 foot depth) at the point when the phones drop. The first problem of reflector configuration can only be compensated for subjectively through the interpreter's ability to accurately follow each of the primary reflection arrivals across the sonobuoy record. However, an explicit correction for the abrupt vertical shift in the reflectors can be made during the data reduction after the reflectors are digitized in their shifted configuration. The program determines the time of the hydrophone release by asking the interpreter to mark the direct time on the trace recorder where the release occurred. Then, based on the final hydrophone depth (input earlier), a correction value is calculated and subtracted from all reflection times along prior traces. The effect is to change the data to appear as if the hydrophone had released immediately. SLOWI then corrects all reflection times for the hydrophone depth. This "delayed hydrophone release correction" is an option with the SLOWI digitizing program, and is usually called after digitizing the record, but before the $X^2 - T^2$ calculations. However, the correction can be called from other parts of the digitizing program. Therefore, it may be desirable to calculate the $X^2 - T^2$ plot without the correction, check the residual values, then add the correction to see whether the solutions improve. The option to add the correction can also be used to remove the same correction if it is determined that the original data is better. Often, the effect of the delayed release will be very noticeable as a discontinuity on the X^2-T^2 plot.

Slope Corrections

Slope corrections are important for both the wide angle reflection and refraction data to insure good velocity and thickness values. The slope information usually comes either from the dip of the reflectors in the vertical incidence seismic data recorded during the sonobuoy station or from the dip of refraction interfaces seen on a series of back-to-back sonobuoy stations. In both reduction programs LINFT (refraction data) and SLOWI (wide angle reflection data), input dips are <u>relative dips</u> (i.e. the dip for a deeper layer is calculated with respect to the layer directly above it). For example, if two layers are dipping parallel to one another (absolute dip = A), then the relative dip of the shallower layer is A, while that of the deeper layer is 0. The sign convention is the same for both programs and is that upward relative dip in the direction of travel (updip from the buoy) is positive, while downdip is negative (refer to Figure 14). All dip calculations presuppose that the velocity of the overlying layer is-known, whereas usually it is not known. Hence, a trial velocity must be assumed to calculate the dips from the seismic reflection profiles. LINFT and SLOWI differ significantly in the way they use the trial velocities. Therefore, the dips should be determined specifically for the program that is to be used.

In calculating slopes for SLOWI a velocity of 1.5 km/sec (water velocity) must be assumed for the overlying water and sediment layer. SLOWI will iteratively correct the input slopes as better values for the velocity are obtained. The correction is:

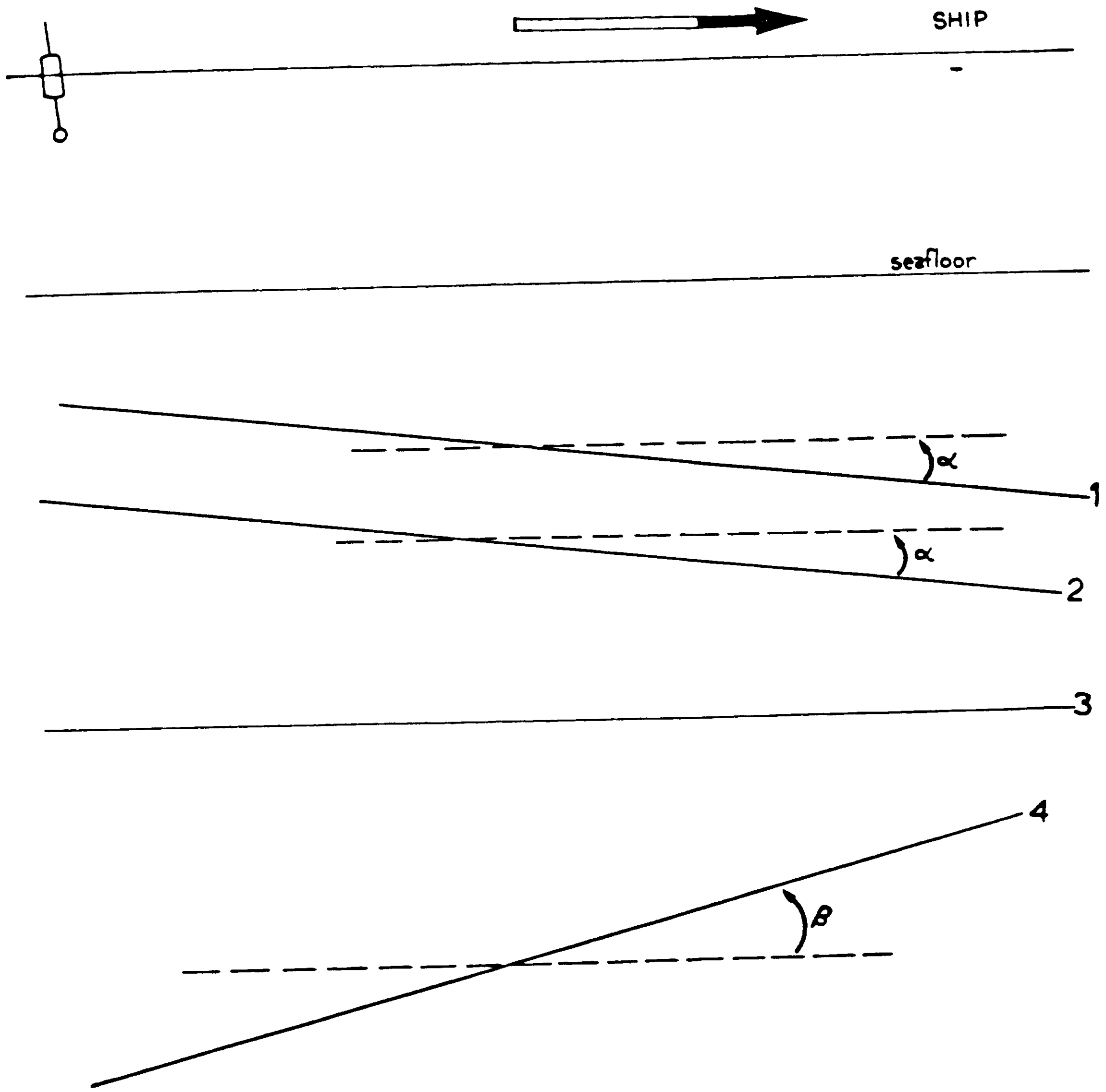
$$\tan W = \frac{v}{v_a} \tan W_a$$

where W and v are corrected slope and velocity and W_a and v_a are input slope and assumed velocity. The final values for the relative slopes of the layers and the slope corrected velocities are given in a summary table.

LINFT, however, uses the correct relative dips, as they would be output from SLOWI. Because there are often no SLOWI solutions for a sonobuoy, or no reflections from a refracting layer, LINFT must be executed twice: the first time with zero slopes to determine trial velocities and a second time with estimated relative dips calculated from the trial velocities. If the dip corrections are large, the velocities may change enough to warrant a third run with recalculated dips.

It is usually necessary to calculate dip for SLOWI and LINFT independently even when good output dips from SLOWI are available. Reflections are observed over a much shorter range (8 km distance in 3000 m of water) than are refractions, (12-30 km distance) and, therefore, are affected by layer dips only in the first part of the sonobuoy record.

Dip corrections are not included in the data sets output by the digitizing programs, and therefore, must be entered into the data set through the text editor.



Layer	Absolute dip	Relative dip
SEAFLOOR	0	0
1	$-\alpha$	$-\alpha$
2	$-\alpha$	0
3	0	$+\alpha$
4	$+\beta$	$+\beta$

Figure 14 Convention used by SLOWI and LINFT to specify slopes of interfaces.

Appendix G

Examples of digitizing programs

The following appendix contains complete examples of both LINDIGIT and SLODIGIT, the Tektronix programs for digitizing refractions and reflections. The examples illustrate the complete process for digitizing the refractions and reflections from a single sonobuoy station, but do not explore all the possible options and variations that are available within the programs.

Either digitizing program is located and invoked by means of the "AUTOLOAD" function. To use, simply insert the program tape into the 4051 and press "AUTOLOAD". Much of the program is controlled through the user definable keys (UD #), and occasionally by the FLAG buttons on the cross hair cursor. When these buttons are us a note is included in the margin of the example listing.

The refraction record is a rather straightforward record of a deep water sonobuoy with both sedimentary and sub-crustal refractors. The option to calculate a seafloor refractor (velocity = 1.55 km/s) is requested, and five points per refractor are picked.

The example used for the reflection digitizing is from the same station as the refraction example. However, the reflection digitizing must be done from two records. The direct times are picked from the 0 - 8 second record, while the reflection times are picked from a delayed 6 second record.

```
SONOBUOY  DIGITIZING  PROGRAMS

WHICH TYPE OF RECORDS DO YOU WISH TO DIGITIZE?

     1. WIDE ANGLE REFLECTIONS
     2. REFRACTIONS

(respond with correct number and type  RETURN )
2
```

```
PROGRAM  LINDIGIT     REFRACTION DIGITIZING

Enter heading for sonobuoy
SONOBUOY TEST D     LEE5-76-BS

Enter date of sonobuoy run
1 APRIL 1978

Enter horizontal sound velocity (in km/sec)
      (default = 1.485 km/sec)                              1.487

Enter average vertical sound velocity (in km/sec)
      (default = 1.5 km/sec)                                              <return>

Enter number of layers to be digitized:                     6

How many points per layer do you wish to pick?
      (default = 5)                                                       <return>
```

```
*****   Position sonobuoy on digitizing tablet   *****

Set the origin of the sonobuoy record.

Determine the scaling factor:

Mark the time tick at the bottom of the record.

How many seconds long is the record?   8


DO YOU WISH TO CHECK THE TIME REFERENCE MARKS?
Y
```

```
YOU CAN HERE MAKE ANY NUMBER OF DATA PICKS IN ORDER
TO CHECK OUT YOUR REFERENCE SYSTEM.  WHEN YOU ARE
SATISFIED, PRESS BUTTON NUMBER 1 ON THE CURSOR.
TO RESET THE ORIGIN, PRESS BUTTON NUMBER 2
 0.000
 0.796
 1.600
 2.402
 3.201
 0.803
 0.801
 5.601
 7.999
10.399
10.401
12.000
```

< flag number 1 on cursor >

DOES THE RECORD HAVE A DEEP WATER DELAY?   N

MARK THE DIRECT ARRIVAL WHERE IT INTERCEPTS THE FIRST
RECORDER TRACE (x=0).

MARK THE SEAFLOOR REFLECTOR AT THE FIRST TRACE (x=0).

DO YOU WISH TO INPUT A SEAFLOOR TIME?   N

DO YOU WISH TO ADD AN ASSUMED SEAFLOOR REFRACTOR?   Y

WHAT IS THE SEAFLOOR VELOCITY:
    (default = 1.55 km/s)   <return>

```
START DIGITIZING THE DATA POINTS

   Pick first the direct time, D(i), and then the ref-
   ractor time, R(i), for each data point.  10 picks
   must be made for each refractor.

 11.646 12.461 12.198 12.903 12.710 13.306 13.410 13.876 14.048 14.390
  8.659  9.798  8.993  9.974  9.290 10.128 10.206 10.594 10.764 10.888
 11.229 11.028 11.712 11.214 12.393 11.487 13.223 11.818 14.080 12.161
 10.539 10.485 10.904 10.577 11.325 10.692 11.870 10.829 12.518 10.999
 12.644 11.057 13.250 11.194 13.732 11.305 14.843 11.548 15.403 11.670
 12.611 11.611 13.378 11.746 14.084 11.867 14.917 12.013 15.487 12.114


DO YOU WISH TO SEE A LINFT FORMATTED DATA LIST?
Y
```

```
   LINFT FORMATTED OUTPUT LIST

SONO 22      LEE5:76:BS
22 DECEMBER 1977
  1.5000  1.4870  1.0000   0.105
   1    1    0    0
   5    5    5    5    5    5    5

1.5000
  2.105  3.282  4.105  5.200  6.105  7.119  8.105  9.038 10.105 10.956
 11.646 12.461 12.198 12.903 12.710 13.306 13.410 13.876 14.048 10.888
  8.659  9.798  8.993  9.974  9.290 10.128 10.206 10.594 10.764 10.888
 11.229 11.028 11.712 11.214 12.393 11.487 13.223 11.818 14.080 12.161
 10.539 10.485 10.904 10.577 11.325 10.682 11.870 10.829 12.518 10.999
 12.644 11.057 13.250 11.194 13.732 11.305 14.843 11.548 15.403 11.670
 12.611 11.611 13.378 11.746 14.084 11.867 14.917 12.013 15.487 12.114
   1


DO YOU WISH TO WRITE THE OUTPUT TO TAPE?
Y
```

```
INSERT THE OBJECT TAPE IN THE TAPE READER.

WHICH TAPE FILE DO YOU WISH TO WRITE TO?
11

THE HEADER OF THAT FILE READS:
 11     LAST                          3

DO YOU WISH TO MARK THIS FILE?
Y

ARE YOU SURE ?
Y
```

```
         SONOBUOY  DIGITIZING  PROGRAMS


WHICH TYPE OF RECORDS DO YOU WISH TO DIGITIZE?

     1. WIDE ANGLE REFLECTIONS
     2. REFRACTIONS


(respond with correct number and type  RETURN )
1
```

```
PROGRAM  SLODIGIT     REFLECTION  DIGITIZING

Do you wish to recover data from tape - (please answer [y] or [n] ):   N

Enter heading for sonobuoy
SONOBUOY TEST D     LEE5-76-BS

Enter date of sonobuoy run
1 APRIL 1978

Enter horizontal sound velocity (in km/sec)
     (default = 1.485 km/s)
1.487

Enter average vertical sound velocity (in km/sec):
     (default = 1.500 km/s)                                    <return>

Enter hydrophone depth lower (in feet):   120

Enter number of layers to be digitized:
        ( A maximum of 12 is allowed. )   8
```

```
YOU CAN HERE MAKE ANY NUMBER OF DATA PICKS IN ORDER
TO CHECK OUT YOUR REFERENCE SYSTEM.  WHEN YOU ARE
SATISFIED, PRESS FLAG NUMBER 1 ON THE CURSOR.

IF YOU WISH TO RESET ORIGIN, PRESS FLAG NUMBER 2


  0.000
  0.800
  1.600
  2.400
  3.202
  3.999
  4.798
  5.596
  6.396
  7.194
  7.997
  6.395
  7.195
  7.197
  7.199
  7.999
```

< flag number 1 on cursor >

Mark the point on the direct trace when the phones dropped.

```
ARE YOU PICKING DATA POINTS OFF TWO RECORDS:   YES

MARK THE SEAFLOOR ARRIVAL ON THE FIRST RECORD


START DIGITIZING DIRECT TIMES
( A MAXIMUM OF 36 ARE ALLOWED )
     To stop digitizing, press u.d. key #4 and
     digitize any point.

 0.108
 0.756
 1.094
 1.425
 1.626
 1.829
 2.031
 2.163
 2.299
 2.438
 2.570
 2.705
 2.843
 2.943
 3.043
 3.060  R
 3.142
 3.241
 3.341
 3.445
 3.547
 3.644
```

< "R" indicates a correction with UD 1 >

3.743
3.847
3.912
3.981
4.046
4.114
4.185
4.248
4.314

< stop digitizing:
UD 4 >

```
PLACE SECOND RECORD ON THE DIGITIZING TABLET.

Set the origin of the sonobuoy record.
Determine the scaling factor:

Mark the time tick at the bottom of the record.

How many seconds long is the record:   6

DO YOU WISH TO CHECK THE TIME REFERENCE MARKS:   Y
```

```
YOU CAN HERE MAKE ANY NUMBER OF DATA PICKS IN ORDER
TO CHECK OUT YOUR REFERENCE SYSTEM.  WHEN YOU ARE
SATISFIED, PRESS FLAG NUMBER 1 ON THE CURSOR.

IF YOU WISH TO RESET ORIGIN, PRESS FLAG NUMBER 2


  0.603
  1.202
  1.805
  0.601
  0.599
```

< flag number 2 on cursor >

```
*****   Position sonobuoy on digitizing tablet.   *****

Set the origin of the sonobuoy record.
Determine the scaling factor:

Mark the time tick at the bottom of the record.

How many seconds long is the record:   6


DO YOU WISH TO CHECK THE TIME REFERENCE MARKS:   Y
```

```
YOU CAN HERE MAKE ANY NUMBER OF DATA PICKS IN ORDER
TO CHECK OUT YOUR REFERENCE SYSTEM.  WHEN YOU ARE
SATISFIED, PRESS FLAG NUMBER 1 ON THE CURSOR.

IF YOU WISH TO RESET ORIGIN, PRESS FLAG NUMBER 2


  0.601
  3.602
  5.399
  1.199
  1.201
  1.802
  3.600

MARK THE SEAFLOOR ARRIVAL ON THE SECOND RECORD
```

< flag number 1 on cursor >

```
 START DIGITIZING REFLECTION TIMES
    When finished, hit u.d. key #4 and touch the cursor.

  0.108  5.108  5.342  5.600  5.902  6.270  6.949  7.407  7.940
  0.756  5.151  5.386  5.645  5.938  6.300  6.965  7.426  7.967
  1.094  5.205  5.438  5.691  5.985  6.339  6.978  7.439  7.989
  1.425  5.275  5.506  5.755  6.044  6.391  6.695R  7.016  7.478  8.012
  1.626  5.329  5.557  5.803  6.089  6.429  7.042  7.507  8.033
  1.829  5.388  5.615  5.859  6.138  6.474  7.088  7.540  8.066
  2.031  5.455  5.678  5.919  6.196  6.529  6.822R  7.132  7.575  8.093
  2.163  5.504  5.723  5.963  6.235  6.566  7.165  7.599  8.116
  2.299  5.551  5.772  6.008  6.275  6.601  7.194  7.629  8.137
  2.438  5.585  5.797  6.039  6.176R  6.312  6.635  7.216  7.663  8.152
  2.570  5.643  5.851  6.092  6.359  6.667  7.257  7.699  8.174
  2.705  5.701  5.910  6.144  6.412  6.712  7.300  7.734  8.204
```

< "R" indicates a correction with UD 1 >

2.843	5.763	5.970	6.202	6.465	6.763	7.339	7.770	8.229	
2.943	5.811	6.016	6.244	6.507	6.800	7.366	7.795	8.256	
3.043	5.859	6.061	6.289	6.547	6.837	7.396	7.815	8.274	
3.142	5.908	6.109	6.333	6.586	6.877	7.430	7.845	8.305	
3.241	5.963	6.161	6.385	6.630	6.919	7.469	7.875	8.322	
3.341	6.008	6.208	6.430	6.668	6.958	7.501	7.911	8.351	
3.445	6.066	6.262	6.483	6.722	7.007	7.540	7.940	8.375	
3.547	6.118	6.311	6.533	6.763	7.041	7.576	7.977	8.395	
3.644	6.173	6.365	6.582	6.813	7.086	7.609	8.017	8.421	
3.743	6.231	6.423	6.637	6.866	7.134	7.649	8.048	8.446	
3.847	6.286	6.473	6.688	6.912	7.180	7.685	7.997	8.470	
3.912	6.328	6.513	6.726	6.947	7.214	7.711	8.021R	8.108	8.488
3.981	6.364	6.556	6.760	6.980	7.246	7.747	8.040	8.504	
4.046	6.405	6.593	6.799	7.018	7.279	7.773	8.156	8.523	
4.114	6.440	6.626	6.831	7.048	7.308	7.803	8.186	8.537	
4.185	6.484	6.670	6.873	7.087	7.345	7.828	8.215	8.554	
4.248	6.524	6.710	6.910	7.123	7.379	7.862	8.238	8.567	
4.314	6.567	6.745	6.945	7.156	7.407	7.887	8.268	8.587	

SUGGESTED PROCEDURE:

1.	MAKE COPY OF INPUT PARAMETERS	< U.D. KEY #5 >
2.	MAKE COPY OF DIGITIZED PICKS	#15
3.	SAVE RAW DATA ON TAPE	#18
4.	ADD HYDROPHONE DELAYED RELEASE CORRECTION AND GO TO X2 - T2	#12
or		
4.	GO DIRECTLY TO X2 - T2	#11

< UD 5 >

INPUT PARAMETER LIST

SONOBUOY TEST D   LEE5-76-BS
1 APRIL 1978

Horizontal sound velocity in water = 1.487 km/sec

Average vertical sound velocity = 1.500 km/sec

Hydrophone depth = 120.0 feet

Water depth= 3912.1 meters

Conversion factor is 0.016684 sec/millimeter

Delta: time zero correction factor is -0.1084 sec

Hydrophones dropped at a direct time of 2.384 sec

8 layers were picked

30 traces were picked

DATA PICKS WERE FROM TWO SEPARATE RECORDS

Conversion factor for second record is 0.0125235 mm/sec

Reference point on first record is 5.096 sec.

Reference point on second record is 0.589 sec.

Reference point time difference is 4.508 sec.

< "MAKE COPY" >

< UD 15 >

TABLE OF DIGITIZED PICKS: D(J);R(I,J)

0.108	5.108	5.342	5.600	5.902	6.270	6.949	7.407	7.940
0.756	5.151	5.386	5.645	5.938	6.300	6.965	7.426	7.967
1.094	5.205	5.438	5.691	5.985	6.339	6.978	7.439	7.989
1.425	5.275	5.506	5.755	6.044	6.391	7.016	7.478	8.012
1.626	5.329	5.557	5.803	6.089	6.429	7.042	7.507	8.033
1.829	5.388	5.615	5.859	6.138	6.474	7.088	7.540	8.066
2.031	5.455	5.678	5.919	6.196	6.529	7.132	7.575	8.093
2.163	5.504	5.723	5.963	6.235	6.566	7.165	7.599	8.116
2.299	5.551	5.772	6.008	6.275	6.601	7.194	7.629	8.137
2.438	5.585	5.797	6.039	6.312	6.635	7.216	7.663	8.152
2.570	5.643	5.851	6.092	6.359	6.667	7.257	7.699	8.174
2.705	5.701	5.910	6.144	6.412	6.712	7.300	7.734	8.204
2.843	5.763	5.970	6.202	6.465	6.763	7.339	7.770	8.229
2.943	5.811	6.016	6.244	6.507	6.800	7.366	7.795	8.256
3.043	5.859	6.061	6.289	6.547	6.837	7.396	7.815	8.274
3.142	5.908	6.109	6.333	6.586	6.877	7.430	7.845	8.305
3.241	5.963	6.161	6.385	6.630	6.919	7.469	7.875	8.322
3.341	6.008	6.208	6.430	6.668	6.958	7.501	7.911	8.351
3.445	6.066	6.262	6.483	6.722	7.007	7.540	7.940	8.375
3.547	6.118	6.311	6.533	6.763	7.041	7.576	7.977	8.395
3.644	6.173	6.365	6.582	6.813	7.086	7.609	8.017	8.421
3.743	6.231	6.423	6.637	6.866	7.134	7.649	8.048	8.446
3.847	6.286	6.473	6.688	6.912	7.180	7.685	7.997	8.470
3.912	6.328	6.513	6.726	6.947	7.214	7.711	8.108	8.488
3.981	6.364	6.556	6.760	6.980	7.246	7.747	8.040	8.504
4.046	6.405	6.593	6.799	7.018	7.279	7.773	8.156	8.523
4.114	6.440	6.626	6.831	7.048	7.308	7.803	8.186	8.537
4.185	6.484	6.670	6.873	7.087	7.345	7.828	8.215	8.554
4.248	6.524	6.710	6.910	7.123	7.379	7.862	8.238	8.567
4.314	6.567	6.745	6.945	7.156	7.407	7.887	8.268	8.587

<"MAKE COPY">
< UD 18 >

```
CHECK TO INSURE THAT THE 4924 IS TURNED ON AND
THAT YOUR TAPE CARTRIDGE IS WRITE ENABLED

INSERT YOUR TAPE IN THE 4924

WHICH TAPE FILE DO YOU WISH TO WRITE TO?
5

IS THE FILE YOU ARE WRITING TO ALREADY MARKED?
N
```

<UD 12>

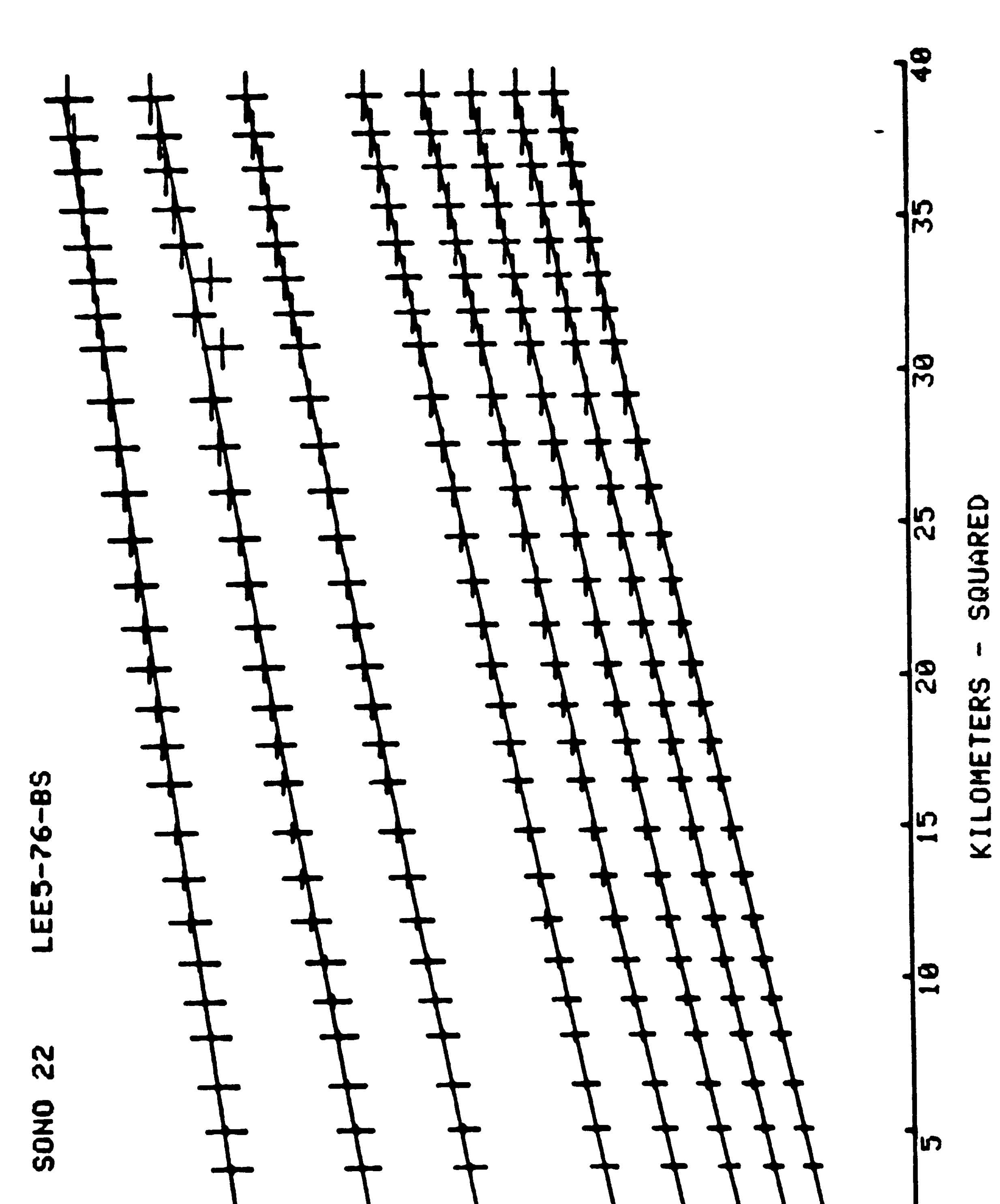
```
   DO YOU WISH TO SEE DATA FROM ALL LAYERS?
N

DO YOU WISH TO SEE DATA FROM ANY OF THE LAYERS?
N



(press return to continue)
```

LAYER	RMS VELOCITY (KM/SEC)	INTERCEPT TIME (SEC)	DEPTH (1) (KM)	INTERVAL VELOCITY (2) (KM/SEC)	FIT
1	1.522	4.983	3.791	1.559	0.99998
2	1.523	5.219	3.975	1.564	0.99998
3	1.525	5.478	4.178	1.900	0.99998
4	1.547	5.780	4.471	2.059	0.99993
5	1.582	6.138	4.854	2.193	0.99997
6	1.650	6.793	5.605	2.327	0.99979
7	1.703	7.265	6.184	3.486	0.99945
8	1.887	7.823	7.380		0.99892

(1) Depth to the top of the refracter: V(rms)*intercept

(2) Interval velocity calculated from Dix' equation.

DO YOU WISH TO SEE THE X2-T2 PLOT?
YES


SONO 22
LEE5-76-BS
KILOMETERS - SQUARED
SECONDS - SQUARED
0
5
10
15
20
25
30
35
40
20
25
30
35
40
45
50
55
60
65
70
75

```
DO YOU WANT TO SEE THE PLOT AT A DIFFERENT SCALE?
N
```

< UD 16 >

EDITOR

PRESENTLY, THE EDITOR PERFORMS THE FOLLOWING FUNCTIONS, WHICH ARE CALLED BY THE USER DEFINABLE KEYS:

6	REMOVES OR REINSERTS AN ENTIRE LAYER
7	REMOVES OR REINSERTS AN ENTIRE TRACE
8	EDITS INDIVIDUAL POINTS
9	PRINTS OUT A TABLE OF RESIDUAL VALUES
10	LISTS SLOWI FORMATTED OUTPUT ON THE SCREEN
20	WRITES SLOWI FORMATTED OUTPUT TO TAPE

TO PERFORM EDITING FUNCTIONS, PRESS THE DESIRED U.D. KEY AND FOLLOW THE DIRECTIONS.

<UD 9>

TABLE OF RESIDUAL VALUES (X10**-3 sec↑2)

T	LAYER 1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	-56	-81	-95	-97	13	348	166	-222						
2	-24	-17	2	-66	13	227	124	-59						
3	-4	7	-10	-26	10	-40	-105	-56						
4	-13	11	-16	-32	-12	-135	-113	-166						
5	3	21	-13	-22	-37	-237	-119	-187						
6	-4	30	2	-41	-47	-131	-131	-72						
7	4	27	-2	-18	5	-113	-171	-98						
8	29	30	11	-27	17	-74	-212	-57						
9	-12	33	-8	-68	-39	-133	-202	-78						
10	-18	-48	6	66	122	-27	155	121						
11	15	-33	36	67	-18	43	218	83						
12	9	-3	12	102	-29	106	229	143						
13	4	-4	16	93	-3	71	218	91						
14	17	6	1	114	-2	10	177	185						
15	16	-9	7	95	-15	-21	45	120						
16	17	0	-8	53	2	-4	58	260						
17	75	45	61	61	32	72	57	160						
18	-3	10	23	-29	2	27	132	242						
19	32	21	46	50	72	51	64	213						
20	-5	-31	29	-43	-67	26	118	115						
21	12	-3	18	0	-40	-28	233	126						
22	41	49	59	56	4	-3	183	102						
23	-14	-47	0	-27	-24	-81	-1208	26						
24	38	-3	34	-2	23	-84	180	23						
25	-18	44	-17	-39	11	33	-1306	-37						
26	11	39	20	14	34	19	159	-33						
27	-62	-46	-63	-68	-25	41	231	-133						
28	-51	-17	-42	-55	1	-38	262	-202						
29	-33	15	-32	-30	36	67	241	-304						
30	-6	-45	-78	-75	-42	8	310	-307						

< UD 8 >

```
YOU CAN EDIT POINTS ACCORDING TO TRACE NUMBER AND LAYER
TYPE THE LAYER NUMBER, TRACE NUMBER AND THE LETTER:
          D - DELETE A BAD POINT
          R - REPICK A POINT
          I - INSERT A PREVIOUSLY DELETED POINT
          Q - QUIT EDITING


LAYER,TRACE,ACTION
6,1,D


LAYER,TRACE,ACTION
6,2,D


LAYER,TRACE,ACTION
7,23,D


LAYER,TRACE,ACTION
7,23,D

THAT POINT HAS ALREADY BEEN DELETED!


LAYER,TRACE,ACTION
7,25,D


LAYER,TRACE,ACTION
1,1Q
```

< UD 11 >

LAYER 1

SLOPE = 0.432 INTERCEPT = 24.829 FIT = 0.99998
NUMBER OF POINTS USED = 30

DIRECT	RANGE	R	R2	COMP R2	DIFF
0.1080	0.0000	5.0856	24.7727	24.8292	-0.0565
0.7560	0.9273	5.1288	25.2049	25.2297	-0.0248
1.0940	2.1479	5.1831	25.7525	25.7569	-0.0044
1.4250	3.8329	5.2534	26.4711	26.4846	-0.0135
1.6260	5.0926	5.3076	27.0320	27.0286	0.0034
1.8290	6.5461	5.3669	27.6516	27.6564	-0.0048
2.0310	8.1733	5.4341	28.3635	28.3591	0.0043
2.1630	9.3342	5.4833	28.8898	28.8605	0.0293
2.2990	10.6108	5.5305	29.3993	29.4118	-0.0125
2.4380	12.0001	5.5850	29.9931	30.0119	-0.0187
2.5700	13.3985	5.6430	30.6318	30.6158	0.0160
2.7050	14.9084	5.7010	31.2772	31.2679	0.0093
2.8430	16.5352	5.7630	31.9745	31.9705	0.0040
2.9430	17.7666	5.8110	32.5196	32.5023	0.0173
3.0430	19.0423	5.8590	33.0694	33.0533	0.0161
3.1420	20.3488	5.9080	33.6354	33.6175	0.0179
3.2410	21.6986	5.9630	34.2763	34.2005	0.0759
3.3410	23.1061	6.0080	34.8053	34.8083	-0.0030
3.4450	24.6167	6.0660	35.4930	35.4608	0.0322
3.5470	26.1448	6.1180	36.1153	36.1207	-0.0054
3.6440	27.6406	6.1730	36.7794	36.7667	0.0126
3.7430	29.2102	6.2310	37.4862	37.4446	0.0416
3.8470	30.9058	6.2860	38.1627	38.1769	-0.0142
3.9120	31.9898	6.3280	38.6834	38.6451	0.0384
3.9810	33.1610	6.3640	39.1325	39.1509	-0.0183

4.0460	34.2835	6.4050	39.6472	39.6357	0.0115
4.1140	35.4778	6.4400	40.0892	40.1515	-0.0623
4.1850	36.7467	6.4840	40.6483	40.6995	-0.0512
4.2480	37.8912	6.5240	41.1599	41.1938	-0.0339
4.3140	39.1091	6.5670	41.7135	41.7198	-0.0062

LAYER 2

SLOPE = 0.431 INTERCEPT = 27.238 FIT = 0.99998
NUMBER OF POINTS USED = 30

DIRECT	RANGE	R	R2	COMP R2	DIFF
0.1080	0.0000	5.3196	27.1568	27.2379	-0.0811
0.7560	0.9273	5.3638	27.6195	27.6375	-0.0180
1.0940	2.1479	5.4161	28.1712	28.1635	0.0078
1.4250	3.8329	5.4843	28.9008	28.8895	0.0113
1.6260	5.0926	5.5356	29.4540	29.4323	0.0217
1.8290	6.5461	5.5938	30.0895	30.0587	0.0308
2.0310	8.1733	5.6570	30.7873	30.7599	0.0275
2.1630	9.3342	5.7022	31.2906	31.2601	0.0306
2.2990	10.6108	5.7514	31.8433	31.8102	0.0331
2.4380	12.0001	5.7970	32.3602	32.4088	-0.0487
2.5700	13.3985	5.8510	32.9775	33.0114	-0.0340
2.7050	14.9084	5.9100	33.6586	33.6621	-0.0035
2.8430	16.5352	5.9700	34.3584	34.3630	-0.0047
2.9430	17.7666	6.0160	34.8997	34.8937	0.0061

3.0430	19.0423	6.0610	35.4334	35.4434	-0.0099
3.1420	20.3488	6.1090	36.0072	36.0064	0.0008
3.2410	21.6986	6.1610	36.6340	36.5880	0.0460
3.3410	23.1061	6.2080	37.2051	37.1945	0.0106
3.4450	24.6167	6.2620	37.8668	37.8454	0.0214
3.5470	26.1448	6.3110	38.4722	38.5039	-0.0316
3.6440	27.6406	6.3650	39.1450	39.1485	-0.0034
3.7430	29.2102	6.4230	39.8742	39.8248	0.0494
3.8470	30.9058	6.4730	40.5081	40.5554	-0.0473
3.9120	31.9898	6.5130	41.0189	41.0226	-0.0037
3.9810	33.1610	6.5560	41.5715	41.5272	0.0443
4.0460	34.2835	6.5930	42.0500	42.0109	0.0391
4.1140	35.4778	6.6260	42.4791	42.5256	-0.0465
4.1850	36.7467	6.6700	43.0546	43.0723	-0.0177
4.2480	37.8912	6.7100	43.5811	43.5655	0.0156
4.3140	39.1091	6.7450	44.0445	44.0903	-0.0459

LAYER 3

SLOPE = 0.430 INTERCEPT = 30.008 FIT = 0.99998
NUMBER OF POINTS USED = 30

DIRECT	RANGE	R	R2	COMP R2	DIFF
0.1080	0.0000	5.5776	29.9124	30.0081	-0.0957
0.7560	0.9273	5.6228	30.4087	30.4067	0.0021
1.0940	2.1479	5.6690	30.9204	30.9313	-0.0109

1.4250	3.8329	5.7333	31.6393	31.6555	-0.0162
1.6260	5.0926	5.7815	32.1837	32.1969	-0.0132
1.8290	6.5461	5.8377	32.8247	32.8217	0.0030
2.0310	8.1733	5.8979	33.5184	33.5211	-0.0027
2.1630	9.3342	5.9421	34.0317	34.0201	0.0116
2.2990	10.6108	5.9872	34.5607	34.5688	-0.0081
2.4380	12.0001	6.0390	35.1720	35.1659	0.0061
2.5700	13.3985	6.0920	35.8035	35.7670	0.0365
2.7050	14.9084	6.1440	36.4285	36.4160	0.0125
2.8430	16.5352	6.2020	37.1320	37.1152	0.0168
2.9430	17.7666	6.2440	37.6456	37.6445	0.0011
3.0430	19.0423	6.2890	38.1998	38.1928	0.0070
3.1420	20.3488	6.3330	38.7456	38.7543	-0.0087
3.2410	21.6986	6.3850	39.3957	39.3345	0.0612
3.3410	23.1061	6.4300	39.9626	39.9395	0.0232
3.4450	24.6167	6.4830	40.6355	40.5888	0.0468
3.5470	26.1448	6.5330	41.2755	41.2456	0.0299
3.6440	27.6406	6.5820	41.9075	41.8885	0.0190
3.7430	29.2102	6.6370	42.6226	42.5631	0.0595
3.8470	30.9058	6.6880	43.2911	43.2919	-0.0008
3.9120	31.9898	6.7260	43.7926	43.7578	0.0348
3.9810	33.1610	6.7600	44.2438	44.2612	-0.0174
4.0460	34.2835	6.7990	44.7641	44.7437	0.0204
4.1140	35.4778	6.8310	45.1934	45.2571	-0.0637
4.1850	36.7467	6.8730	45.7598	45.8024	-0.0426
4.2480	37.8912	6.9100	46.2618	46.2944	-0.0326
4.3140	39.1091	6.9450	46.7391	46.8178	-0.0787

LAYER 4

SLOPE = 0.418 INTERCEPT = 33.405 FIT = 0.99993
NUMBER OF POINTS USED = 30

DIRECT	RANGE	R	R2	COMP R2	DIFF
0.1080	0.0000	5.8796	33.3070	33.4048	-0.0978
0.7560	0.9273	5.9158	33.7257	33.7922	-0.0665
1.0940	2.1479	5.9630	34.2760	34.3021	-0.0262
1.4250	3.8329	6.0222	34.9731	35.0061	-0.0330
1.6260	5.0926	6.0674	35.5094	35.5323	-0.0230
1.8290	6.5461	6.1166	36.0980	36.1396	-0.0416
2.0310	8.1733	6.1748	36.8008	36.8194	-0.0186
2.1630	9.3342	6.2139	37.2772	37.3044	-0.0272
2.2990	10.6108	6.2541	37.7691	37.8377	-0.0686
2.4380	12.0001	6.3120	38.4847	38.4182	0.0665
2.5700	13.3985	6.3590	39.0700	39.0024	0.0676
2.7050	14.9084	6.4120	39.7354	39.6332	0.1022
2.8430	16.5352	6.4650	40.4064	40.3128	0.0935
2.9430	17.7666	6.5070	40.9421	40.8273	0.1148
3.0430	19.0423	6.5470	41.4556	41.3602	0.0953
3.1420	20.3488	6.5860	41.9593	41.9061	0.0532
3.2410	21.6986	6.6300	42.5313	42.4700	0.0613
3.3410	23.1061	6.6680	43.0284	43.0580	-0.0296
3.4450	24.6167	6.7220	43.7397	43.6891	0.0506
3.5470	26.1448	6.7630	44.2837	44.3275	-0.0438
3.6440	27.6406	6.8130	44.9517	44.9524	-0.0008
3.7430	29.2102	6.8660	45.6652	45.6082	0.0570
3.8470	30.9058	6.9120	46.2890	46.3166	-0.0276
3.9120	31.9898	6.9470	46.7664	46.7694	-0.0030
3.9810	33.1610	6.9800	47.2189	47.2587	-0.0398
4.0460	34.2835	7.0180	47.7426	47.7277	0.0149

4.1140	35.4778	7.0480	48.1580	48.2267	-0.0686
4.1850	36.7467	7.0870	48.7009	48.7568	-0.0559
4.2480	37.8912	7.1230	49.2046	49.2349	-0.0303
4.3140	39.1091	7.1560	49.6687	49.7437	-0.0751

LAYER 5

SLOPE = 0.400 INTERCEPT = 37.677 FIT = 0.99997
NUMBER OF POINTS USED = 30

DIRECT	RANGE	R	R2	COMP R2	DIFF
0.1080	0.0000	6.2476	37.6900	37.6769	0.0131
0.7560	0.9273	6.2778	38.0610	38.0477	0.0133
1.0940	2.1479	6.3169	38.5457	38.5356	0.0100
1.4250	3.8329	6.3691	39.1966	39.2092	-0.0127
1.6260	5.0926	6.4073	39.6757	39.7128	-0.0371
1.8290	6.5461	6.4524	40.2466	40.2939	-0.0472
2.0310	8.1733	6.5076	40.9498	40.9444	0.0053
2.1630	9.3342	6.5447	41.4263	41.4085	0.0178
2.2990	10.6108	6.5799	41.8797	41.9189	-0.0391
2.4380	12.0001	6.6350	42.5965	42.4743	0.1223
2.5700	13.3985	6.6670	43.0152	43.0333	-0.0181
2.7050	14.9084	6.7120	43.6075	43.6369	-0.0294
2.8430	16.5352	6.7630	44.2837	44.2873	-0.0036
2.9430	17.7666	6.8000	44.7775	44.7796	-0.0021
3.0430	19.0423	6.8370	45.2741	45.2895	-0.0155

3.1420	20.3488	6.8770	45.8139	45.8118	0.0021
3.2410	21.6986	6.9190	46.3843	46.3515	0.0328
3.3410	23.1061	6.9580	46.9170	46.9141	0.0029
3.4450	24.6167	7.0070	47.5907	47.5180	0.0726
3.5470	26.1448	7.0410	48.0609	48.1289	-0.0680
3.6440	27.6406	7.0860	48.6869	48.7269	-0.0400
3.7430	29.2102	7.1340	49.3591	49.3544	0.0047
3.8470	30.9058	7.1800	50.0075	50.0322	-0.0247
3.9120	31.9898	7.2140	50.4896	50.4656	0.0240
3.9810	33.1610	7.2460	50.9453	50.9338	0.0115
4.0460	34.2835	7.2790	51.4175	51.3825	0.0350
4.1140	35.4778	7.3080	51.8342	51.8600	-0.0258
4.1850	36.7467	7.3450	52.3684	52.3673	0.0011
4.2480	37.8912	7.3790	52.8616	52.8248	0.0368
4.3140	39.1091	7.4070	53.2696	53.3117	-0.0421

LAYER 6

SLOPE = 0.371 INTERCEPT = 46.047 FIT = 0.99986
NUMBER OF POINTS USED = 28

DIRECT	RANGE	R	R2	COMP R2	DIFF
1.0940	2.1479	6.9558	46.8873	46.8426	0.0447
1.4250	3.8329	6.9940	47.4112	47.4670	-0.0558

1.6260	5.0926	7.0201	47.7714	47.9338	-0.1624
1.8290	6.5461	7.0662	48.4111	48.4724	-0.0613
2.0310	8.1733	7.1103	49.0272	49.0754	-0.0483
2.1630	9.3342	7.1434	49.4917	49.5056	-0.0139
2.2990	10.6108	7.1725	49.9019	49.9786	-0.0767
2.4380	12.0001	7.2160	50.5180	50.4935	0.0245
2.5700	13.3985	7.2570	51.1025	51.0117	0.0908
2.7050	14.9084	7.3000	51.7191	51.5712	0.1479
2.8430	16.5352	7.3390	52.2816	52.1740	0.1076
2.9430	17.7666	7.3660	52.6728	52.6303	0.0424
3.0430	19.0423	7.3960	53.1091	53.1030	0.0061
3.1420	20.3488	7.4300	53.6058	53.5872	0.0187
3.2410	21.6986	7.4690	54.1784	54.0874	0.0911
3.3410	23.1061	7.5010	54.6505	54.6089	0.0416
3.4450	24.6167	7.5400	55.2287	55.1687	0.0600
3.5470	26.1448	7.5760	55.7650	55.7349	0.0301
3.6440	27.6406	7.6090	56.2590	56.2892	-0.0302
3.7430	29.2102	7.6490	56.8606	56.8709	-0.0102
3.8470	30.9058	7.6850	57.4049	57.4992	-0.0943
3.9120	31.9898	7.7110	57.7995	57.9009	-0.1013
3.9810	33.1610	7.7470	58.3482	58.3349	0.0133
4.0460	34.2835	7.7730	58.7461	58.7508	-0.0047
4.1140	35.4778	7.8030	59.2069	59.1934	0.0135
4.1850	36.7467	7.8280	59.5922	59.6636	-0.0714
4.2480	37.8912	7.8620	60.1183	60.0877	0.0306
4.3140	39.1091	7.8870	60.5066	60.5390	-0.0324

LAYER 7

SLOPE = 0.353 INTERCEPT = 52.709 FIT = 0.99961
NUMBER OF POINTS USED = 28

DIRECT	RANGE	R	R2	COMP R2	DIFF
0.1080	0.0000	7.3846	52.9433	52.7087	0.2347<<>>
0.7560	0.9273	7.4037	53.2214	53.0363	0.1851<<>>
1.0940	2.1479	7.4168	53.4126	53.4677	-0.0551
1.4250	3.8329	7.4559	53.9859	54.0630	-0.0771
1.6260	5.0926	7.4850	54.4142	54.5081	-0.0940
1.8290	6.5461	7.5181	54.9036	55.0217	-0.1182
2.0310	8.1733	7.5532	55.4251	55.5967	-0.1717
2.1630	9.3342	7.5773	55.7841	56.0069	-0.2228<<>>
2.2990	10.6108	7.6074	56.2344	56.4580	-0.2237<<>>
2.4380	12.0001	7.6630	57.0720	56.9489	0.1230
2.5700	13.3985	7.6990	57.6172	57.4431	0.1741
2.7050	14.9084	7.7340	58.1498	57.9766	0.1732
2.8430	16.5352	7.7700	58.7001	58.5514	0.1487
2.9430	17.7666	7.7950	59.0838	58.9866	0.0973
3.0430	19.0423	7.8150	59.3917	59.4373	-0.0456
3.1420	20.3488	7.8450	59.8550	59.8990	-0.0440
3.2410	21.6986	7.8750	60.3201	60.3759	-0.0559
3.3410	23.1061	7.9110	60.8806	60.8733	0.0073
3.4450	24.6167	7.9400	61.3340	61.4071	-0.0731
3.5470	26.1448	7.9770	61.9149	61.9470	-0.0321
3.6440	27.6406	8.0170	62.5460	62.4756	0.0704
3.7430	29.2102	8.0480	63.0372	63.0302	0.0070
3.9120	31.9898	8.1080	63.9936	64.0124	-0.0188
4.0460	34.2835	8.1560	64.7639	64.8228	-0.0590
4.1140	35.4778	8.1860	65.2476	65.2449	0.0028

4.1850	36.7467	8.2150	65.7170	65.6932	0.0237
4.2480	37.8912	8.2380	66.0904	66.0977	-0.0073
4.3140	39.1091	8.2680	66.5791	66.5280	0.0511

LAYER 8

SLOPE = 0.281 INTERCEPT = 61.206 FIT = 0.99892
NUMBER OF POINTS USED = 30

DIRECT	RANGE	R	R2	COMP R2	DIFF
0.1080	0.0000	7.9176	60.9839	61.2064	-0.2225<<>>
0.7560	0.9273	7.9447	61.4073	61.4670	-0.0597
1.0940	2.1479	7.9668	61.7537	61.8099	-0.0562
1.4250	3.8329	7.9898	62.1172	62.2833	-0.1661
1.6260	5.0926	8.0109	62.4497	62.6372	-0.1875<<>>
1.8290	6.5461	8.0440	62.9736	63.0456	-0.0720
2.0310	8.1733	8.0711	63.4042	63.5028	-0.0986
2.1630	9.3342	8.0941	63.7719	63.8290	-0.0570
2.2990	10.6108	8.1152	64.1088	64.1876	-0.0788
2.4380	12.0001	8.1520	64.6995	64.5780	0.1215
2.5700	13.3985	8.1740	65.0539	64.9709	0.0830
2.7050	14.9084	8.2040	65.5387	65.3951	0.1436
2.8430	16.5352	8.2290	65.9441	65.8522	0.0920
2.9430	17.7666	8.2560	66.3834	66.1982	0.1852<<>>
3.0430	19.0423	8.2740	66.6770	66.5566	0.1204
3.1420	20.3488	8.3050	67.1843	66.9237	0.2606<<>>

3.2410	21.6986	8.3220	67.4632	67.3029	0.1603
3.3410	23.1061	8.3510	67.9405	67.6983	0.2421<<>>
3.4450	24.6167	8.3750	68.3367	68.1228	0.2139<<>>
3.5470	26.1448	8.3950	68.6677	68.5521	0.1156
3.6440	27.6406	8.4210	69.0993	68.9724	0.1269
3.7430	29.2102	8.4460	69.5156	69.4134	0.1022
3.8470	30.9058	8.4700	69.9164	69.8898	0.0266
3.9120	31.9898	8.4880	70.2177	70.1943	0.0234
3.9810	33.1610	8.5040	70.4861	70.5234	-0.0373
4.0460	34.2835	8.5230	70.8055	70.8388	-0.0333
4.1140	35.4778	8.5370	71.0413	71.1743	-0.1330
4.1850	36.7467	8.5540	71.3282	71.5308	-0.2027<<>>
4.2480	37.8912	8.5670	71.5479	71.8524	-0.3045<<>>
4.3140	39.1091	8.5870	71.8867	72.1946	-0.3079<<>>

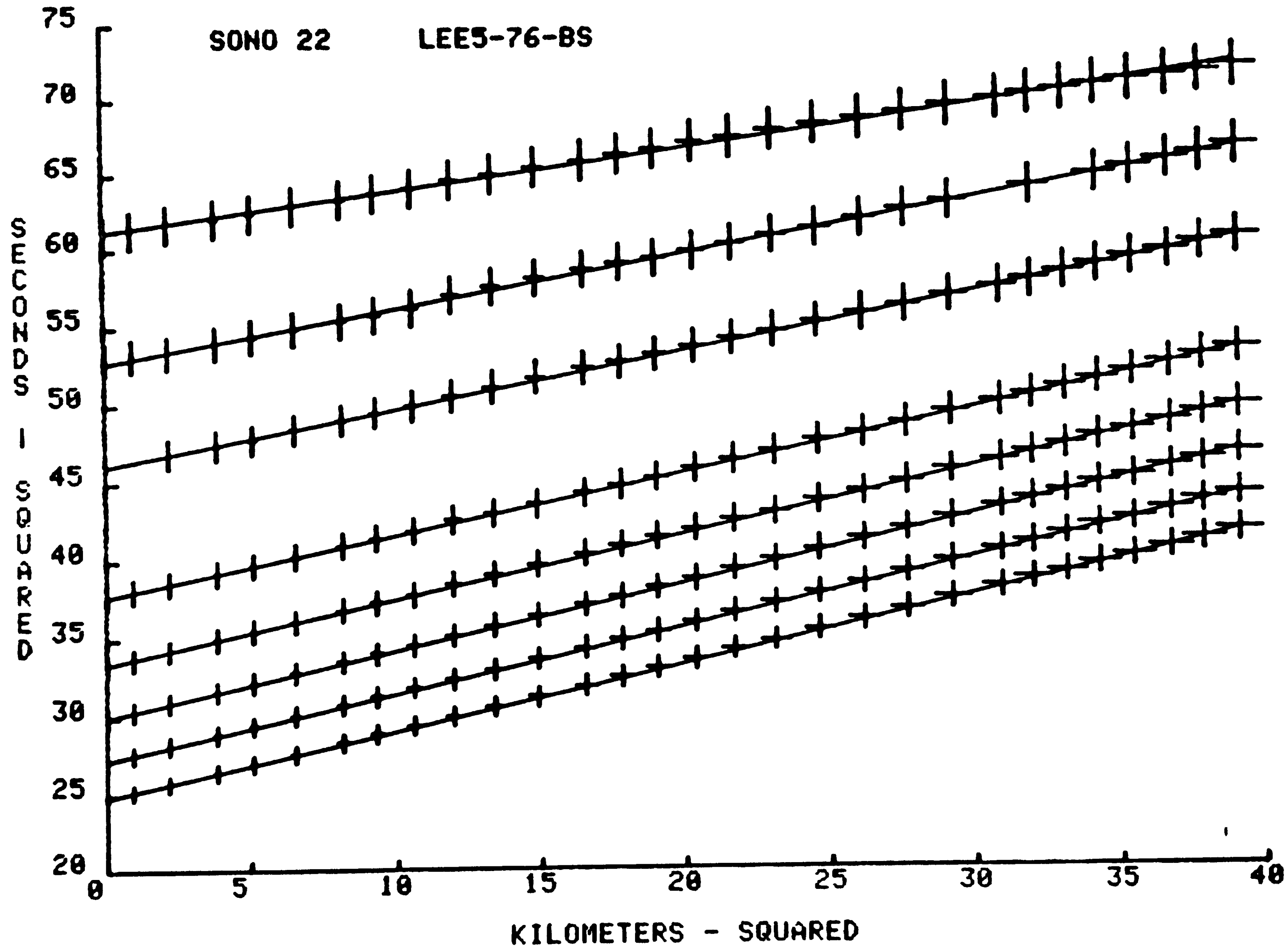
(press return to continue)

LAYER	RMS VELOCITY (KM/SEC)	INTERCEPT TIME (SEC)	DEPTH (1) (KM)	INTERVAL VELOCITY (2) (KM/SEC)	FIT
1	1.522	4.983	3.791	1.559	0.99998
2	1.523	5.219	3.975	1.564	0.99998
3	1.525	5.478	4.178	1.900	0.99998
4	1.547	5.780	4.471	2.059	0.99993
5	1.582	6.138	4.854	2.137	0.99997
6	1.643	6.786	5.574	2.170	0.99986
7	1.682	7.260	6.107	3.599	0.99961
8	1.887	7.823	7.380		0.99892

(1) Depth to the top of the refracter: V(rms)*intercept

(2) Interval velocity calculated from Dix' equation.

DO YOU WISH TO SEE THE X2-T2 PLOT? Y



<"MAKE COPY">
<"HOME PAGE">

```
DO YOU WANT TO SEE THE PLOT AT A DIFFERENT SCALE?
N
```

< UD 16 >

< UD 10 >

1 APRIL 1978
SONOBUOY TEST D   LEE5-76-BS

3912.	1.5000	1.4870	1.0000	-0.108	120.

1	1	0	1	1			
30	30	30	30	30	28	28	30

0.108	5.086	0.756	5.129	1.094	5.183	1.425	5.253	1.626
5.308	1.829	5.367	2.031	5.434	2.163	5.483	2.299	5.531
2.438	5.585	2.570	5.643	2.705	5.701	2.843	5.763	2.943
5.811	3.043	5.859	3.142	5.908	3.241	5.963	3.341	6.008
3.445	6.066	3.547	6.118	3.644	6.173	3.743	6.231	3.847
6.286	3.912	6.328	3.981	6.364	4.046	6.405	4.114	6.440
4.185	6.484	4.248	6.524	4.314	6.567			
0.108	5.320	0.756	5.364	1.094	5.416	1.425	5.484	1.626
5.536	1.829	5.594	2.031	5.657	2.163	5.702	2.299	5.751
2.438	5.797	2.570	5.851	2.705	5.910	2.843	5.970	2.943
6.016	3.043	6.061	3.142	6.109	3.241	6.161	3.341	6.208
3.445	6.262	3.547	6.311	3.644	6.365	3.743	6.423	3.847
6.473	3.912	6.513	3.981	6.556	4.046	6.593	4.114	6.626
4.185	6.670	4.248	6.710	4.314	6.745			
0.108	5.578	0.756	5.623	1.094	5.669	1.425	5.733	1.626
5.781	1.829	5.838	2.031	5.898	2.163	5.942	2.299	5.987
2.438	6.039	2.570	6.092	2.705	6.144	2.843	6.202	2.943
6.244	3.043	6.289	3.142	6.333	3.241	6.385	3.341	6.430
3.445	6.483	3.547	6.533	3.644	6.582	3.743	6.637	3.847
6.688	3.912	6.726	3.981	6.760	4.046	6.799	4.114	6.831
4.185	6.873	4.248	6.910	4.314	6.945			
0.108	5.880	0.756	5.916	1.094	5.963	1.425	6.022	1.626
6.067	1.829	6.117	2.031	6.175	2.163	6.214	2.299	6.254
2.438	6.312	2.570	6.359	2.705	6.412	2.843	6.465	2.943

6.507	3.043	6.547	3.142	6.586	3.241	6.630	3.341	6.668
3.445	6.722	3.547	6.763	3.644	6.813	3.743	6.866	3.847
6.912	3.912	6.947	3.981	6.980	4.046	7.018	4.114	7.048
4.185	7.087	4.248	7.123	4.314	7.156			

0.108	6.248	0.756	6.278	1.094	6.317	1.425	6.369	1.626
6.407	1.829	6.452	2.031	6.508	2.163	6.545	2.299	6.580
2.438	6.635	2.570	6.667	2.705	6.712	2.843	6.763	2.943
6.800	3.043	6.837	3.142	6.877	3.241	6.919	3.341	6.958
3.445	7.007	3.547	7.041	3.644	7.086	3.743	7.134	3.847
7.180	3.912	7.214	3.981	7.246	4.046	7.279	4.114	7.308
4.185	7.345	4.248	7.379	4.314	7.407			

1.094	6.956	1.425	6.994	1.626	7.020	1.829	7.066	2.031
7.110	2.163	7.143	2.299	7.173	2.438	7.216	2.570	7.257
2.705	7.300	2.843	7.339	2.943	7.366	3.043	7.396	3.142
7.430	3.241	7.469	3.341	7.501	3.445	7.540	3.547	7.576
3.644	7.609	3.743	7.649	3.847	7.685	3.912	7.711	3.981
7.747	4.046	7.773	4.114	7.803	4.185	7.828	4.248	7.862
4.314	7.887							

0.108	7.385	0.756	7.404	1.094	7.417	1.425	7.456	1.626
7.485	1.829	7.518	2.031	7.553	2.163	7.577	2.299	7.607
2.438	7.663	2.570	7.699	2.705	7.734	2.843	7.770	2.943
7.795	3.043	7.815	3.142	7.845	3.241	7.875	3.341	7.911
3.445	7.940	3.547	7.977	3.644	8.017	3.743	8.048	3.912
8.108	4.046	8.156	4.114	8.186	4.185	8.215	4.248	8.238
4.314	8.268							

0.108	7.918	0.756	7.945	1.094	7.967	1.425	7.990	1.626
8.011	1.829	8.044	2.031	8.071	2.163	8.094	2.299	8.115
2.438	8.152	2.570	8.174	2.705	8.204	2.843	8.229	2.943
8.256	3.043	8.274	3.142	8.305	3.241	8.322	3.341	8.351
3.445	8.375	3.547	8.395	3.644	8.421	3.743	8.446	3.847
8.470	3.912	8.488	3.981	8.504	4.046	8.523	4.114	8.537

```
   4.185   8.554   4.248   8.567   4.314   8.587

DO YOU WISH TO WRITE THIS DATA SET ONTO A TAPE FILE?
Y

WHICH FILE DO YOU WISH TO WRITE TO?
   (IF YOU ARE IN DOUBT AS TO WHICH FILE IS FREE,
    TYPE 999 TO DO A TLIST, WHICH WILL INDICATE
    THE FIRST AVAILABLE FILE)
999
```

```
 1       ASCII   PROGRAM   AD      768
 2       BINARY  PROGRAM _DIGIT   10240
 3       BINARY  P     "   HDRC    4096
 4       BINARY  P     "   X2T2   10240
 5       BINARY  PROGRAM  EDIT     9216
 6       BINARY  PROGRAM  DUMP     3840
 7       BINARY  PROGRAM           1024
 8       BINARY  PROGRAM _DIGIT    7424
 9       BINARY  DATA              4608
 10      BINARY  DATA              4608
 11      ASCII   PROGRAM           1280
 12      LAST                      768


WHICH FILE DO YOU WISH TO WRITE TO?
12


IS THE FILE YOU ARE WRITING TO ALREADY MARKED?
n
```

Appendix H

Examples of reduction programs

This appendix includes examples of the reduction programs SLOWI and LINFT. Shown are the input and output segments only. Refer to section IV.4 to determine the process for executing the programs themselves. The input segments are the same as those listed in the introductory comments to the program listings. (See Appendix J.) Furthermore, the input segment for the SLOWI example is derived from the output of the program SONOMODEL, (see Appendix I.1), and is based on the test model of Figure 5. By comparing the SLOWI result with the input model to SONOMODEL, one can verify that both programs are operating correctly.

The LINFT example is shown twice with identical input data sets, save only for the output parameters. The data listings are suppressed in the second example (ISSW1 = 1).

The examples used in these programs are included in the introductory comments prefacing the program listings (see Appendix K), so that if these programs are installed elsewhere, test programs are available for comparison.

Note: No attempt has been made to describe the output tables produced by these programs. However, a considerable amount of information is available, which can be invaluable in interpreting the results. This is particularly true of the SLOWI output lists. To interpret this information fully, refer to Knott & Hoskins ,1975.

Example of SLOWI input data set

This example input data set is described in the comments prefacing the SLOWI program listing (App. K, p.201). The output result from this data set follows.

The data for this test program was artificially produced through the program SONOMODEL (see App. I.1, p.165), so that the results could be compared with a known input.

```
 1 APRIL 1978
SONOBUOY TEST A
 3755.   1.5000   1.4P70   1.0000   -0.000       60.
 1   1    0   1    1
15  15   15  15   15
 0.000    0.000    0.000    0.000    0.000
 0.000    5.007    0.265    5.014    0.531    5.034    0.800    5.069    1.074    5.119
 1.353    5.183    1.641    5.264    1.939    5.363    2.249    5.480    2.573    5.619
 2.916    5.781    3.280    5.970    3.669    6.189    4.090    6.442    4.547    6.737
 0.000    6.028    0.192    6.031    0.384    6.039    0.576    6.052    0.770    6.070
 0.966    6.094    1.164    6.124    1.364    6.159    1.567    6.201    1.774    6.248
 1.985    6.302    2.200    6.363    2.422    6.431    2.649    6.508    2.884    6.592
 0.000    7.083    0.217    7.086    0.435    7.093    0.654    7.105    0.874    7.122
 1.095    7.144    1.319    7.172    1.545    7.204    1.775    7.242    2.009    7.286
 2.247    7.336    2.490    7.392    2.739    7.455    2.995    7.525    3.260    7.603
 0.000    8.046    0.216    8.047    0.433    8.052    0.650    8.059    0.869    8.070
 1.089    8.083    1.311    8.099    1.536    8.119    1.763    8.142    1.994    8.169
 2.229    8.199    2.469    8.233    2.714    8.271    2.966    8.314    3.225    8.361
 0.000    9.895    0.400    9.897    0.800    9.901    1.203    9.909    1.608    9.919
 2.018    9.933    2.434    9.950    2.855    9.971    3.285    9.995    3.724   10.022
 4.175   10.054    4.639   10.091    5.118   10.132    5.616   10.178    6.135   10.230
 0
```

SLOWI output listings from test data set.

Refer to Knott & Hoskins, 1975, pp. 51-59, for a complete explanation of these result listings.

```
PROGRAM SLOWI          DECEMBER 1976

  1 APRIL 1978                                                                                  SONOBUOY TEST A

 SONOBUOY TEST A

E/S WATER DEPTH= 3755.   MEAN VERTICAL SOUND VELOCITY= 1.5000
HORIZ SOUND VELOCITY= 1.4870   SEC/INCH= 1.0000
TIME ZERO CORR=  0.000   HYDRO DEPTH=  60.
ISSWO= 1   ISSW1= 1   ISSW2= 0   ISSW12= 1   ISSW13= 1
NUMBER OF DATA POINTS FOR EACH LAYER
15  15  15  15  15
INCREMENTAL SLOPES OF LAYERS
 0.000   0.000   0.000   0.000   0.000

VERIFICATION OF DATA PICKS IN LAYER   1
 0.000   5.007   0.265   5.014   0.531   5.034   0.800   5.069   1.074   5.119
 1.353   5.183   1.641   5.264   1.939   5.363   2.249   5.480   2.573   5.619
 2.916   5.781   3.280   5.970   3.669   6.189   4.090   6.442   4.547   6.737

VERIFICATION OF DATA PICKS IN LAYER   2
 0.000   6.028   0.192   6.031   0.384   6.039   0.576   6.052   0.770   6.070
 0.966   6.094   1.164   6.124   1.364   6.159   1.567   6.201   1.774   6.248
 1.985   6.302   2.200   6.363   2.422   6.431   2.649   6.508   2.884   6.592

VERIFICATION OF DATA PICKS IN LAYER   3
 0.000   7.083   0.217   7.086   0.435   7.093   0.654   7.105   0.874   7.122
 1.095   7.144   1.319   7.172   1.545   7.204   1.775   7.242   2.009   7.286
 2.247   7.336   2.490   7.392   2.739   7.455   2.995   7.525   3.260   7.603

VERIFICATION OF DATA PICKS IN LAYER   4
 0.000   8.046   0.216   8.047   0.433   8.052   0.650   8.059   0.869   8.070
 1.089   8.083   1.311   8.099   1.536   8.119   1.763   8.142   1.994   8.169
 2.729   8.199   2.469   8.233   2.714   8.271   2.966   8.314   3.225   8.361

VERIFICATION OF DATA PICKS IN LAYER   5
 0.000   9.895   0.400   9.897   0.800   9.901   1.203   9.909   1.608   9.919
 2.018   9.933   2.434   9.950   2.855   9.971   3.285   9.995   3.724  10.022
 4.175  10.054   4.639  10.091   5.118  10.132   5.616  10.178   6.135  10.230

 DIR (IN)   REF (IN)   DIR (SEC)   REF (SEC)
   0.000      5.007      0.000      5.007
   0.265      5.014      0.265      5.014
   0.531      5.034      0.531      5.034
   0.800      5.069      0.800      5.069
   1.074      5.119      1.074      5.119
   1.353      5.183      1.353      5.183
   1.641      5.264      1.641      5.264
   1.939      5.363      1.939      5.363
   2.249      5.480      2.249      5.480
   2.573      5.619      2.573      5.619
   2.916      5.781      2.916      5.781
   3.280      5.970      3.280      5.970
   3.669      6.189      3.669      6.189
   4.090      6.442      4.090      6.442
   4.547      6.737      4.547      6.737

 DSQ(KM)    R2(SEC)   R2 COMPUTED  DIFFERENCE
   0.000     25.070     25.067       0.003
```

STANDARD DEVIATION= 0.004 NEGATIVE D VALUES DISCARDED 0 / 15
COEFFICIENTS OF FITTED POLYNOMIAL: INTERCEPT=25.0666 X2= 0.9827
X3= 0.1413 X4=-0.0049 X5=-0.0002

VH CORRECTED= 1.4870 VH SUPPLIED= 1.4870
LAYER 1 VELOCITY= 1.500 REFLECTION TIME= 5.007 THICKNESS= 3.755
DEPTH= 3.755 SV= 0.000 SLOPE 0.00

DIR (IN)	REF (IN)	DIR (SEC)	REF (SEC)
0.000	6.028	0.000	6.028
0.192	6.031	0.192	6.031
0.384	6.039	0.384	6.039
0.576	6.052	0.576	6.052
0.770	6.070	0.770	6.070
0.966	6.094	0.966	6.094
1.164	6.124	1.164	6.124
1.364	6.159	1.364	6.159
1.567	6.201	1.567	6.201
1.774	6.248	1.774	6.248
1.985	6.302	1.985	6.302
2.200	6.363	2.200	6.363
2.422	6.431	2.422	6.431
2.649	6.508	2.649	6.508
2.884	6.592	2.884	6.592

DSQ(KM)	R2(SEC)	R2 COMPUTED	DIFFERENCE
0.006	0.002	0.002	0.000
0.024	0.007	0.006	0.001
0.055	0.014	0.013	0.000
0.100	0.023	0.024	-0.001
0.158	0.037	0.038	-0.001
0.230	0.056	0.055	0.000
0.318	0.076	0.076	-0.001
0.421	0.102	0.101	0.001
0.543	0.130	0.131	-0.000
0.686	0.164	0.165	-0.000
0.851	0.205	0.205	0.000
1.046	0.250	0.251	-0.001
1.275	0.308	0.306	0.001

STANDARD DEVIATION= 0.001 NEGATIVE D VALUES DISCARDED 1 / 14
COEFFICIENTS OF FITTED POLYNOMIAL: INTERCEPT= 0.0001 X2= 0.2402
X3= 0.0959 X4= 0.0001 X5=-0.0005
LAYER 2 VELOCITY= 2.040 REFLECTION TIME= 6.028 THICKNESS= 1.041
DEPTH= 4.797 SV= 0.009 SLOPE 0.00
4.07 MINIMUM CRITICAL RANGE, 2.72 WATER TRAVEL TIME FOR LAYER 2

DIR (IN)	REF (IN)	DIR (SEC)	REF (SEC)
0.000	7.083	0.000	7.083
0.217	7.086	0.217	7.086
0.435	7.093	0.435	7.093
0.654	7.105	0.654	7.105
0.874	7.122	0.874	7.122
1.095	7.144	1.095	7.144
1.319	7.172	1.319	7.172
1.545	7.204	1.545	7.204
1.775	7.242	1.775	7.242
2.009	7.286	2.009	7.286
2.247	7.336	2.247	7.336
2.490	7.392	2.490	7.392

2.739	7.455	2.739	7.455
2.995	7.525	2.995	7.525
3.260	7.603	3.260	7.603

DSQ(KM)	R2(SEC)	R2 COMPUTED	DIFFERENCE
0.008	0.002	0.002	0.001
0.033	0.006	0.006	0.000
0.076	0.013	0.013	-0.000
0.137	0.023	0.024	-0.000
0.216	0.037	0.037	-0.001
0.314	0.055	0.054	0.001
0.433	0.075	0.075	-0.000
0.574	0.099	0.099	-0.000
0.742	0.128	0.128	-0.000
0.938	0.162	0.162	0.000
1.168	0.201	0.202	-0.000
1.439	0.248	0.248	0.000
1.760	0.304	0.304	-0.000

STANDARD DEVIATION= 0.000 NEGATIVE D VALUES DISCARDED 1 / 14
COEFFICIENTS OF FITTED POLYNOMIAL: INTERCEPT= 0.0003 X2= 0.1724
X3= 0.0683 X4= 0.0004 X5=-0.0003
LAYER 3 VELOCITY= 2.409 REFLECTION TIME= 7.083 THICKNESS= 1.271
DEPTH= 6.068 SV= 0.008 SLOPE 0.00
4.65 MINIMUM CRITICAL RANGE, 3.10 WATER TRAVEL TIME FOR LAYER 3

DIR (IN)	REF (IN)	DIR (SEC)	REF (SEC)
0.000	8.046	0.000	8.046
0.216	8.047	0.216	8.047
0.433	8.052	0.433	8.052
0.650	8.059	0.650	8.059
0.869	8.070	0.869	8.070
1.089	8.083	1.089	8.083
1.311	8.099	1.311	8.099
1.536	8.119	1.536	8.119
1.763	8.142	1.763	8.142
1.994	8.169	1.994	8.169
2.229	8.199	2.229	8.199
2.469	8.233	2.469	8.233
2.714	8.271	2.714	8.271
2.966	8.314	2.966	8.314
3.225	8.361	3.225	8.361

DSQ(KM)	R2(SEC)	R2 COMPUTED	DIFFERENCE
0.014	0.000	0.001	-0.001
0.062	0.005	0.004	0.001
0.142	0.010	0.010	-0.000
0.255	0.019	0.018	0.001
0.402	0.029	0.028	0.000
0.585	0.041	0.041	-0.001
0.805	0.056	0.057	-0.000
1.065	0.075	0.075	-0.001
1.370	0.097	0.097	0.000
1.727	0.122	0.122	-0.000
2.141	0.151	0.151	-0.000
2.623	0.185	0.186	-0.000
3.187	0.226	0.225	0.001

STANDARD DEVIATION= 0.001 NEGATIVE D VALUES DISCARDED 1 / 14
COEFFICIENTS OF FITTED POLYNOMIAL: INTERCEPT=-0.0000 X2= 0.0707

```
X3= 0.0410   X4= 0.0006   X5=-0.0002
LAYER  4   VELOCITY= 3.760   REFLECTION TIME= 8.046   THICKNESS= 1.810
  DEPTH= 7.877   SV= 0.033   SLOPE  0.00
   3.37 MINIMUM CRITICAL RANGE,    2.24 WATER TRAVEL TIME FOR LAYER  4
```

DIR (IN)	REF (IN)	DIR (SEC)	REF (SEC)
0.000	9.895	0.000	9.895
0.400	9.897	0.400	9.897
0.800	9.901	0.800	9.901
1.203	9.909	1.203	9.909
1.608	9.919	1.608	9.919
2.018	9.933	2.018	9.933
2.434	9.950	2.434	9.950
2.855	9.971	2.855	9.971
3.285	9.995	3.285	9.995
3.724	10.022	3.724	10.022
4.175	10.054	4.175	10.054
4.639	10.091	4.639	10.091
5.118	10.132	5.118	10.132
5.616	10.178	5.616	10.178
6.135	10.230	6.135	10.230

DSO(KM)	R2(SEC)	R2 COMPUTED	DIFFERENCE
0.171	0.005	0.004	0.001
0.696	0.015	0.016	-0.001
1.582	0.037	0.036	0.001
2.835	0.062	0.064	-0.001
4.476	0.100	0.100	-0.000
6.529	0.145	0.146	-0.001
9.012	0.203	0.201	0.002
11.979	0.268	0.267	0.001
15.470	0.343	0.345	-0.002
19.558	0.434	0.436	-0.002
24.318	0.543	0.542	0.001
29.850	0.666	0.665	0.001
36.302	0.808	0.808	-0.001

```
STANDARD DEVIATION=  0.001      NEGATIVE D VALUES DISCARDED  1 / 14
COEFFICIENTS OF FITTED POLYNOMIAL:  INTERCEPT= 0.0006   X2= 0.0222
X3= 0.0124   X4= 0.0001   X5=-0.0000
LAYER  5   VELOCITY= 6.704   REFLECTION TIME= 9.895   THICKNESS= 6.199
  DEPTH=14.076   SV= 0.061   SLOPE  0.00
   2.91 MINIMUM CRITICAL RANGE,    1.94 WATER TRAVEL TIME FOR LAYER  5
```

1 APRIL 1978
SONOBUOY TEST A

	VELOCITY	REFL TIME	THICKNESS	DELTA TT	DEVIATION	SLOPE
1	1.500	5.007	3.755	5.007	0.000	0.000
2	2.040	6.028	1.041	1.021	0.009	0.000
3	2.409	7.083	1.271	1.055	0.008	0.000
4	3.760	8.046	1.810	0.963	0.033	0.000
5	6.704	9.895	6.199	1.849	0.061	0.000

Compare these results with the model from which this data set was produced (p. 165).

Example of LJNFT input data set

This example input data set is described in the comments prefacing the LINFT program listings (App. K, p. 193). Refer to the listings for description of the input parameters and formats. The output result from this data set follows.

This data set represents real data, with slope corrections included. The output parameters (ISSW1) specifies that all data shall be listed.

```
 1 APRIL 1978
 SONOBUOY TEST B
 1.500   1.490   1.000   -0.025
 1   0   0   0
 5   5   4   6
 0.000  0.100 -0.100  0.000
1.500
 2.020   2.775   4.020   4.638   6.020   6.500   8.020   8.363  10.020  10.225
 4.790   5.612   5.617   6.126   6.740   6.830   7.215   7.138   7.695   7.449
 4.790   5.568   5.617   5.998   6.740   6.580   7.215   6.840
 6.740   6.619   7.215   6.826   7.695   7.020   8.000   7.150   8.540   7.390
 8.779   7.494
 0
```

LINFT output listing from test data set, complete listing

```
PROGRAM LINEAR FIT
     2 DECEMBER 1976

  1 APRIL 1978                                                          1 APRIL 1978
                                                                        SONOBUOY TEST B
  SONOBUOY TEST B
MEAN VERT SOUND VEL= 1.5000   HORIZONTAL SOUND VEL= 1.4900
INCH/SEC= 1.0000   TIME ZERO CORR= -0.020
ISSW0= 1   ISSW1= 0   ISSW2= 0   ISSW3= 0
NUMBER OF POINTS EACH LAYER
 5   5   4   6
INCREMENTAL LAYER SLOPES
0.000  0.100 -0.100  0.000

AVERAGE VELOCITY ABOVE SHALLOWEST REFRACTION= 1.5000

 DDATA   TDATA     KM      SEC     DVAL     TVAL     RES  ANG INC
LAYER  1
 2.020   2.775   2.980   2.755   2.980   2.755  -0.000
 4.020   4.638   5.960   4.618   5.960   4.618   0.000
 6.020   6.500   8.940   6.480   8.940   6.480  -0.000
 8.020   8.363  11.920   8.343  11.920   8.343   0.000
10.020  10.225  14.900  10.205  14.900  10.205  -0.000
A=0.6250  B=  0.893  VLAVE(1)=  1.600  ORTIM(1)=  0.893  DEPTH(1)= 1.924

 DDATA   TDATA     KM      SEC     DVAL     TVAL     RES  ANG INC
LAYER  2
 4.790   5.612   7.107   5.592   7.107   5.592   0.005
 5.617   6.126   8.340   6.106   8.340   6.106  -0.003
 6.740   6.830  10.013   6.810  10.013   6.810  -0.009
 7.215   7.138  10.721   7.118  10.721   7.118  -0.001
 7.695   7.449  11.436   7.429  11.436   7.429   0.007
A=0.4239  B=  2.574  VLAVE(2)=  2.359  ORTIM(2)=  2.574  DEPTH(2)= 2.501

 DDATA   TDATA     KM      SEC     DVAL     TVAL     RES  ANG INC
LAYER  3
 4.790   5.568   7.107   5.548   7.107   5.548   0.002
 5.617   5.998   8.340   5.978   8.340   5.978  -0.001
 6.740   6.580  10.013   6.560  10.013   6.560  -0.006
 7.215   6.840  10.721   6.820  10.721   6.820   0.005
A=0.3511  B=  3.051  VLAVE(3)=  2.849  ORTIM(3)=  3.051  DEPTH(3)= 2.692

 DDATA   TDATA     KM      SEC     DVAL     TVAL     RES  ANG INC
LAYER  4
 6.740   6.619  10.013   6.599  10.013   6.599   0.002
 7.215   6.826  10.721   6.806  10.721   6.806   0.005
 7.695   7.020  11.436   7.000  11.436   7.000  -0.006
 8.000   7.150  11.890   7.130  11.890   7.130  -0.007
 8.540   7.390  12.695   7.370  12.695   7.370   0.002
 8.779   7.494  13.051   7.474  13.051   7.474   0.004
A=0.2872  B=  3.721  VLAVE(4)=  3.481  ORTIM(4)=  3.721  DEPTH(4)= 3.093

AVERAGE VELOCITY ABOVE SHALLOWEST REFRACTION= 1.5000

LAYER  INTCPT  DEPTH  THICK  VELOCITY  TT INC  SLOPE
  1     0.893  1.924  1.924    1.600    2.565  0.000
  2     2.574  2.574  0.650    2.354    0.813  0.100
  3     3.051  2.992  0.418    2.845    0.355 -0.100
  4     3.721  4.042  1.049    3.476    0.738  0.000
```

LINFT input data set

This data set is identical to the previous example, with the exception that complete output listings are suppressed. The result from this example follows

```
  1 APRIL 1978
  SONOBUOY TEST B
 1.500   1.490   1.000   -0.025
 1   1   0   0
 5   5   4   6
0.000  0.100 -0.100  0.000
1.500
 2.020   2.775   4.020   4.638   6.020   6.500   8.020   8.363  10.020  10.225
 4.790   5.612   5.617   6.126   6.740   6.830   7.215   7.138   7.695   7.449
 4.790   5.568   5.617   5.998   6.740   6.580   7.215   6.840
 6.740   6.619   7.215   6.826   7.695   7.020   8.000   7.150   8.540   7.390
 8.779   7.494
 0
```

LINFT test result, abbreviated listing

```
  PROGRAM LINFAR FIT
       2 DECEMBER 1976


   1 APRIL 1978                                                          1 APRIL 1978
                                                                         SONOBUOY TEST B
   SONOBUOY TEST B
MEAN VERT SOUND VEL= 1.5000   HORIZONTAL SOUND VEL= 1.4900
INCH/SEC= 1.0000   TIME ZERO CORR= -0.020
ISSW0= 1   ISSW1= 1   ISSW2= 0   ISSW3= 0
NUMBER OF POINTS EACH LAYER
 5   5   4   6
INCREMENTAL LAYER SLOPES
0.000  0.100 -0.100  0.000

AVERAGE VELOCITY ABOVE SHALLOWEST REFRACTION= 1.5000
LAYER  1
A=0.6250  B=  0.893  VLAVE(1)=  1.600  ORTIM(1)=  0.893  DEPTH(1)= 1.924
LAYER  2
A=0.4239  B=  2.574  VLAVE(2)=  2.359  ORTIM(2)=  2.574  DEPTH(2)= 2.501
LAYER  3
A=0.3511  B=  3.051  VLAVE(3)=  2.849  ORTIM(3)=  3.051  DEPTH(3)= 2.692
LAYER  4
A=0.2872  B=  3.721  VLAVE(4)=  3.481  ORTIM(4)=  3.721  DEPTH(4)= 3.093

AVERAGE VELOCITY ABOVE SHALLOWEST REFRACTION= 1.5000

LAYER  INTCPT  DEPTH  THICK  VELOCITY  TT INC  SLOPE
  1     0.893  1.924  1.924    1.600    2.565  0.000
  2     2.574  2.574  0.650    2.354    0.813  0.100
  3     3.051  2.992  0.418    2.845    0.355 -0.100
  4     3.721  4.042  1.049    3.476    0.738  0.000

EOJ - REFRACTIONS
```

Appendix I

Examples of interpretation programs

This appendix contains two sections:

1. Example of SONOMODEL
2. Calculation of sediment thickness versus travel time curves: Example of program POLYFIT.

The model used in the SONOMODEL example is also listed in the introductory comments prefacing the program listing (see Appendix L). The printed output from the program is listed after the model input segment, and the plot result is shown in Figure 15. This plot is also used in Figure 5. The modelling program also produces from the calculations of the reflection hyperbolas, a data set of direct time - travel time pairs that can be input to the wide angle reflection reduction program, SLOWI. We have used the SLOWI formated output set from this model example in our SLOWI example (see Appendix G). The close correlation of the model input to SONOMODEL and the SLOWI results indicate that both programs are working as we would expect them to.

The second part of the appendix illustrates the use of the polynomial regression program POLYFIT. This program is available through the Tektronix Plot 50 Statistics Package, volume 3. Complete instructions for it's use are contained in the manual for the statistics package.

In the example, the regression program is used to fit a third order polynomial equation to depth and travel time solutions from sonobuoy data of the Bering Sea region. The solution, depth as a third order function of travel time, is shown at the bottom of the figure. The solution is constrained to pass through the origin (0 thickness at 0 travel time). A curve or equation of this type is very useful when converting travel times from vertical incidence seismic records to true depth.

SONOMODEL example input data set

This example input data set is described in the comments prefacing the SONOMODEL program listing (App. L, p. 215). The input parameters and format are described there.

From this model , an experimental data set was constructed for input to program SLOWI. The results from SLOWI (p. 159) compare very favorably with this input model.

This model was used to produce the SONOMODEL plots shown in Figures 6 and 15.

```
SONOBUOY TEST A
    1 APRIL 1978
5      1.487       7.953
    0.500      2.364          20.000         -0.100
 1.500      2.040      2.411       3.761       6.712
 3.755      1.042      1.772       1.811       6.707
```

Output listings from SONOMODEL example

```
date:          1 APRIL 1978
model:         SONOBUOY TEST A

horizontal velocity of sound= 1.4870
plot parameters are:      xscal= 0.5000     yscal= 2.3640     ylen=  18.00
                            initial time offset=-0.1000

layer     velocity(km/sec)   thickness(km)
-----     ---------------   -------------
 1          1.500              3.755
 2          2.040              1.042
 3          2.411              1.272
 4          3.761              1.810
 5          6.712              6.207
 6          7.953
layer     phi       x(km)     t(sec)     critical distance    critical travel time
 1                                            8.15                  7.39
           1      0.000      5.007
           3      0.789      5.034
           6      2.012      5.183
           9      3.344      5.480
          12      4.877      5.970
          15      6.762      6.737
          18      9.274      7.956
          21     13.008     10.013
          24     19.564     13.971
          27     35.331     24.080
          30     ******     95.657
 2                                            9.28                  8.31
           1      0.000      6.028
           3      0.570      6.039
           6      1.437      6.094
           9      2.330      6.201
          12      3.272      6.363
          15      4.288      6.592
          18      5.417      6.904
          21      6.723      7.330
          24      8.341      7.933
          27     10.659      8.902
          30     16.713     11.705
 3                                            6.74                  8.05
           1      0.000      7.083
           3      0.647      7.093
           6      1.628      7.144
           9      2.640      7.242
          12      3.703      7.392
          15      4.847      7.603
          18      6.117      7.891
          21      7.588      8.287
          24      9.421      8.854
          27     12.084      9.784
          30     19.149     12.537
 4                                            5.81                  8.50
           1      0.000      8.046
           3      0.644      8.052
           6      1.619      8.083
           9      2.622      8.142
```

	12	3.671	8.233		
	15	4.796	8.361		
	18	6.041	8.536		
	21	7.488	8.778		
	24	9.316	9.132		
	27	12.099	9.746		
	30	20.515	11.837		
5				24.28	11.80
	1	0.000	9.895		
	3	1.190	9.901		
	6	3.001	9.933		
	9	4.885	9.995		
	12	6.898	10.091		
	15	9.123	10.230		
	18	11.693	10.430		
	21	14.865	10.723		
	24	19.223	11.193		
	27	26.657	12.106		
	30	52.841	15.747		

slowi formatted output

0.000	5.007	0.265	5.014	0.531	5.034	0.800	5.069	1.074	5.119
1.353	5.183	1.641	5.264	1.939	5.363	2.249	5.480	2.573	5.619
2.916	5.781	3.280	5.970	3.669	6.189	4.090	6.442	4.547	6.737
0.000	6.028	0.192	6.031	0.384	6.039	0.576	6.052	0.770	6.070
0.966	6.094	1.164	6.124	1.364	6.159	1.567	6.201	1.774	6.248
1.985	6.302	2.200	6.363	2.422	6.431	2.649	6.508	2.884	6.592
0.000	7.083	0.217	7.086	0.435	7.093	0.654	7.105	0.874	7.122
1.095	7.144	1.319	7.172	1.545	7.204	1.775	7.242	2.009	7.286
2.247	7.336	2.490	7.392	2.739	7.455	2.995	7.525	3.260	7.603
0.000	8.046	0.216	8.047	0.433	8.052	0.650	8.059	0.869	8.070
1.089	8.083	1.311	8.099	1.536	8.119	1.763	8.142	1.994	8.169
2.229	8.199	2.469	8.233	2.714	8.271	2.966	8.314	3.225	8.361
0.000	9.895	0.400	9.897	0.800	9.901	1.203	9.909	1.608	9.919
2.018	9.933	2.434	9.950	2.855	9.971	3.285	9.995	3.724	10.022
4.175	10.054	4.639	10.091	5.118	10.132	5.616	10.178	6.135	10.230

This SLOWI formatted data set
is used to test program SLOWI
(see pp. 151-155).

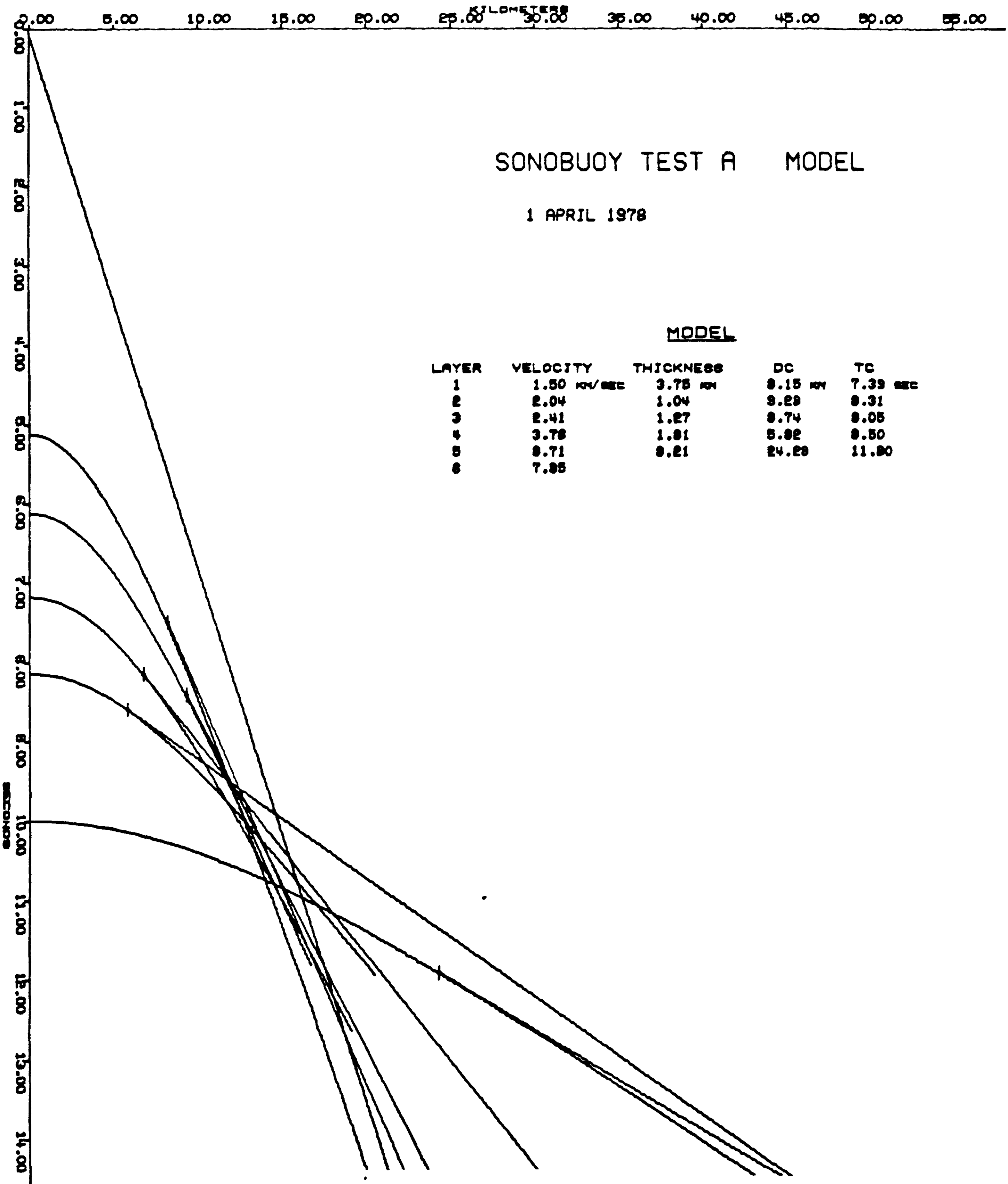


Figure 15 Example plot output produced by SONOMODEL. Model of a deep water (3750 meters) sonobuoy station. This plot is also used in Figure 6.

A Sediment thickness versus Travel Time Curve

An equation for sediment velocity as a function of travel time can easily be computed from the wide angle reflection (SLOWI) and refraction (LINFT) results. A good approximation to the velocity-travel time data is obtained with a third order polynomial (Houtz et al., 1968):

$$V = C_0 + C_1 T + C_2 T^2 + C_3 T^3 \qquad (A)$$

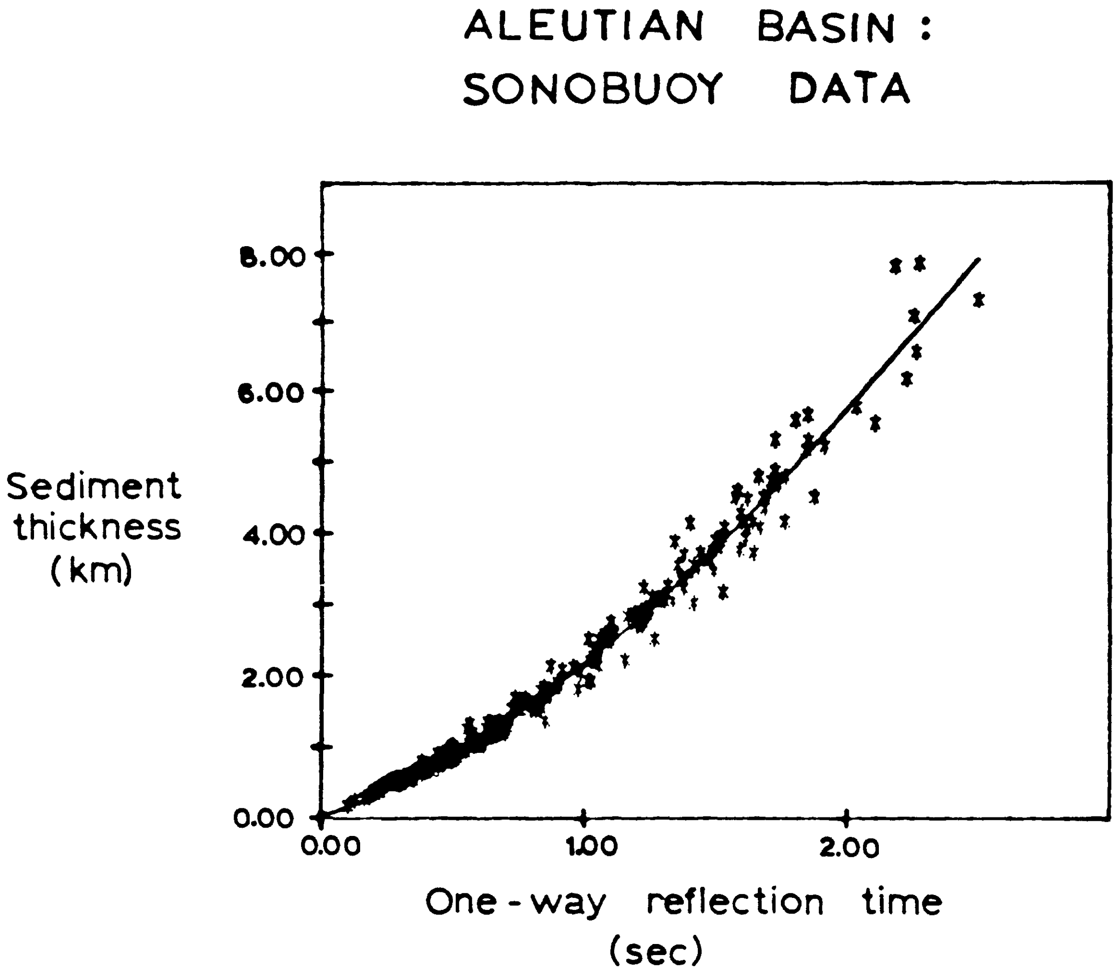
where the C_i's are the coefficient, T is the one-way travel time beneath the seafloor, and C_0 is the velocity at the water-sediment interface. Usually, a large number of data values from sonobuoy stations in the same physiographic region are used to determine the coefficients by a least squares fit to the data. If sonobuoy data are sparse, the coefficients can be determined by as few as four velocity-travel time data pairs.

A more useful equation for sediment thickness versus travel time is obtained by integrating the above equation:

$$D = \int V dt = C_{-1} + C_0 T + \frac{1}{2} C_1 T^2 + \frac{1}{3} C_2 T^3 + \frac{1}{4} C_3 T^4 \qquad (B)$$

where C_{-1}, which is the thickness at zero reflection time, is normally 0. Using the thickness versus one-way travel time equation (equation B), reflection times in vertical incidence seismic profiles can quickly be converted to sediment thickness (or depth below sea level, if the water depth is known).

A computer program for determining the third-order polynomial equation to the velocity-reflection time data (equation A) is available on the Tektronix 4051 through the "statistical package". Complete documentation for the program exists in the Statistical Reference Manual. An example of this analysis which was performed on sonobuoy reflection data from the Bering Sea is shown in Figure 16.



Polynomial regression:

$$d = 1.287t + 0.931t^2 - 0.073t^3$$

Figure 16 Example of polynomial regression used to determine sediment depth (in km) as a function of one way sub-seafloor travel time (in seconds) from sonobuoy data in the Bering Sea deep ocean basins.

Appendix J

Listings of digitizing programs

This appendix contains line numbered listings of the digitizing programs LINDIGIT and SLODIGIT. Both progams are in Tektronix BASIC language. Special characters unique to the Tek language are:

G	(control G):	rings bell
H	(control H):	backspaces the cursor
J	(control J):	moves the cursor down one line
_	(control _):	" " " " " "
K	(control K):	moves the cursor up one line
L	(control L):	erases the screen and moves the cursor to home

^ - arithmetic symbol to indicate exponent (e.g. 2^3 = 8)

These characters do not print, so they are shown simply as the upper case letters or underscore. Their context, in print or image statements, identify them.

```
1 REM   LINFT FORMATTED DIGITIZING PROGRAM   SONOBUOY REFRACTIONS
2 INIT
3 GO TO 100
56 REM      MULTICS LOGIN
57 FIND 7
58 CALL "LINK",100
59 RETURN
100 DIM A$(40),B$(40),Z$(1),Q$(1)
110 PAGE
120 PRINT @32,26:2
130 SET KEY
140 SET DEGREES
145 PRINT "      PROGRAM  LINDIGIT     REFRACTION DIGITIZING___"
150 PRINT "Enter heading for sonobuoy"
160 INPUT A$
170 PRINT "_Enter date of sonobuoy run"
180 INPUT B$
190 PRINT "__Enter horizontal sound velocity (in km/sec)"
200 PRINT "      (default = 1.485 km/sec)                ";
210 B1=1.485
220 INPUT V$
230 IF V$="" THEN 250
240 B1=VAL(V$)
250 PRINT "___Enter average vertical sound velocity (in km/sec)"
260 PRINT "      (default = 1.5 km/sec)                  ";
270 B7=1.5
280 INPUT V$
290 IF V$="" THEN 310
300 B7=VAL(V$)
310 PRINT "___Enter number of layers to be digitized:          ";
320 INPUT N1
330 PRINT "__How many points per layer do you wish to pick?"
340 PRINT "      (default = 5)                           ";
350 N2=5
360 INPUT V$
370 IF V$="" THEN 390
380 N2=VAL(V$)
390 GOSUB 420
400 GO TO 630
410 REM  FOLLOWING LINES ARE A SUBROUTINE TO SET ORIGIN AND SCALE
420 PRINT "L*****   Position sonobuoy on digitizing tablet   *****"
430 PRINT "__Set the origin of the sonobuoy record."
440 INPUT @8:X,Y,Z$
450 PRINT "GGG__Determine the scaling factor:"
460 PRINT "_Mark the time tick at the bottom of the record."
470 INPUT @8:X,Y,Z$
480 PRINT "GGG";
490 REM      CALCULATE ANGLES FOR COORDINATE ROTATION
500 A1=SIN(ATN(Y/X))
510 A2=Y/X
520 A3=COS(ATN(Y/X))
530 PRINT "_How many seconds long is the record?   ";
540 INPUT S
545 X=Y*A1+X*A3
550 B3=S/X
560 PRINT "____DO YOU WISH TO CHECK THE TIME REFERENCE MARKS?"
570 INPUT Q$
580 IF Q$="N" THEN 620
590 IF Q$<>"Y" THEN 560
600 GOSUB 2110
```

```
610 IF Z<8 THEN 430
620 RETURN
630 PRINT "LDOES THE RECORD HAVE A DEEP WATER DELAY?"
640 INPUT Q$
650 IF Q$="N" THEN 760
660 IF Q$<>"Y" THEN 630
670 PRINT "_WHAT IS THE PRECISE WATER DEPTH (in 2 way seconds)?"
680 INPUT B6
690 PRINT "__MARK THE SEAFLOOR AT THE FIRST RECORDER TRACE (x=0)."
700 INPUT @8:X,Y,Z
710 PRINT "GGG";
720 X=(Y*A1+X*A3)*B3
730 D1=B6-X
740 B4=0
750 GO TO 930
760 PRINT "__MARK THE DIRECT ARRIVAL WHERE IT INTERCEPTS THE FIRST"
770 PRINT "RECORDER TRACE (x=0)."
780 D1=0
790 INPUT @8:X,Y,Z$
800 B4=(Y*A1+X*A3)*B3
810 PRINT "GGG__MARK THE SEAFLOOR REFLECTOR AT THE FIRST TRACE (x=0).'
820 INPUT @8:X,Y,Z$
830 PRINT "GGG";
840 B6=(Y*A1+X*A3)*B3
850 B6=B6-B4
860 PRINT "__DO YOU WISH TO INPUT A SEAFLOOR TIME?   ";
880 INPUT Q$
890 IF Q$="N" THEN 930
900 IF Q$<>"Y" THEN 860
910 PRINT "  SEAFLOOR TIME (2-WAY SECONDS):        ";
920 INPUT B6
930 REM  THE FOLLOWING VARIABLES ARE:
940 REM       V1 - ASSUMED SEAFLOOR VELOCITY
950 REM       O1 - OUTPUT DEVICE NUMBER
960 V1=1.55
970 O1=32
980 N3=1
1010 REM  CALCULATE ASSUMED SEAFLOOR REFRACTOR, VELOCITY = 1.55 KM/SE(
1020 PRINT "__DO YOU WISH TO ADD AN ASSUMED SEAFLOOR REFRACTOR?    ";
1030 INPUT Q$
1040 IF Q$="N" THEN 1180
1050 IF Q$<>"Y" THEN 1020
1060 N1=N1+1
1065 DIM D(N1,N2),R(N1,N2)
1066 D=0
1067 R=0
1070 N3=2
1080 PRINT "__WHAT IS THE SEAFLOOR VELOCITY:"
1090 PRINT "     (default = 1.55 km/s)          ";
1100 INPUT V$
1110 IF V$="" THEN 1130
1120 V1=VAL(V$)
1130 FOR I=1 TO N2
1140 D(1,I)=I*2
1150 R(1,I)=(B1*D(1,I)+B6*(V1*V1-B7*B7)^0.5)/V1+B4
1160 D(1,I)=D(1,I)+B4
1170 NEXT I
1175 GO TO 1260
1180 DIM D(N1,N2),R(N1,N2)
1190 D=0
```

```
1200 R=0
1260 PRINT "LSTART DIGITIZING THE DATA POINTS"
1280 PRINT "_    Pick first the direct time, D(i), and then the ref-"
1290 PRINT "   ractor time, R(i), for each data point.  ";
1295 PRINT USING "2D,"" picks""":2*N2
1300 PRINT "   must be made for each refractor.__"
1310 FOR I=N3 TO N1
1320 FOR J=1 TO N2
1330 INPUT @8:X,Y,Z$
1340 D(I,J)=(Y*A1+X*A3)*B3+D1
1350 PRINT USING 1360:D(I,J)
1360 IMAGE "GGG",3D.3D,S
1365 IMAGE "GG",3D.3D,S
1370 INPUT @8:X,Y,Z$
1380 R(I,J)=(Y*A1+X*A3)*B3+D1
1390 PRINT USING 1365:R(I,J)
1400 NEXT J
1410 PRINT USING 1420:
1420 IMAGE /,"GGG",S
1430 NEXT I
1440 PRINT @32,26:0
1450 PRINT "___DO YOU WISH TO SEE A LINFT FORMATTED DATA LIST?"
1460 INPUT Q$
1470 IF Q$="N" THEN 1500
1480 IF Q$<>"Y" THEN 1450
1490 GOSUB 1530
1500 END
1530 REM   GOSUB TO WRITE OUTPUT LIST AND LINFT FORMATTED
1540 REM            OUTPUT SET TO TAPE
1550 PRINT "L   LINFT FORMATTED OUTPUT LIST"
1560 PRINT
1570 PRINT @01,12:A$
1580 PRINT @01,12:B$
1590 PRINT @01,12: USING 1600:B7,B1,-B4
1600 IMAGE 3D.4D,3D.4D,"  1.0000",4D.3D
1610 PRINT @01,12:"   1   1   0   0"
1620 FOR I=1 TO N1
1630 PRINT @01,12: USING "2X,2D,S":N2
1640 NEXT I
1650 PRINT @01,12: USING "/":
1660 PRINT @01,12:"1.5000"
1670 FOR I=1 TO N1
1680 FOR J=1 TO N2
1690 IF O1<>32 THEN 1730
1700 PRINT @01,12: USING 1710:D(I,J),R(I,J)
1710 IMAGE 2(3D.3D),S
1720 GO TO 1750
1730 PRINT @01,12: USING 1740:D(I,J),R(I,J)
1740 IMAGE 2(4D.3D),S
1750 NEXT J
1760 PRINT @01,12:
1770 NEXT I
1780 PRINT @01,12:"   0"
1790 IF O1<>32 THEN 1870
1800 PRINT "____DO YOU WISH TO WRITE THE OUTPUT TO TAPE?"
1810 INPUT Q$
1820 IF Q$="N" THEN 1870
1830 IF Q$<>"Y" THEN 1800
1835 O1=1
1840 GOSUB 1890
```

```
1860 GO TO 1570
1870 PRINT @32,26:0
1875 PRINT @01,2:
1880 RETURN
1890 REM  FIND TAPE FILE AND MARK
1900 PRINT "LINSERT THE OBJECT TAPE IN THE TAPE READER."
1910 PRINT "__WHICH TAPE FILE DO YOU WISH TO WRITE TO?"
1915 PRINT "(TYPE  [999]  FOR A TAPE LIST)"
1920 INPUT N
1922 IF N<999 THEN 1930
1925 GOSUB 2300
1928 GO TO 1910
1930 PRINT @01,0:0,0,1
1940 FIND @01:N
1950 INPUT @01:C$
1960 PRINT "__THE HEADER OF THAT FILE READS:"
1970 PRINT C$
1980 PRINT @01,0:0,0,0
1982 PRINT "__DO YOU STILL WISH TO WRITE TO THIS FILE?   ";
1984 INPUT Q$
1986 IF Q$="N" THEN 1910
1988 IF Q$<>"Y" THEN 1982
1990 PRINT "__DO YOU WISH TO MARK THIS FILE?   ";
2000 INPUT Q$
2010 IF Q$="N" THEN 2090
2020 IF Q$<>"Y" THEN 1990
2030 PRINT "__ARE YOU SURE ?   ";
2040 INPUT Q$
2050 IF Q$="N" THEN 1910
2060 IF Q$<>"Y" THEN 2030
2070 FIND @01:N
2080 MARK @01:1,(6+N1)*80
2090 FIND @01:N
2100 RETURN
2110 REM   GOSUB TO CHECK REFERENCE PICKS
2120 PRINT "LYOU CAN HERE MAKE ANY NUMBER OF DATA PICKS IN ORDER"
2130 PRINT "TO CHECK OUT YOUR REFERENCE SYSTEM.  WHEN YOU ARE"
2140 PRINT "SATISFIED, PRESS BUTTON NUMBER 1 ON THE CURSOR."
2150 PRINT "TO RESET THE ORIGIN, PRESS BUTTON NUMBER 2"
2160 INPUT @8:X,Y,Z
2170 IF Z>1 THEN 2210
2180 X=(Y*A1+X*A3)*B3
2190 PRINT USING """GG"",2D.3D":X
2200 GO TO 2160
2210 RETURN
2300 REM   SUBROUTINE TO PERFORM TAPE LIST AT ANY DEVICE
2305 PAGE
2310 PRINT @01,0:0,0,1
2320 FOR N=1 TO 999
2330 FIND @01:N
2340 INPUT @01:C$
2350 PRINT C$
2360 C$=SEG(C$,9,4)
2370 IF C$="LAST" THEN 2390
2380 NEXT N
2390 PRINT @01,0:0,0,0
2400 RETURN
```

```
1 REM    PROGRAM SLODIGIT     WIDE ANGLE REFLECTION DIGITIZING
2 INIT
3 GO TO 100
4 REM  REPICK POINT
5 F1=4
6 RETURN
8 REM   SKIP A LAYER WITHIN A TRACE
9 F1=5
10 RETURN
12 REM   STOP MARKING ALONG A TRACE
13 F1=2
14 RETURN
16 REM   STOP PICKING DATA COMPLETELY
17 F1=3
18 RETURN
20 REM   LIST PARAMETERS
21 GOSUB 1880
22 RETURN
44 REM   LINK TO X2-T2
45 FIND 4
46 CALL "LINK",100
47 RETURN
48 REM  CORRECTION FOR DELAYED HYDROPHONE RELEASE
49 FIND 3
50 CALL "LINK",1
51 RETURN
52 REM   OPTION TO CHECK REFERENCE POINTS
53 GOSUB 2310
54 RETURN
56 REM     MULTICS LOGIN
57 FIND 7
58 CALL "LINK",100
59 RETURN
60 REM    LIST INPUT DATA
61 GOSUB 2210
62 RETURN
72 REM  OPTION TO DUMP DATA ONTO TAPE
73 FIND 6
74 CALL "LINK",100
75 RETURN
76 REM  RECYCLE DATA FROM TAPE
77 FIND 6
78 CALL "LINK",500
79 RETURN
100 DIM A$(40),B$(40),Z$(1),Q$(1)
120 PRINT @32,26:2
130 SET KEY
132 SET DEGREES
134 PRINT "L        REFLECTION  DIGITIZING  PROGRAM___"
140 SET DEGREES
141 PRINT "Do you wish to recover data from tape - ";
142 PRINT "(please answer [y] or [n] ):   ";
143 INPUT Q$
144 IF Q$="N" THEN 150
145 IF Q$<>"Y" THEN 142
146 FIND 6
147 CALL "LINK",500
150 PRINT "__Enter heading for sonobuoy"
160 INPUT A$
170 PRINT "___Enter date of sonobuoy run"
```

```
180 INPUT B$
190 PRINT "___Enter horizontal sound velocity (in km/sec)   "
192 PRINT "      (default = 1.485 km/s)"
194 B1=1.485
196 INPUT V$
198 IF V$="" THEN 210
200 B1=VAL(V$)
210 PRINT "_Enter average vertical sound velocity (in km/sec):   "
212 PRINT "      (default = 1.500 km/s)"
214 B7=1.5
216 INPUT V$
218 IF V$="" THEN 230
220 B7=VAL(V$)
230 PRINT "_Enter hydrophone depth lower (in feet):   ";
240 INPUT B2
250 PRINT "___Enter number of layers to be digitized:"
255 PRINT "        ( A maximum of 14 is allowed. )   ";
260 INPUT N1
265 IF N1>14 THEN 255
270 GOSUB 290
280 GO TO 420
290 PRINT "LPosition sonobuoy on digitizing tablet."
300 PRINT "_Set the origin of the sonobuoy record."
310 INPUT @8:X,Y,Z$
320 PRINT "_Determine the scaling factor:"
330 PRINT "Mark the time tick at the bottom of the record."
340 INPUT @8:X,Y,Z$
350 A1=SIN(ATN(Y/X))
360 A2=Y/X
370 A3=COS(ATN(Y/X))
380 PRINT "How many seconds long is the record:   ";
390 INPUT S
395 X=Y*A1+X*A3
400 B3=S/X
410 RETURN
420 PRINT "DO YOU WISH TO CHECK THE TIME REFERENCE MARKS:   ";
430 INPUT Q$
440 IF Q$="N" THEN 470
450 IF Q$<>"Y" THEN 420
460 GOSUB 2310
470 B8=B3
480 PRINT "__Mark the point on the direct trace when the phones"
490 PRINT "  dropped."
500 INPUT @8:X,Y,Z$
510 X=Y*A1+X*A3
520 B5=X*B3
530 DIM D(40),R(N1,40),C4(N1),C6(N1)
540 DATA 0,0,3,10
550 READ N3,F1,C1,C3
560 D=0
570 R=0
580 N2=0
585 C6=0
590 PRINT "L_  ARE YOU PICKING DATA POINTS OFF TWO RECORDS:   ";
600 INPUT Q$
610 IF Q$="Y" THEN 1070
620 IF Q$<>"N" THEN 590
630 Q1=-1
640 PRINT "___START DIGITIZING THE DATA POINTS"
650 PRINT "    The order is a direct time followed by n reflection"
```

```
660 PRINT "    times, where n is the number of layers specified above."
670 PRINT "    When finished, press u.d. key #4 and digitize any point."
675 PRINT "   (A maximum of 40 traces is allowed.)"
680 FOR I=1 TO 40
690 INPUT @8:X,Y,Z$
700 X=Y*A1+X*A3
710 IF F1=3 THEN 1790
720 IF F1<>4 THEN 810
730 PRINT USING """R""",S":
740 I=I-1
750 J=J-1
760 INPUT @8:X,Y,Z$
770 X=Y*A1+X*A3
780 R(J,I)=X*B3
790 PRINT USING 1010:R(J,I)
800 GO TO 1040
810 N3=N3+1
820 D(I)=X*B3
830 PRINT USING 840:D(I);
840 IMAGE "GGG_",2D.3D,S
850 FOR J=1 TO N1
860 INPUT @8:X,Y,Z$
870 X=Y*A1+X*A3
880 IF F1=3 THEN 1790
890 IF F1=2 THEN 1040
900 IF F1=5 THEN 1020
910 IF F1<>4 THEN 990
920 PRINT USING """R""",S":
930 IF J=1 THEN 960
940 J=J-2
950 GO TO 1020
960 N3=N3-1
970 I=I-1
980 GO TO 1040
990 P(J,I)=X*B3
1000 PRINT USING 1010:R(J,I);
1010 IMAGE "G",3D.3D,S
1020 F1=0
1030 NEXT J
1040 F1=0
1050 NEXT I
1060 GO TO 1790
1070 REM OPTION TO PICK TIMES FROM TWO SEPARATE RECORDS
1080 Q1=1
1090 PRINT "__MARK THE SEAFLOOR ARRIVAL ON THE FIRST RECORD"
1100 INPUT @8:X,Y,Z$
1110 X=Y*A1+X*A3
1120 P1=X*B3
1130 PRINT " START DIGITIZING DIRECT TIMES"
1140 PRINT "      To stop digitizing, press u.d. key #4 and"
1145 PRINT "      digitize any point."
1150 FOR I=1 TO 40
1160 INPUT @8:X,Y,Z$
1170 X=Y*A1+X*A3
1180 IF F1=3 THEN 1300
1190 IF F1<>4 THEN 1240
1200 PRINT USING """  R""",S":
1210 N3=N3-1
1220 I=I-2
1230 GO TO 1280
```

```
1240 N3=N3+1
1250 D(I)=X*B3
1260 PRINT USING 1270:D(I)
1270 IMAGE /,"GG",2D.3D,S
1280 F1=0
1290 NEXT I
1300 REM SECOND RECORD
1310 PRINT "LPLACE SECOND RECORD ON THE DIGITIZING TABLET."
1320 GOSUB 290
1330 PRINT "___DO YOU WISH TO CHECK THE TIME REFERENCE MARKS:   ";
1340 INPUT Q$
1350 IF Q$="N" THEN 1380
1360 IF Q$<>"Y" THEN 1330
1370 GOSUB 2310
1380 PRINT "_MARK THE SEAFLOOR ARRIVAL ON THE SECOND RECORD"
1390 INPUT @8:X,Y,Z$
1400 X=Y*A1+X*A3
1410 P2=X*B3
1420 P3=P1-P2
1430 F1=0
1440 PRINT "JJJ START DIGITIZING REFLECTION TIMES"
1450 PRINT "      When finished, press u.d. key #4 and digitize"
1455 PRINT "      any point"
1460 FOR I=1 TO N3
1470 IF F1<>4 THEN 1560
1480 I=I-1
1490 J=J-1
1500 INPUT @8:X,Y,Z$
1510 R(J,I)=(Y*A1+X*A3)*B3
1520 PRINT USING """R"",S":
1530 PRINT USING 1010:R(J,I)
1540 J=J+1
1550 GO TO 1770
1560 PRINT USING "/,""GGG"",3D.3D,S":D(I)
1570 FOR J=1 TO N1
1580 INPUT @8:X,Y,Z$
1590 X=Y*A1+X*A3
1600 IF F1=3 THEN 1790
1610 IF F1=2 THEN 1770
1620 IF F1=5 THEN 1750
1630 IF F1<>4 THEN 1720
1640 IF J<>1 THEN 1690
1650 I=I-1
1660 J=N1-1
1670 PRINT USING """     R     "",S":
1680 GO TO 1750
1690 PRINT USING """R"",S":
1700 J=J-2
1710 GO TO 1750
1720 R(J,I)=X*B3+P3
1730 PRINT USING 1740:R(J,I)
1740 IMAGE "G",3D.3D,S
1750 F1=0
1760 NEXT J
1770 F1=0
1780 NEXT I
1790 B4=-D(1)
1800 B6=(R(1,1)-B4)*B7*1000/2
1810 PRINT "LSUGGESTED PROCEDURE:"
1820 PRINT "__      1.  MAKE COPY OF INPUT PARAMETERS     ( U.D. KEY #5";
```

```
1821 PRINT " )"
1830 PRINT "_     2.  MAKE COPY OF DIGITIZED PICKS                #15"
1840 PRINT "_     3.  SAVE RAW DATA ON TAPE                       #18"
1850 PRINT "_     4.  ADD HYDROPHONE DELAYED RELEASE"
1855 PRINT "          CORRECTION AND GO TO X2 - T2                #12"
1856 PRINT "_     or"
1860 PRINT "_     4.  GO DIRECTLY TO X2 - T2                      #11"
1870 END
1880 REM  prints out list of parameters
1890 PRINT "L  INPUT PARAMETER LIST_  "
1900 PRINT A$
1910 PRINT B$
1920 PRINT USING 2010:B1
1930 PRINT USING 2020:B7
1940 PRINT USING 2040:B2
1950 PRINT USING 2030:B6
1960 PRINT USING 2050:B8
1970 PRINT USING 2060:D4
1980 PRINT USING 2070:B5
1990 PRINT USING 2080:N1
2000 PRINT USING 2090:N3
2010 IMAGE "__Horizontal sound velocity in water =",2d.3d," km/sec"
2020 IMAGE "_Average vertical sound velocity =",2d.3d," km/sec"
2030 IMAGE "_Water depth=",5d.1d," meters"
2040 IMAGE "_Hydrophone depth =",4d.1d," feet"
2050 IMAGE "_Conversion factor is",2d.6d," sec/millimeter"
2060 IMAGE "_Delta: time zero correction factor is ",-1d.4d," sec"
2070 IMAGE "_Hydrophones dropped at a direct time of",2d.3d," sec"
2080 IMAGE "_",2d," layers were picked"
2090 IMAGE "_",3d," traces were picked"
2100 IF Q1<0 THEN 2200
2110 PRINT "JJDATA PICKS WERE FROM TWO SEPARATE RECORDS"
2120 PRINT USING 2160:B3
2130 PRINT USING 2170:P1
2140 PRINT USING 2180:P2
2150 PRINT USING 2190:P3
2160 IMAGE "_Conversion factor for second record is",2d.7d," mm/sec"
2170 IMAGE "_Reference point on first record is",3d.3d," sec."
2180 IMAGE "_Reference point on second record is",3d.3d," sec."
2190 IMAGE "_Reference point time difference is",2d.3d," sec."
2200 RETURN
2210 REM PRINTS OUT DATA TABLE (if # of layers < 9)
2220 PRINT "LTABLE OF DIGITIZED PICKS: D(J);R(I,J)JJ"
2230 FOR I=1 TO N3
2240 PRINT USING "/,3D.3D,S":D(I)
2250 FOR J=1 TO N1
2260 PRINT USING "3D.3D,S":R(J,I)
2270 NEXT J
2280 NEXT I
2290 PRINT
2300 RETURN
2310 REM   GOSUB TO CHECK REFERENCE PICKS
2320 PRINT "YOU CAN HERE MAKE ANY NUMBER OF DATA PICKS IN ORDER"
2330 PRINT "TO CHECK OUT YOUR REFERENCE SYSTEM.  WHEN YOU ARE"
2340 PRINT "SATISFIED, PRESS BUTTON NUMBER 1 ON THE CURSOR."
2350 INPUT @8:X,Y,Z
2360 IF Z=8 THEN 2400
2370 X=(Y*A1+X*A3)*B3
2380 PRINT X
2390 GO TO 2350
2400 RETURN
```

```
1 REM     SLODIGIT      SUBROUTINE  HDRC
2 GO TO 100
44 REM  GO TO X2-T2
45 GOSUB 400
47 RETURN
100 REM SUBPROGRAM TO CORRECT FOR DELAYED RELEASE OF HYDROPHONE
110 PRINT "THIS SECTION WILL DO EITHER:"
120 PRINT "            1.)  CORRECT FOR DELAYED RELEASE OF HYDROPHONE"
130 PRINT "            2.)  THE REVERSE, REMOVE A PREVIOUS CORRECTION"
140 PRINT "WHICH OPTION DO YOU WANT?"
150 INPUT Q$
160 IF Q$="1" THEN 180
170 IF Q$<>"2" THEN 140
180 C2=B2*0.3048
190 FOR I=1 TO N1
200 C5=(R(I,1)-R(1,1))/2
210 C4(I)=(1.23*C5+1.03*C5^2-0.12*C5^3)*1000
220 C6(I)=B6-C3+C4(I)
230 NEXT I
240 FOR I=1 TO 20
250 IF D(I)>B5 THEN 360
260 X=D(I)*P1*1000
270 FOR J=1 TO N1
280 C7=1/(B7*1000)
290 T=C7*(((X/2)^2+(C6(J)-C2)^2)^0.5-((X/2)^2+(C6(J)-C1)^2)^0.5)
300 IF R(J,I)=0 THEN 350
310 IF Q$="2" THEN 340
320 R(J,I)=R(J,I)+T
330 GO TO 350
340 R(J,I)=R(J,I)-T
350 NEXT J
360 NEXT I
400 REM  BRANCH CORRECTLY TO X2-T2
410 IF Q1>2 THEN 460
420 Q1=3
430 FIND 4
440 CALL "LINK",100
450 RETURN
460 FIND 4
470 CALL "LINK",130
480 RETURN
```

```
1 REM     SLODIGIT  -  SUBROUTINE X2T2
2 GO TO 100
48 REM  RETURN TO HYDROPHONE RELEASE DELAY CORRECTION
49 FIND 3
50 CALL "LINK",1
51 RETURN
64 REM   LINK TO EDIT AND OUTPUT SEGMENT
65 FIND 5
66 CALL "LINK",1
67 RETURN
90 REM SUBPROGRAM TO DO X2-T2 AND PLOT
100 DIM T1(N1),T2(N1),T5(N1),T6(N1),N5(N1),E3(N1),T7(N1),N(N1)
110 PRINT @32,26:0
120 N=N3
130 E1=0
140 E2=0
150 FOR I=1 TO N1
160 IF N(I)<=0 THEN 520
170 S1=0
180 S2=0
190 S3=0
200 S4=0
210 S5=0
220 N5(I)=0
230 FOR J=1 TO N3
240 D2=((D(J)+B4)+B1)^2
250 R2=(R(I,J)+B4)^2
260 IF D(J)<0 THEN 360
270 IF R(I,J)<=0 THEN 360
280 E1=D2 MAX E1
290 E2=R2 MAX E2
300 S1=S1+D2
310 S2=S2+D2^2
320 S3=S3+R2
330 S4=S4+R2^2
340 S5=S5+D2*R2
350 N5(I)=N5(I)+1
360 NEXT J
370 J=J-1
380 E3(I)=D2
390 T1(I)=(N5(I)*S5-S1*S3)/(N5(I)*S2-S1^2)
400 T2(I)=(S3*S2-S1*S5)/(N5(I)*S2-S1^2)
410 T3=SQR((S2-S1^2/N5(I))/(N5(I)-1))
420 T4=SQR((S4-S3^2/N5(I))/(N5(I)-1))
430 T5(I)=(N5(I)*S5-S1*S3)/(N5(I)*(N5(I)-1)*T3*T4)
440 T6(I)=SQR(1/T1(I))
450 IF I=1 THEN 520
460 J=I-1
470 IF N(J)>0 THEN 500
480 J=J-1
490 GO TO 470
500 T7(J)=(T2(I)*T6(I)^2-T2(J)*T6(J)^2)/(T2(I)-T2(J))
510 T7(J)=SQR(T7(J))
520 NEXT I
530 REM GOSUB ROUTINE FOR LLSQ DATA
540 PRINT USING "///":
550 PRINT "   DO YOU WISH TO SEE DATA FROM ALL LAYERS?"
560 INPUT Q$
570 IF Q$="Y" THEN 740
580 IF Q$<>"N" THEN 550
```

```
590 PRINT "_DO YOU WISH TO SEE DATA FROM ANY OF THE LAYERS?"
600 INPUT Q$
610 IF Q$="N" THEN 1120
620 IF Q$<>"Y" THEN 590
630 PRINT "_WHICH LAYER?"
640 INPUT I
650 IF I<=N1 THEN 680
660 PRINT "THERE JUST AIN'T THAT MANY LAYERS, DUMMY."
670 GO TO 630
680 GOSUB 840
690 PRINT "ANOTHER LAYER?"
700 INPUT Q$
710 IF Q$="Y" THEN 630
720 IF Q$<>"N" THEN 690
730 GO TO 1120
740 I=1
750 IF N(I)>0 THEN 780
760 PAGE
770 GO TO 790
780 GOSUB 840
790 FOR I=2 TO N1
800 IF N(I)<=0 THEN 820
810 GOSUB 860
820 NEXT I
830 GO TO 1120
840 REM GOSUB FOR WRITING TABLE OF LLSQ DATA
850 PAGE
860 PRINT USING """ LAYER "",3D,""JJJ""":I
870 PRINT USING 880:T1(I),T2(I),T5(I)
880 IMAGE "SLOPE =",2D.3D,"  INTERCEPT =",3D.3D,"  FIT =",2D.5D
890 PRINT USING """   NUMBER OF POINTS USED ="",3D,       ":N5(I)
900 PRINT "JJJ  DIRECT     RANGE          R         R2       COMP R2   DIFF"
910 FOR J=1 TO N3
920 D2=((D(J)+R4)+B1)^2
930 R2=(R(I,J)+R4)^2
940 IF D(J)<0 THEN 1020
950 IF R(I,J)<=0 THEN 1020
960 R3=T2(I)+D2*T1(I)
970 R4=R2-R3
980 PRINT USING "6(5D.4D),S":D(J);D2;R(I,J);R2;R3;R4;
990 IF ABS(R4)<0.3 THEN 1020
1000 PRINT "<<>>"
1010 GO TO 1030
1020 PRINT
1030 NEXT J
1040 IF N3>25 THEN 1100
1050 J=35-10-N3
1060 FOR K=1 TO J
1070 PRINT
1080 NEXT K
1090 GO TO 1110
1100 PRINT "_____"
1110 RETURN
1120 REM GOSUB FOR PRINTING VELOCITY TABLE
1130 PRINT "___(press return to continue)"
1140 INPUT Q$
1150 PAGE
1155 PRINT "_"
1160 PRINT USING "13T,""RMS"",21T,""INTERCEPT"",46T,""INTERVALK2J""":
1170 PRINT "LAYER    VELOCITY     TIME    ";
```

```
1180 PRINT USING "2T,""   DEPTHK1J     VELOCITY        FIT      """:
1190 PRINT USING 1200:
1200 IMAGE 10T,"(KM/SEC)     (SEC)        (KM)       (KM/SEC)_"
1210 FOR I=1 TO N1-1
1220 IF N(I)>0 THEN 1250
1230 PRINT "LAYER DELETED"
1240 GO TO 1280
1250 T3=SQR(T2(I))/2
1260 PRINT USING 1270:I,T6(I),T3,T3*T6(I),T7(I),T5(I)
1270 IMAGE 3D,4X,4D.3D,4X,3(4D.3D,4X),5D.5D
1280 NEXT I
1290 T3=SQR(T2(I))/2
1300 PRINT USING 1310:I,T6(I),T3,T3*T6(I),T5(I)
1310 IMAGE 3D,4X,4D.3D,4X,2(4D.3D,4X),13X,4D.5D
1320 PRINT "JJ(1) Depth to the top of the refracter:  V(rms)*intercept"
1330 PRINT "J(2) Interval velocity calculated from Dix' equation."
1360 PRINT "_____DO YOU WISH TO SEE THE X2-T2 PLOT?"
1370 INPUT Q$
1380 IF Q$="N" THEN 2140
1390 IF Q$<>"Y" THEN 1360
1400 REM PLOTTING SECTION
1410 REM INITIALIZING PLOTTING VALUES
1420 X1=0
1430 X2=(INT(E1/5)+1)*5
1440 Y1=INT(T2(1)/5)*5
1450 Y2=(INT(E2/5)+1)*5
1460 X3=5
1470 Y3=5
1480 GOSUB 1590
1490 PRINT "DO YOU WANT TO SEE THE PLOT AT A DIFFERENT SCALE?"
1500 INPUT Q$
1510 IF Q$="N" THEN 1580
1520 IF Q$<>"Y" THEN 1490
1530 PRINT "WINDOW:  X1,X2,Y1,Y2;   "
1540 INPUT X1,X2,Y1,Y2
1550 PRINT "X-AXIS INTERVAL, Y-AXIS INTERVAL:   "
1560 INPUT X3,Y3
1570 GOSUB 1590
1580 GO TO 2140
1590 PAGE
1600 X$="KILOMETERS - SQUARED"
1610 Y$="SECONDS | SQUARED"
1620 WINDOW X1,X2,Y1,Y2
1630 VIEWPORT 8.95,128.21,8.46,100
1640 AXIS X3,Y3
1650 MOVE X1+(X2-X1)/10,Y2
1660 PRINT "J";A$;
1670 MOVE (X1+X2)/2,Y1
1680 FOR I=1 TO LEN(X$)/2
1690 PRINT "H";
1700 NEXT I
1710 PRINT "JJJ";X$;
1720 FOR I=X1 TO X2 STEP X3
1730 MOVE I,Y1
1740 PRINT "HJ";I;
1750 NEXT I
1760 MOVE X1,(Y2+Y1)/2
1770 PRINT "HHHHH";
1780 FOR I=1 TO LEN(Y$)/2
1790 PRINT "K";
```

```
1800 NEXT I
1810 FOR I=1 TO LEN(Y$)
1820 Z$=SEG(Y$,I,1)
1830 PRINT Z$;"HJ";
1840 NEXT I
1850 FOR I=Y1 TO Y2 STEP Y3
1860 MOVE X1,I
1870 PRINT "HHH";I;
1880 NEXT I
1890 REM PLOT DATA POINTS
1900 FOR I=1 TO N1
1910 IF N(I)<=0 THEN 2100
1920 FOR J=1 TO N3
1930 D2=((D(J)+D4)*B1)^2
1940 R2=(R(I,J)+R4)^2
1950 IF D(J)<0 THEN 2070
1960 IF R(I,J)<=0 THEN 2070
1970 IF D2<X1 THEN 2070
1980 IF D2>X2 THEN 2070
1990 IF R2<Y1 THEN 2070
2000 IF R2>Y2 THEN 2070
2010 X4=0.02*D2
2020 Y4=0.02*R2
2030 MOVE D2,R2+Y4
2040 RDRAW 0,-2*Y4
2050 MOVE D2+X4,R2
2060 RDRAW -2*X4,0
2070 NEXT J
2080 MOVE E3(I),T2(I)+E3(I)*T1(I)
2090 DRAW 0,T2(I)
2100 NEXT I
2110 PRINT "*"
2120 PRINT USING "36(""J"")";
2130 RETURN
2140 END
```

```
1 REM      SLODIGIT      SUBROUTINE EDIT
2 GO TO 100
24 REM DELETE/REINSERT A LAYER
25 GOSUB 340
26 RETURN
28 REM DELETE/REINSERT A TRACE
29 GOSUB 460
30 RETURN
32 REM EDIT POINTS
33 GOSUB 800
34 RETURN
36 REM  PRINT OUT TABLE OF RESIDUAL VALUES
37 GOSUB 560
38 RETURN
40 REM  LIST OF SLOWI FORMATTED OUTPUT TO SCREEN
41 GOSUB 1150
42 RETURN
44 REM  RETURN TO X2-T2
45 FIND 4
46 CALL "LINK",130
47 RETURN
48 REM  RETURN TO HYDROPHONE DELAY RELEASE CORRECTION
49 FIND 3
50 CALL "LINK",1
51 RETURN
80 REM  SLOWI FORMATTED OUTPUT TO TAPE
81 GOSUB 1380
82 RETURN
100 PRINT "L                         EDITOR"
110 PRINT "___PRESENTLY, THE EDITOR PERFORMS THE FOLLOWING FUNCTIONS,"
120 PRINT "WHICH ARE CALLED BY THE USER DEFINABLE KEYS:"
130 PRINT "__      6   REMOVES OR REINSERTS AN ENTIRE LAYER"
140 PRINT "      7   REMOVES OR REINSERTS AN ENTIRE TRACE"
150 PRINT "      8   EDITS INDIVIDUAL POINTS "
160 PRINT "      9   PRINTS OUT A TABLE OF RESIDUAL VALUES"
170 PRINT "     10   LISTS SLOWI FORMATTED OUTPUT ON THE SCREEN"
180 PRINT "     20   WRITES SLOWI FORMATTED OUTPUT TO TAPE"
190 PRINT "__TO PERFORM EDITING FUNCTIONS, PRESS THE DESIRED U.D."
200 PRINT "KEY AND FOLLOW THE DIRECTIONS."
210 GOSUB 230
220 END
230 REM  COUNT THE NUMBER OF POINTS PER LAYER FOR EDITING
240 FOR I=1 TO N1
250 K=0
260 FOR J=1 TO N3
270 IF D(J)<0 THEN 300
280 IF P(I,J)<=0 THEN 300
290 K=K+1
300 NEXT J
310 N(I)=SGN(N(I))*K
320 NEXT I
330 RETURN
340 PRINT "LNUMBER OF POINTS PER LAYER:__"
350 PRINT N;
360 PRINT "__A NEGATIVE NUMBER DELETES THAT LAYER FROM THE CALCULATION"
370 PRINT "_WHICH LAYER DO YOU WISH TO DELETE OR INSERT?"
380 INPUT I
390 N(I)=-N(I)
400 PRINT N;
410 PRINT "__ANOTHER LAYER?"
```

```
420 INPUT Q$
430 IF Q$="Y" THEN 370
440 IF Q$<>"N" THEN 410
450 RETURN
460 PRINT USING """LDIRECT TIMES FOR EACH TRACE__""4(10(3D.3D)/)":D
470 PRINT "__WHICH TRACE DO YOU WISH TO DELETE OR REINSERT?"
480 INPUT I
490 D(I)=-D(I)
500 PRINT USING "4(10(3D.3D)/)":D
510 PRINT "__ANOTHER TRACE?"
520 INPUT Q$
530 IF Q$="Y" THEN 470
540 GOSUB 230
550 RETURN
560 REM ROUTINE TO PRODUCE RESIDUAL TABLE AND EDIT POINTS
570 PRINT "L            TABLE OF RESIDUAL VALUES      (X10**-3 sec^2)"
580 PRINT "_T                          LAYER"
590 PRINT USING """_      1     2     3     4     5     6     7""S":
600 PRINT USING """     8     9    10    11    12    13    14""":
610 REM CALCULATE RESIDUALS
620 FOR J=1 TO N3
630 PRINT USING "/2DS":J
640 IF D(J)<0 THEN 750
650 FOR I=1 TO N1
660 IF R(I,J)<=0 THEN 730
670 R2=(R(I,J)+B4)^2
680 D2=((D(J)+B4)+B1)^2
690 R4=R2-(T2(I)+D2*T1(I))
700 R4=SGN(R4)*INT(ABS(R4*1000))
710 PRINT USING "5DS":R4
720 GO TO 740
730 PRINT USING "7XS":
740 NEXT I
750 NEXT J
760 FOR I=1 TO 30-N3+1
770 PRINT
780 NEXT I
790 RETURN
800 PRINT "LYOU CAN EDIT POINTS ACCORDING TO TRACE NUMBER AND LAYER"
810 PRINT "TYPE THE LAYER NUMBER, TRACE NUMBER AND THE LETTER:"
820 PRINT "           D - DELETE A BAD POINT"
830 PRINT "           R - REPICK A POINT"
840 PRINT "           I - INSERT A PREVIOUSLY DELETED POINT"
850 PRINT "           Q - QUIT EDITING"
860 PRINT "__LAYER,TRACE,ACTION"
870 INPUT I,J,Q$
880 IF Q$="Q" THEN 1130
890 IF Q$="D" THEN 920
900 IF Q$="I" THEN 940
910 IF Q$="R" THEN 960
920 GOSUB 980
930 GO TO 860
940 GOSUB 1030
950 GO TO 860
960 GOSUB 1110
970 GO TO 860
980 IF R(I,J)<=0 THEN 1010
990 R(I,J)=-R(I,J)
1000 RETURN
1010 PRINT "_THAT POINT HAS ALREADY BEEN DELETED!GG"
```

```
1020 RETURN
1030 IF R(I,J)>0 THEN 1090
1040 IF R(I,J)=0 THEN 1070
1050 R(I,J)=-R(I,J)
1060 RETURN
1070 PRINT "_NO PICK WAS EVER MADE FOR THAT POINT!GG"
1080 RETURN
1090 PRINT "_THAT POINT HAS NEVER BEEN DELETED!GG"
1100 RETURN
1110 PRINT "___THIS OPTION HAS NOT BEEN MADE AVAILABLE YET!GGG"
1120 RETURN
1130 GOSUB 230
1140 RETURN
1150 REM SECTION TO WRITE SLOWI FORMATTED OUTPUT TO TAPE AND SCREEN
1160 PRINT USING "P40A/40A/":B$,A$
1170 PRINT USING 1180:B6,B7,B1,B4,B2
1180 IMAGE  7D.,2(3D.4D),"  1.0000",4D.3D,7D.
1190 PRINT "   0   0   1   1   1"
1200 FOR I=1 TO N1
1210 PRINT USING "4DS":N(I)
1220 NEXT I
1230 PRINT
1240 FOR I=1 TO N1
1250 IF N(I)>0 THEN 1270
1260 I=I+1
1270 PRINT "_"
1280 FOR J=1 TO N3
1290 IF D(J)<0 THEN 1320
1300 IF R(I,J)<=0 THEN 1320
1310 PRINT USING "2(4D.3D)S":D(J),R(I,J)
1320 NEXT J
1330 NEXT I
1340 PRINT "___DO YOU WISH TO WRITE THIS DATA SET ONTO A TAPE FILE?"
1350 INPUT Q$
1360 IF Q$="N" THEN 1880
1370 IF Q$<>"Y" THEN 1340
1380 PRINT "_WHICH FILE DO YOU WISH TO WRITE TO?"
1390 PRINT "   (IF YOU ARE IN DOUBT AS TO WHICH FILE IS FREE,"
1400 PRINT "    TYPE 999 TO DO A TLIST, WHICH WILL INDICATE"
1410 PRINT "    THE FIRST AVAILABLE FILE)"
1420 INPUT I
1430 IF I<>999 THEN 1550
1440 IF I<=255 THEN 1470
1450 PRINT "FILE NUMBER IS TOO LARGE !!GGGGGGGGGGGGG"
1460 GO TO 1380
1470 PAGE
1480 FOR I=1 TO 200
1490 FIND @1,27:I
1500 INPUT @1,9:H$
1510 PRINT H$
1520 NEXT I
1530 PRINT "WHICH FILE DO YOU WISH TO WRITE TO?"
1540 INPUT I
1550 IF I<=255 THEN 1580
1560 PRINT "FILE NUMBER IS TOO LARGE !!GGGGGGGGGG"
1570 GO TO 1530
1580 PRINT "__IS THE FILE YOU ARE WRITING TO ALREADY MARKED?"
1590 INPUT Q$
1600 IF Q$="Y" THEN 1640
1610 IF Q$<>"N" THEN 1580
```

```
1620 FIND @1,27:I
1630 MARK @1,28:1,7000
1640 FIND @1,27:I
1650 PRINT @1,12: USING "40A/40A ":B$,A$
1660 PRINT @1,12: USING 1180:B6,B7,B1,B4,B2
1670 PRINT @1,12:"   0    0    1    1    1"
1680 FOR I=1 TO N1
1690 IF N(I)<=0 THEN 1710
1700 PRINT @1,12: USING "4DS":N(I)
1710 NEXT I
1720 PRINT @1,12:
1730 FOR I=1 TO N1
1740 IF N(I)<=0 THEN 1860
1750 PRINT @1,12:
1760 K=1
1770 FOR J=1 TO N3
1780 IF D(J)<0 THEN 1850
1790 IF R(I,J)<=0 THEN 1850
1800 PRINT @1,12: USING "2(4D.3D)S":D(J),R(I,J)
1810 IF K-INT(K/5)*5<>0 THEN 1840
1820 IF K=N(I) THEN 1850
1830 PRINT @1,12:
1840 K=K+1
1850 NEXT J
1860 NEXT I
1865 PRINT @1,12:"   1"
1870 PRINT @1,2:
1880 END
```

```
1 REM      SLODIGIT      SUBROUTINE DUMP/RECOVER FROM TAPE
2 GO TO 500
44 REM      GO TO X2-T2
45 FIND 3
46 CALL "LINK",100
47 RETURN
48 REM      LINK TO DELAYED HYDROPHONE RELEASE CORRECTION
49 FIND 2
50 CALL "LINK",1
51 RETURN
100 REM  THIS SUBROUTINE DUMPS THE DATA FROM THE DIGITIZING
110 REM  SECTION OF THE PROGRAM ONTO TAPE, IN MACHINE DEP-
120 REM  ENDENT BINARY FORM.  THE RECYCLE KEY WILL READ
130 REM  THIS SAME DATA FROM THE TAPE AND DEPOSIT YOU BACK
140 REM  IN PART 1, AS THOUGH YOU HAD JUST FINISHED DIGIT-
150 REM  IZING A RECORD.  YOU CAN THAN CONTINUE AS YOU NOR-
160 REM  MALLY WOULD.
170 PRINT "LCHECK TO INSURE THAT THE 4924 IS TURNED ON AND"
180 PRINT "THAT YOUR TAPE CARTRIDGE IS WRITE ENABLED"
190 PRINT "__INSERT YOUR TAPE IN THE 4924"
200 PRINT "_WHICH TAPE FILE DO YOU WISH TO WRITE TO?"
210 INPUT I
220 PRINT "_IS THE FILE YOU ARE WRITING TO ALREADY MARKED?"
230 INPUT Q$
240 IF Q$="Y" THEN 280
250 IF Q$<>"N" THEN 220
260 FIND @1,27:I
270 MARK @1,28:1,1000+9*(N1+N3+N1*N3)
280 FIND @1,27:I
290 WRITE @1,15:A$,B$,B1,B2,B3,B4,B5,B6,B7,B8,N1,N3,Q1,C1,C3,C6,D,R
300 IF Q1<>1 THEN 320
310 WRITE @1,15:P1,P2,P3
315 PRINT @1,2:
320 GO TO 1000
500 REM  THIS IS THE RECYCLE SUBROUTINE, WHICH WILL READ
510 REM  DATA DUMPED ONTO TAPE, AND THEN DEPOSIT YOU AT
520 REM  THE END OF PART 1, AS THOUGH YOU HAD JUST
530 REM  FINISHED DIGITIZING A RECORD.
540 PRINT "LCHECK TO INSURE THAT THE 4924 IS TURNED ON"
550 PRINT "AND THAT YOUR TAPE IS WRITE PROTECTED."
560 PRINT "__INSERT DATA TAPE"
570 PRINT "___ WHICH TAPE FILE DO YOU WISH TO READ FROM?"
580 INPUT I
590 FIND @1,27:I
595 DIM A$(40),B$(40),Z$(1),Q$(1)
600 READ @1,14:A$,B$,B1,B2,B3,B4,B5,B6,B7,B8,N1,N3,Q1,C1,C3
610 DIM C6(N1),D(40),R(N1,40)
620 READ @1,14:C6,D,R
630 IF Q1<>1 THEN 650
640 READ @1,14:P1,P2,P3
650 FIND 2
660 CALL "LINK",1870
1000 END
```

Appendix K

Listings of reduction programs

This appendix contains line numbered listings of SLOWI and LINFT. The absolute pathnames for these programs are:

>udd>Marine>JChilds>sonobuoy>slowi.fortran
>udd>Marine>JChilds>sonobuoy>linft.fortran

The introductory comments prefacing the program listings describe the input required. All input is from file05 and all output is targeted for file06. Therefore, file attaches must be made to these files before executing the programs. Both programs have been modified to run on Honeywell 60 series computer under Multics., and are compiled with Honeywell Multics fortran (release 4). The pathnames of the object segments are:

>udd>Marine>JChilds>sonobuoy>slowi
>udd>Marine>JChilds>sonobuoy>linft

Program SLOWI consists of a main program and three subroutines. The main program and subroutines are numbered sequentially, but the subroutines are set off on separate pages.

```
c      PROGRAM LINT
c DATE 27 JANUARY 1976
c REVISED FOR USGS (MENLO PARK, OFFICE OF MARINE GEOLOGY)
c BY J. CHILDS AND A COOPER
c AUTH: HOSKINS
c LINT - PROGRAM FOR FITTING LINE TO RANGE SQUARED - TRAVEL TIME
c  SQUARED PLOT OF OBLIQUE REFLECTION ARRIVALS, OR RANGE - TRAVEL
c  TIME PLOT OF REFRACTION ARRIVALS
c
c HANDLES AS MANY AS FIFTEEN TRACES DELINEATED BY UP TO SEVENTY-
c  FIVE POINTS EACH.
c ANGLE OF SEAFLOOR INCIDENCE COMPUTATION ASSUMES FIRST TRAVEL
c  TIME VALUE IS NORMAL INCIDENCE.
c
c   INPUT REQUIRED:
c     Card 1
c          IANOT - date and time of run or sonobuoy             FORMAT(10A4)
c     Card 2
c          CRUISE - label of cruise, sonobuoy number, etc.      FORMAT(10A4)
c     Card 3                                                     FORMAT(3F8.4,F8.3)
c          VLINT - mean vertical sound velocity in water
c          VH - horizontal sound velocity in water
c          SCALE - scale factor in inches/second. (SCALE =
c                  1.0000 if all input values are in seconds)
c          DELTA - time zero correction in seconds
c     Card 4                                                     FORMAT(4I4)
c          ISSW0,ISSW1,ISSW2,ISSW3
c
c          The ISSW variables allow for various options to be
c          specified within the program.  The value of each
c          variable is set to either 0 or 1, depending upon
c          whether the option is desired or not.  The following
c          options are available:
c
c          ISSW0 - specifies type of data initially
c                = 1  refractions
c                = 0  reflections
c          ISSW1 = 1  omits data listing
c                = 0  lists input data
c          ISSW2 - specifies input units for XDATA(I) (range).
c                = 1  distances are true ranges (in kilometers)
c                = 0  distance is direct water wave travel time
c          ISSW3 = 1  skips slope corrections
c                = 0 corrects for slope
c
c     Card 5                                                     FORMAT(15I4)
c          N(I) - number of points per layer.  If negative,
c                 will cause the program to skip that layer.
c     Card 6 (and 7, if more than 10 layers)                     FORMAT(10F7.3)
c          SLOP(I) - incremental slopes of layers in degrees.
c                    Slope of layer with respect to the layer
c                    above.  (e.g. if two successive layers
c                    have equal absolute slope, alpha, than
c                    SLOP(1) = alpha,  SLOP(2) = 0.0
c                    Slope downward in the direction of travel is
c                    is negative.
c     Card 8    (included for refraction data sets only)         FORMAT(F7.4)
c            AVELO - average velocity above shallowest refractor
c     Card 9 - end                                               FORMAT(10F8.3)
c            Data: XDATA(I),YDATA(I) - pairs of ranges (in
```

```
c                   seconds or kilometers; see ISSW2 below)
c                   and travel times (in seconds).
c      Final card                                                     FORMAT(I4)
c           ICHECK - card signalling end of data set
c                   = 0  no additional data sets follow
c                   = -1 reflection data set follows
c                   = +1 refraction data set follows
c
c      THIS PROGRAM WILL DO ANY NUMBER OF DATA SETS,
c    WITH ANY COMBINATION OF REFLECTION AND REFRACTION
c    PROFILES.  AFTER EACH DATA SET, A CHECK CARD (ICHECK)
c    MUST BE INSERTED.  THE VALUE OF ICHECK SHOULD BE CON-
c    TAINED IN THE FIRST TEN COLUMNS OF THE CARD, AND
c    WILL DEPEND UPON WHAT DATA FOLLOWS.  IF THERE IS
c    NO SUBSEQUENT DATA, ICHECK SHOULD BE ZERO OR NULL;
c    IF THE FOLLOWING DATA IS ANOTHER REFLECTION SET,
c    ICHECK SHOULD BE NEGATIVE; AND IF THE FOLLOWING DATA
c    IS OF A REFRACTION, ICHECK SHOULD BE POSITIVE.
c    EACH DATA SET REQUIRES ALL INPUT DATA (DATE,
c    CRUISE, PARAMETERS, ETC) UNLESS IT IS A REFRAC-
c    TION FOLLOWING A REFLECTION SET FROM THE SAME RECORD.
c    (WE ASSUME THAT THERE WILL BE NO REFLECTION DATA
c    FOLLOWED IMMEDIATELY BY REFRACTION DATA FROM A DIF-
c    FERENT RECORD.  ARRANGE THE DATA SETS SO THAT THE
c    REFRACTION WOULD COME FIRST, OR WOULD FOLLOW THE
c    REFRACTION DATA FROM ANOTHER RECORD.  WITH REFLECTIONS
c    AND REFRACTIONS FROM THE SAME RECORD, ALWAYS PUT THE
c    REFLECTIONS FIRST)
c
c
c      Example input refraction data set
c
c     1 APRIL 1978
c     SONOBUOY TEST B
c    1.500   1.490   1.000   -0.025
c    1   0   0   0
c    5   5   4   6
c  0.000  0.100 -0.100  0.000
c 1.500
c    2.020   2.775   4.020   4.638   6.020   6.500   8.020   8.363  10.020  10.225
c    4.790   5.612   5.617   6.126   6.740   6.830   7.215   7.138   7.695   7.449
c    4.790   5.568   5.617   5.998   6.740   6.580   7.215   6.840
c    6.740   6.619   7.215   6.826   7.695   7.020   8.000   7.150   8.540   7.390
c    8.779   7.494
c    0
c
c
c
c
          dimension ianot(10),n(18),xval(75),yval(75),res(75),
           xxval(75),yyval(75),xdata(75),ydata(75),vlave(16),ortim(15),
           depth(16),angle(75),slop(15),alph(15),beta(15),reslo(15),
           hight(15),cruise(10)
c      FORTRAN STATEMENT FUNCTION NECESSARY FOR MULTICS.
          arsin(x) = atan(x/sqrt(1-x**2))
          iin=5
          iout=6
          angle(1)=0.
1         j=0
          kkk=1
```

```
            factr=1.0
            scale=1.
            delta=0.
            write(iout,1000)
1000        format("1","    PROGRAM LINEAR FIT",/8x," 2 DECEMBER 1976",/)
c
c ENTER PARAMETERS
            write(iout,1001)
1001        format(" ")
            read(iin,1002) ianot
1002        format(10a4)
            write(iout,2007) ianot
2007        format(" ",10a4)
            write(iout,1003) ianot
1003        format(" ",95x,10a4)
            read(iin,2008) cruise
            write(iout,1004) cruise,cruise
2008        format (10a4)
1004        format(" ",10a4,55x,10a4)
            read(iin,2001) vlint,vh,scale,delta
2001        format(3f8.4,f8.3)
            write(iout,1020) vlint,vh,scale,delta
1020        format("  MEAN VERT SOUND VEL=",f7.4,3x,"HORIZONTAL SOUND ",
             "VEL=",f7.4,/"  INCH/SEC=",f7.4,3x,"TIME ZERO CORR=",
             f7.3)
            scal1=scale
            scal2=scale
14          do 15 i=1,15
            depth(i)=0.
            vlave(i)=0.
            ortim(i)=0.
            slop(i)=0
15          n(i)=0
            n(16)=0
            n(17)=0
            n(18)=0
            read(iin,900) issw0,issw1,issw2,issw3
900         format(4i4)
            write(iout,901) issw0,issw1,issw2,issw3
901         format(" ISSW0=",i2,"    ISSW1=",i2,"    ISSW2=",i2,"    ISSW3=",i2)
            write(iout,1005)
1005        format("  NUMBER OF POINTS EACH LAYER")
            read(iin,1021) (n(i),i=1,15)
            nref=0
c COUNT NUMBER OF LAYERS
            do 44 i=1,15
            if(n(i)) 45,44,45
45          nref=nref+1
44          continue
            write(iout,1021) (n(i),i=1,nref)
1021        format(15i4)
            write(iout,1023)
1023        format("  INCREMENTAL LAYER SLOPES")
            read(iin,1024) (slop(i),i=1,nref)
            write(iout,1024) (slop(i),i=1,nref)
1024        format(10f7.3)
            do 61 i=1,nref
61          slop(i)=slop(i)/57.29578
c CONVERT INCREMENTAL SLOPES TO ABSOLUTE SLOPES
            do 67 i=2,nref
```

```
67        slop(i)=slop(i)+slop(i-1)
c CHECK IF INPUTS ARE REASONABLE OR WITHIN DIMENSIONED ARRAYS
          do 86 i=1,15
          if(n(i).gt.75) write(iout,1030)
86        if(abs(slop(i)).gt.0.35) write(iout,1030)
          if(vlint.gt.1.6.or.vlint.lt.1.4) write(iout,1030)
          if(vh.gt.1.6.or.vh.lt.1.4) write(iout,1030)
          if(abs(scale).gt.6.) write(iout,1030)
          if(abs(delta).gt.5.) write(iout,1030)
1030      format("  INPUT VALUE OFF SCALE")
          if(issw0.eq.0) go to 19
          read(iin,2002) avelo
2002      format(f7.4)
          if(avelo.lt. 1.4) avelo=vlint
          write(iout,1011) avelo
1011      format(/"  AVERAGE VELOCITY ABOVE SHALLOWEST REFRACTION=",f7.4)
c READ DATA POINTS
19        j=j+1
84        layer=n(j)
          if(layer) 80,2,3
c SKIP OVER SPECIFIED DATA POINTS
80        ikj=(-layer)
          read(iin,2003) (xdata(i),ydata(i),i=1,ikj)
2003      format(10f8.3)
          ikj=(nref+3)
          do 82 i=j,ikj
82        n(i)=n(i+1)
          nref=nref-1
          go to 84
3         if(issw1.ne.0) go to 42
43        write(iout,1006)
1006      format(/"   DDATA   TDATA     KM     SEC     DVAL",
           "    TVAL    RES  ANG INC")
42        write(iout,1007) j
1007      format("  LAYER ",i2)
          read(iin,2003) (xdata(i),ydata(i),i=1,layer)
          do 10 i=1,layer
          xxval(i)=(xdata(i)+delta)*factr/scal1
          yyval(i)=(ydata(i)+delta)/scal2
c OPTION TO USE RANGES RATHER THAN DIRECT WATER WAVE TT
          if(issw2.ne.0) go to 5
4         xxval(i)=xxval(i)*vh
c OPTION TO OMIT SLOPE CORRECTION
5         if(issw3.ne.0 .or. issw0.ne.0) go to 55
62        xxval(i)=xxval(i)-yyval(1)*vlint*sin(slop(j))
55        xval(i)=xxval(i)
          yval(i)=yyval(i)
c SET NEGATIVE RANGES TO ZERO
          if(xval(i).lt.0.) xval(i)=0.
          if(issw0.ne.0) go to 10
c SQUARE VALUES FOR OBLIQUE REFLECTION TRACES
8         xval(i)=xval(i)*xval(i)
          yval(i)=yval(i)*yval(i)
10        continue
c
c FIT LEAST SQUARES LINE
c  SUM T SQUARES
27        sumt2=0.
          do 20 i=1,layer
20        sumt2=sumt2+yval(i)
```

```
c  SUM D SQUARES
           sumd2=0.
           do 21 i=1,layer
21         sumd2=sumd2+xval(i)
c  SUM D2 SQUARES
           sumd4=0.
           do 22 i=1,layer
22         sumd4=sumd4+xval(i)*xval(i)
c  SUM D2T2
           sd2t2=0.
           do 23 i=1,layer
23         sd2t2=sd2t2+xval(i)*yval(i)
c
           a=(float(layer)*sd2t2-sumd2*sumt2)/(float(layer)*sumd4%
            -sumd2*sumd2)
           b=(sumd4*sumt2-sumd2*sd2t2)/(float(layer)*sumd4%
            -sumd2*sumd2)
           if(issw0.ne.0) go to 9
11         vlave(j)=sqrt(abs(1./a))
           ortim(j)=sqrt(abs(b))
           depth(j)=vlave(j)*ortim(j)/2.
           if(kkk-1) 26,12,26
c BECAUSE DIRECT WATER WAVE MAY BE DIFFICULT TO DETERMINE AT RANGE
c  CORRECTION IS APPLIED TO RANGES SO TO MAKE MEAN VERTICAL VELOCITY
c  AGREE WITH MATTHEWS TABLES.
12         factr=vlint/vlave(1)
           vhh=vh*factr
           kkk=0
           write(iout,1009) factr,vhh,vh
1009       format("  FACTOR=",f7.3,3x,"VH APPARENT=",f7.4,3x,
           "VH SUPPLIED=",f7.3)
           do 24 i=1,layer
           xxval(i)=xxval(i)*factr
24         xval(i)=xval(i)*factr*factr
           go to 27
c
9          vlave(j)=1./a
           ortim(j)=b
c MINIMUM DEPTH FOR REFRACTING SURFACE - ASSUMES FLATNESS AND
c  OVERBURDEN TO BE ALL WATER.
           if(1.5*a-1.) 31,32,32
32         depth(j)=0.
           go to 26
31         depth(j)=(0.75*b*sqrt(1.-(1.5*a)**2.))/(1.-2.25*a**2.)
c
c FIND DEVIATIONS FROM BEST FITTING LINE
c POSITIVE RESIDUE MEANS DATA POINT GREATER (DEEPER) THAN FITTED LINE
26         do 33 i=1,layer
33         res(i)=yval(i)-(a*xval(i)+b)
c
c DETERMINE ANGLE OF INCIDENCE ON SEAFLOOR FOR FIRST TRACE
           if(j.ne.1.or.issw0.ne.0) go to 52
           do 57 i=2,layer
           cosag=yyval(1)/yyval(i)
57         angle(i)=arcos(cosag)*57.29578
c
c LIST DATA AND COMPUTED POINTS
52         if(issw1.ne.0) go to 47
58         do 49 i=1,layer
           if(issw0.ne.0.or.i.eq.1.or.j.gt.1) go to 54
```

```
c FOR REFLECTIONS, FLAG DEVIATIONS > 0.3 SEC2.  FOR REFRACTIONS, FLAG
c  DEVIATIONS > 0.015 SEC.
            if(res(i).lt.-0.3) write(iout,1025) xdata(i),ydata(i),xxval(i),
             yyval(i),xval(i),yval(i),res(i),angle(i)
            if(res(i).gt.0.3) write(iout,1026) xdata(i),ydata(i),xxval(i),
             yyval(i),xval(i),yval(i),res(i),angle(i)
            if(abs(res(i)).gt.0.3) go to 49
            write(iout,1008) xdata(i),ydata(i),xxval(i),yyval(i),
             xval(i),yval(i),res(i),angle(i)
            go to 49
54          if(res(i).lt.-0.3.and.issw0.eq.0) write(iout,1025) xdata(i),
             ydata(i),xxval(i),yyval(i),xval(i),yval(i),res(i)
            if(res(i).gt.0.3.and.issw0.eq.0) write(iout,1026) xdata(i),
             ydata(i),xxval(i),yyval(i),xval(i),yval(i),res(i)
            if(abs(res(i)).gt.0.3.and.issw0.eq.0) go to 49
            if(res(i).lt.-0.015.and.issw0.ne.0) write(iout,1025) xdata(i),
             ydata(i),xxval(i),yyval(i),xval(i),yval(i),res(i)
            if(res(i).gt.0.015.and.issw0.ne.0) write(iout,1026) xdata(i),
             ydata(i),xxval(i),yyval(i),xval(i),yval(i),res(i)
            if(abs(res(i)).gt.0.015.and.issw0.ne.0) go to 49
            write(iout,1008) xdata(i),ydata(i),xxval(i),yyval(i),
             xval(i),yval(i),res(i)
49          continue
1025        format(7f8.3,"<",f6.1)
1026        format(7f8.3,">",f6.1)
1008        format(7f8.3,f7.1)
47          write(iout,1015) a,b,j,vlave(j),j,ortim(j),j,depth(j)
1015        format("E A=",f6.4,2x,"B=",f7.3,2x,"VLAVE(",i1,")=",f7.3,2x,
             "ORTIM(",i1,")=",f7.3,2x,"DEPTH(",i1,")=",f6.3)
            go to 19
c
2           if(issw0.ne.0) go to 29
c COMPUTE INTERVAL VELOCITIES AND THICKNESSES
28          j=j-1
            write(iout,1017)
1017        format(/"  LAYER DEPTH THICK  VELOCITY  TT INC  REFL TT")
            write(iout,1018) depth(1),vlave(1),ortim(1)
1018        format(4x,"1",f8.3,9x,f6.3,9x,f9.3)
            do 41 i=2,j
            thick=depth(i)-depth(i-1)
            deltt=ortim(i)-ortim(i-1)
            vint=(thick*2.)/deltt
41          write(iout,1012) i,depth(i),thick,vint,deltt,ortim(i)
1012        format(i5,f8.3,f6.3,3f9.3)
            write(iout,1016)
1016        format(/"  EOJ - REFLECTIONS"//)
            read(iin,2000) icheck
2000        format(i10)
            if(icheck) 1,7000,2004
2004        issw0=-1
            j=0
            go to 14
c
c SORT REFRACTION INTERCEPTS BY DEPTH
29          if (nref.eq.1)  go to 87
            nn=nref-1
            do 70 i=1,nn
            j=i+1
            do 70 k=j,nref
            if(ortim(k)-ortim(i)) 71,71,70
```

```
71      vlav=vlave(i)
        vlave(i)=vlave(k)
        vlave(k)=vlav
        rotim=ortim(i)
        ortim(i)=ortim(k)
        ortim(k)=rotim
        dip=slop(i)
        slop(i)=slop(k)
        slop(k)=dip
70      continue
c DELETE VELOCITY INVERSIONS
        j=2
        nn=nref
        do 74 i=2,nn
        if(vlave(j)-vlave(j-1)) 75,75,74
75      nref=nref-1
        do 76 k=j,nn
        vlave(k)=vlave(k+1)
        ortim(k)=ortim(k+1)
76      slop(k)=slop(k+1)
        j=j-1
74      j=j+1
c SLOPE CORRECTED VELOCITY AND THICKNESS COMPUTATION AFTER C.OFFICER
c  TRAVEL TIME INCREMENTS DETERMINED FROM VELOCITY OF LAYER ABOVE
87      do 88 ijk=1,nref
              ikj=ijk-1
              j=nref-ikj
88            vlave(j+1)=vlave(j)
        vlave(1)=avelo
        depth(1)=0.
        reslo(1)=slop(1)
        do 89 i=2,nref
89      reslo(i)=slop(i)-slop(i-1)
c
        write(iout,1011) avelo
        write(iout,1013)
1013    format(/"  LAYER  INTCPT  DEPTH  THICK  VELOCITY  TT INC  SLOPE")
        do 90 j=1,nref
        heit=0.
        alph(1)=arsin(avelo/vlave(j+1))+reslo(1)
        if(j.eq.1) go to 92
        do 91 k=2,j
        anga=sin(alph(k-1))*vlave(k)/vlave(k-1)
91      alph(k)=arsin(anga)+reslo(k)
92      vlave(j+1)=vlave(j)/sin(alph(j))
        if (j.eq.1) go to 95
        beta(j)=alph(j)
        jki=(j-1)
        do 93 ijk=1,jki
              ikj=ijk-1
              k=j-ikj
              angb=sin(beta(k)+reslo(k))*vlave(k-1)/vlave(k)
93            beta(k-1)=arsin(angb)
        ikj=(j-1)
        do 94 k=1,ikj
        angc=cos(alph(k))+cos(beta(k))
94      heit=heit+(angc*hight(k)/vlave(k))
95      rtime=ortim(j)-heit
        hight(j)=0.5*vlave(j)*rtime/cos(alph(j))
        deltt=2.0*hight(j)/vlave(j)
```

```
      depth(j+1)=hight(j)+depth(j)
      slope=reslo(j)*57.2958
90    write(iout,1027) j,ortim(j),depth(j+1),hight(j),vlave(j+1),
       deltt,slope
1027  format(3x,i2,f10.3,f7.3,f7.3,f9.3,f9.3,f7.3)
      write(iout,1010)
1010  format(/"  EOJ - REFRACTIONS")
      read(iin,2000) icheck
      if (icheck) 2005,7000,1
2005  continue
      issw0=0
      go to 1
7000  stop
      end
```

```
c     PROGRAM  SLOWI
c DATE: JANUARY 1976
c AUTH: LE PICHON / HOSKINS
c THIS PROGRAM HAS BEEN MODIFIED TO RUN ON THE MULTICS
c SYSTEM AT USGS, MENLO PARK.
c PROGRAM TO SOLVE SLOPING WIDE ANGLE REFLECTION PROFILES BY
c  REDUCING EACH LAYER TO INDIVIDUAL FLAT LAYER AND THEN
c  FITTING DATA USING X2-T2.  FINDS RAY EMERGENCE ANGLE
c  BY DERIVATION OF FOURTH ORDER POLYNOMIAL FITTED TO
c  DATA.  USES EMERGENCE ANGLE TO COMPUTE THEORETICAL
c  TRAVEL TIME.
c  HANDLES AS MANY AS FIFTEEN LAYERS AND SEVENTY-FIVE
c  POINTS PER LAYER.
c  USES SUBROUTINES MAIND, KAUS AND CRNGE
c  XAVIER LE PICHON   REVISED MARCH 17 1967
c
c     INPUT REQUIRED:
c     Card 1                                                     FORMAT(10A4)
c          DATE - date and time of run or sonobuoy
c     Card 2                                                     FORMAT(10A4)
c          CRUISE - label of cruise, sonobuoy number, etc.
c     Card 3                                                     FORMAT(F8.0,3F8.4,F8.3,F8.0)
c          DPWTR - water depth in uncorrected meters from
c                  echo sounder
c          VV  - mean vertical sound velocity from Matthew's
c                Tables, in km/sec
c          VH  - horizontal sound velocity measured from
c                velocimeter, in km/sec
c          SCALE - scale factor in inches/second.  (SCALE =
c                  1.0000 if all input values are in seconds.)
c          DELTA - time zero correction in seconds
c          DEPLOY - hydrophone deployment depth, in feet.
c                   (generally, 60, 120 or 240 feet)
c     Card 4                                                     FORMAT(5I4)
c          ISSW0, ISSW1, ISSW2, ISSW12, ISSW13
c
c
c     The ISSW variables allow for various options within
c     the program.  The value of each variable is set to
c     either 0 or 1, depending upon whether the option  is
c     desired or not.  The following options are available:
c
c          ISSW0 = 0  omits input data lists
c                = 1  lists input data
c          ISSW1 = 0  omits subroutine MAIND listing of reduced
c                     ranges and travel times
c                = 1  lists subroutine MAIND results
c          ISSW2 = 0  omits correction to echo sounding depth
c                = 1  allows correction to echo sounding ddepth
c          ISSW12 = 0  punches out ranges, travel times and
c                     emergence angles
c                = 1  suppresses punch
c          ISSW13 = 0  prints out ranges, travel times and
c                     emergence angles
c                 = 1  suppresses printout
c
c
c     Card 5                                                     FORMAT(15I4)
c          N(I) - number of points per layer.  If negative,
c                 will cause the program to skip that layer.
```

```
c     Card 6 (and 7, if more than 10 layers)                      FORMAT(10D8.3)
c          SLOP(I) - incremental slopes of layers  in degrees.
c                    Slope of layer with respect to the layer
c                    above  (e.g. if two successive layers
c                    have equal absolute slope, alpha, than
c                    SLOP(1) = alpha,  SLOP(2) = 0.0
c                    Slope downward in the direction of travel
c                    is negative.
c     Card 8 - end                                                FORMAT(10D8.3)
c          Data:  DIR(I,J);TT(I,J) - pairs of direct and
c                reflected two way travel times, in seconds,
c                for each horizon traced.
c     Final card                                                  FORMAT(I4)
c          ICHECK - card signalling end of data set
c                 = 0  no additional data set follows
c                 ^= 0 additional data set follows
c
c
c          Example data set:
c
c   1 APRIL 1978
c  SONOBUOY TEST A
c   3755.  1.5000  1.4870  1.0000  -0.000     60.
c   1   1   0   1   1
c  15  15  15  15  15
c   0.000  0.000  0.000  0.000  0.000
c   0.000  5.007  0.265  5.014  0.531  5.034  0.800  5.069  1.074  5.119
c   1.353  5.183  1.641  5.264  1.939  5.363  2.249  5.480  2.573  5.619
c   2.916  5.781  3.280  5.970  3.669  6.189  4.090  6.442  4.547  6.737
c   0.000  6.028  0.192  6.031  0.384  6.039  0.576  6.052  0.770  6.070
c   0.966  6.094  1.164  6.124  1.364  6.159  1.567  6.201  1.774  6.248
c   1.985  6.302  2.200  6.363  2.422  6.431  2.649  6.508  2.884  6.592
c   0.000  7.083  0.217  7.086  0.435  7.093  0.654  7.105  0.874  7.122
c   1.095  7.144  1.319  7.172  1.545  7.204  1.775  7.242  2.009  7.286
c   2.247  7.336  2.490  7.392  2.739  7.455  2.995  7.525  3.260  7.603
c   0.000  8.046  0.216  8.047  0.433  8.052  0.650  8.059  0.869  8.070
c   1.089  8.083  1.311  8.099  1.536  8.119  1.763  8.142  1.994  8.169
c   2.229  8.199  2.469  8.233  2.714  8.271  2.966  8.314  3.225  8.361
c   0.000  9.895  0.400  9.897  0.800  9.901  1.203  9.909  1.608  9.919
c   2.018  9.933  2.434  9.950  2.855  9.971  3.285  9.995  3.724 10.022
c   4.175 10.054  4.639 10.091  5.118 10.132  5.616 10.178  6.135 10.230
c   0
c          (end of sample set)
c
c
c
         dimension to(15),hh(15),v(15),w(15),sw(15),cw(15),
          tw(15),d(75),r(75),zm(75),p(5,6),x(5),ti(75),
          u(75),s(75),thick(15),dii(75),rii(75),dir(15,75),
          tt(15,75),date(10),cruise(10),numb(15),ww(15),sv(15),
          inam(3)
         common to,hh,v,w,tr,dr,sw,cw,tw,d,r,zm,p,c,svn,vh,x,
          tit,m,ind,ko,l,thick,issw1
         double precision c,con,cw,d,delta,depth,dii,dir,dmin,
          dr,dref,factor,hh,p,perce,perc2,r,rii,s,scale,
          scal2,svn,sw,thick,ti,tit,to,tr,tt,tw,u,v,vh,xb,
          vhh,vv,w,wt,ww,x,zm,sv,perc,datan,dsin,dabs,dsqrt,dcos,darsin
         darsin(x)=datan(x/dsqrt(1.0d0-x*x))
         iin=5
         iout=6
```

```
c
c      VALUES REMOVED FROM ORIGINAL INPUT LIST
c           DREF - ALGEBRAIC ADDITIVE CONSTANT APPLIED TO REFLECTED
c                  TRAVEL TIMES TO SHIFT THE REFLECTION TRACES WITH
c                  RESPECT TO THE DIRECT TRACE.
c           FILTR - FILTER RISE TIME CORRECTION (IN SECONDS).  FOR
c                   FURTHER REFERENCE, SEE KNOTT & HOSKINS, P. 52
c           DEPHY - TRAVEL TIME DIFFERENCE BETWEEN SONOBUOY DATUM AND
c                   AND ECHO SOUNDING DATUM (IN SECONDS)
c                 = (HYDROPHONE DEPTH-SOURCE DEPTH)*2/VV
c
1         dref = 0.0d0
          filtr = 0.0
          write(iout,190)
190       format("1"," PROGRAM SLOWI",10x," DECEMBER 1976")
          write(iout,191)
191       format(" ")
          read(iin,192) date
192       format(10a4)
          write(iout,194) date
193       format(" ",95x,10a4)
194       format(" ",10a4)
          read(iin,192) cruise
          write(iout,193) cruise
          write(iout,194) cruise
          read(iin,10) dpwtr,vv,vh,scale,delta,deploy
10        format(f8.0,3f8.4,f8.3,f8.0)
          vhh=vh
          perce=scale
          perc2=delta
          scal2=delta
          write(iout,106) dpwtr,vv,vh,scale,delta,deploy
106       format(/"  E/S WATER DEPTH=",f6.0,3x,"MEAN VERTICAL SOUND VELOCITY="
         ,f7.4,/,"  HORIZ SOUND VELOCITY=",f7.4,3x,"SEC/INCH=",f7.4,
         /,"  TIME ZERO CORR=",f7.3,3x,"HYDRO DEPTH=",f5.0)
c CONVERT UNCORR METERS  TO TT AND CORRECT TO SB DATUM
          dephy = (deploy-30.0)/5000.
          dpwtr=dpwtr*0.54681
          dpwtr=dpwtr/400.-dephy+filtr
c    READ SWITCH OPTIONS
          read(iin,198)  issw0,issw1,issw2,issw12,issw13
198       format(5i4)
          write(iout,108) issw0,issw1,issw2,issw12,issw13
108       format("  ISSW0=",i2,"   ISSW1=",i2,"   ISSW2=",i2,"   ISSW12=",i2,"   ISSW13=",i2)
c CLEAR POINTS PER TRACE AND SLOPE BUFFERS
204       do 206 i=1,15
          w(i)=0.d0
206       numb(i)=0
          write(iout,197)
197       format("E NUMBER OF DATA POINTS FOR EACH LAYER")
c IN EDITS, FOR LAYERS BEING SKIPPED, PREFIX NUMBER OF
c  DATA POINTS BY MINUS.
          read(iin,20) (numb(i), i=1,15)
20        format(15i4)
          nref=0
          do 199 i=1,15
199       if(iabs(numb(i)).gt.0) nref=nref+1
          write(iout,219) (numb(i),i=1,nref)
219       format(15i4)
          write(iout,195)
```

```
195     format("E INCREMENTAL SLOPES OF LAYERS")
        read(iin,30) (w(i),i=1,nref)
30      format(10d8.3)
        write(iout,196) (w(i),i=1,nref)
196     format(10f8.3,/5f8.3)
c WHEN DELETING INTERFACES, COMBINE INCREMENTAL SLOPES
c  ACCORDINGLY.
        k=1
        do 229 i=2,nref
        if(numb(i).ge.2) k=k+1
        if(numb(i).ge.2) go to 229
        w(k)=w(k)+w(k+1)
        write(iout,730) (x(m),m=1,5)
730     format(/" FINAL COEFFICIENT X(I) VALUES",5d11.3)
        do 228 j=k,nref
228     w(j+1)=w(j+2)
229     continue
c
        wt=0.d0
c  CHECK IF INPUT VALUES ARE REASONABLE
        do 117 i=1,nref
c SET TRIAL VELOCITIES TO 1.5 KM/SEC
        v(i)=1.5d0
        if(iabs(numb(i)).gt.75) go to 6007
        if(numb(i).le.6.and.numb(i).gt.0) go to 6007
        if (w(i).gt.20..or.w(i).lt.-20.) go to 6007
117     wt=wt+dabs(w(i))
        v(1)=vv
        kw=2
        if(wt-1.d-10)6001,6001,6002
6001    kw=1
c  CONVERT ANGLES TO RADIANS
6002    do 1300 i=1,nref
1300    w(i)=w(i)*0.017453293d0
        v(1)=vv
c INTRODUCE DATA PICKS HERE
        mref=nref
        k=1
        do 203 i=1,mref
        n=iabs(numb(i))
        numb(k)=numb(i)
        write(iout,202) i
202     format(/"E VERIFICATION OF DATA PICKS IN LAYER ",i3)
        read(iin,201) (dir(k,j),tt(k,j),j=1,n)
        write(iout,205) (dir(k,j),tt(k,j),j=1,n)
201     format(10d8.3)
205     format(10f8.3)
624     if(numb(i).gt.2) k=k+1
203     if(numb(i).le.-2) nref=nref-1
c NEGATIVE VALUES FOR NUMB(I) CAUSE READER TO SPACE
c  OVER OMITTED LAYER DATA POINTS.
        depth=0.d0
        l=0
c  MAIN LOOP FOR NREF LAYERS
2       l=l+1
600     write(iout,101)
101     format(/3x,"DIR (IN)",2x,"REF (IN)",2x,"DIR (SEC)",2x,
        "REF (SEC)")
c  K IS USED TO REMOVE ZERO DATA VALUES
c  SCALE DATA TO SCIENTIFIC UNITS
```

```
c MOVE DATA TO WORKING ARRAYS
          ko=numb(l)
          do 4003 i=1,ko
          dii(i)=dir(l,i)
4003      rii(i)=tt(l,i)
          do 5010 n=1,ko
          u(n)=(dii(n)+perc2)/perce
          s(n)=(rii(n)+scal2)/scale+dref
          if (n.eq.1.or.issw0.eq.1) write(iout,102) dii(n),
           rii(n),u(n),s(n)
c  IF NOT FIRST LAYER CONVERT U TO DISTANCE
103       if(l.ne.1) u(n)=u(n)*vh
5010      continue
c  END OF DATA LOADING AND SCALING TO SCIENTIFIC UNITS
c
c FIT CURVE TO DATA TO OBTAIN TO AND LATER DIFFERENTIATE FOR
c  ANGLE OF EMERGENCE
c  IND IS AN INDEX USED IN MAIND TO CONTROL PRINTOUT
          if(l-1) 930,931,930
930       dmin=0.45d0*vh
          xb=1.0d0
          go to 932
931       dmin=0.3d0
          xb=vh
c IS FIRST DATA POINT CLOSE ENOUGH TO ORDINATE TO APPROXIMATE
c  INTERCEPT
932       if(u(1)-dmin) 3,3,923
923       ind=-1
          do 90 k=1,ko
          r(k)=s(k)**2
90        d(k)=(u(k)*xb)**2
          call maind(1,l)
          to(l)=dsqrt(x(1))
          ind=1
          if(l-1)4,4,3
c IF FIRST LAYER COMPUTE THICKNESS AND VH BY X2-T2
4         con=2.0d0*to(1)*dsin(w(1))
          hh(1)=v(1)*to(1)/2.0d0
          do 200 i=1,ko
c  BRING BACK TO FLAT LAYER CASE
          r(i)=s(i)**2+con*u(i)*vh/v(1)
200       d(i)=u(i)**2
          ind=1
          call maind(1,1)
          vh=dsqrt(x(2))*v(1)
          write(iout,111) vh,vhh
111       format(/," VH CORRECTED=",f7.4,3x,"VH SUPPLIED=",f7.4)
c  COMPUTE COEFFICIENTS DERIVATIVE FOR EMERGENCE ANGLE
c OPTION TO COMPUTE EMERGENCE ANGLES
          if (issw13.eq.1)  go to 32
3         do 92 k=1,ko
          r(k)=s(k)
92        d(k)=u(k)*xb
          call maind(4,l)
          x(2)=x(2)*v(1)
          x(3)=x(3)*2.0d0*v(1)
          x(4)=x(4)*3.0d0*v(1)
          x(5)=x(5)*4.0d0*v(1)
          if(u(1)-dmin) 921,921,922
921       to(l)=x(1)
```

```
c  FIND ANGLE EMERGENCE  ZM FOR EACH POINT EXCEPT LAST
922         ko=ko-1
            ind=1
            do 300 i=2,ko
            zm(i)=x(2)+x(3)*u(i)+x(4)*u(i)**2+x(5)*u(i)**3
            zm(i)=darsin(zm(i))
            zmd=zm(i)*57.29577951d0
            if (issw13.eq.0) write(iout,102) u(i),s(i),zmd
300         if(issw12.eq.0) write(7,102) u(i),s(i),zmd
102         format(4f10.3)
            if (l.eq.1) ko=ko+1
            if (l.eq.1) go to 4
            d(1)=-1.d-4
            ti(1)=0.d0
31          ind=-ind
            con=2.0d0*dsin(w(l))/v(l)
            ik=0
            do 350 i=2,ko
            call kaus(l,zm(i),ik)
            ik=1
c  NOTE THAT D IS IN KM
            d(i)=u(i)-dr
            r(i)=s(i)-tr
            ti(i)=tit
            d(i)=d(i)/c
c  ELIMINATE POINTS WITH NEGATIVE REDUCED D
            if(d(i))350,3601,3601
c  REDUCE TO FLAT LAYER CASE
3601        r(i)=r(i)**2+con*d(i)*ti(i)-ti(i)**2
            d(i)=d(i)**2
350         continue
c  SOLVE FOR VELOCITY
            go to (5,6), kw
5           ind=1
6           call maind(1,l)
            vv=v(l)
c  CHECK FOR IMAGINARY VELOCITY
            if(x(2))3100,3100,3101
3101        v(l)=dsqrt(1.0d0/x(2))
c  RESET ANGLE ACCORDING TO NEW VELOCITY
            tw(l)=tw(l)*v(l)/vv
            w(l)=datan(tw(l))
            call kaus(l,zm(2),0)
c  IF IND NEGATIVE RESTART PROCESS
            if(ind)31,31,32
c  SOLUTION LISTING
32          if(l.eq.1) thick(1)=to(1)*v(1)/2.0d0
            if(l.gt.1) thick(l)=(to(l)-to(l-1))*v(l)/2.0d0
            depth=depth+thick(l)
            ww(l)=w(l)/0.017453293d0
            sv(l)=svn
            write(iout,104) l,v(l),to(l),thick(l),depth,svn,ww(l)
104         format(" LAYER ",i2,"   VELOCITY=",f6.3,"  REFLECTION TIME=",
            f6.3,"  THICKNESS=",f6.3,/"   DEPTH=",f6.3,3x,"SV=",f7.3,
            "   SLOPE",f6.2)
            if(l.ne.1) go to 207
c OPTION TO SKIP CORRECTING TO E/S DEPTH
            if(issw2.eq.0) go to 209
210         if(dabs(to(1)-dpwtr).lt.0.005) go to 209
            dref=dpwtr-to(1)
```

```
            write(iout,1010) dref
1010        format(" NORMAL INCIDENCE TT CORRECTION=",f8.3)
            go to 600
209         if(dabs(vhh-vh).lt.0.003) go to 207
            perce=perce*vhh/vh
            factor=vh/vhh
            write(iout,107) factor
107         format(" DIRECT WATER WAVE VELOCITY CORRECTION ",f7.4)
            depth=0.d0
            go to 600
207         if(l.gt.1) call crnge
            if(l.lt.nref) go to 2
c MAKE TABULATION OF RESULTS
259         write(iout,3205) date,cruise
3205        format(///1x,10a4,/1x,10a4,/5x,"VELOCITY  REFL TIME  THICKNESS   D%
ELTA TT  DEVIATION  SLOPE"/)
            delta=to(1)
            do 3201 i=1,nref
            if(i.gt.1) delta=to(i)-to(i-1)
3201        write(iout,3202) i,v(i),to(i),thick(i),delta,sv(i),ww(i)
3202        format(i3,6f10.3)
            read(iin,7000) icheck
7000        format(i10)
            if (icheck) 1,7001,1
3100        write(iout,3200) l
3200        format(" VELOCITY NEGATIVE, REMOVE LAYER ",i2,//)
            if(l.lt.nref) go to 2
            go to 259
6007        write(iout,6008)
6008        format(" IMPOSSIBLE VALUE")
            go to 204
7001        continue
            stop
            end
```

```
      subroutine maind(in,l)
c STORED AS FILE MAINS ON DISC
c DATE: 29 JAN 73
c NUMB: UNASSIGNED
c AUTH: LE PICHON / HOSKINS
      dimension to(15),hh(15),v(15),w(15),sw(15),cw(15),
       tw(15),d(75),r(75),zm(75),p(5,6),x(5)
      common to,hh,v,w,tr,dr,sw,cw,tw,d,r,zm,p,c,svn,vh,x,tit,
       m,ind,ko,l,thick,isswl
      double precision aa,a1,a2,c,cw,d,ddo,dk,dr,d11,d2,d21,
       d211,hh,ok,p,r,rr,std,svn,sw,sx,tit,to,tr,tw,tx,v,vh,
       w,x,zm,dabs,dsqrt
      double precision a(5,5),b(5),weight(5),covmat(5,5),resnrm,u(5)
      iout=6
      ino=in+1
      nq=ino+1
      do 1000 m=1,ino
      do 1001 n=1,m
      p(m,n)=0.d0
      do 1001 i=1,ko
      if(d(i)) 1001,9001,9001
9001  if(m+n-2) 6000,6000,6001
6000  tx=1.0d0
      go to 6002
6001  tx=d(i)**(m+n-2)
6002  p(m,n)=p(m,n)+tx
1001  continue
      p(m,nq)=0.d0
      do 1000 i=1,ko
      if(d(i)) 1000,9002,9002
9002  if(m-1) 6003,6003,6004
6003  tx=r(i)
      go to 6005
6004  tx=d(i)**(m-1)*r(i)
6005  p(m,nq)=p(m,nq)+tx
1000  continue
c     MAKE MATRIX SYMMETRIC
      do 1010 n=1,ino
      do 1010 m=1,n
1010  p(m,n)=p(n,m)
      do 1002 k=1,in
      do 1002 i=1,k
      ii=i+1
      kk=k+1
      a1=dabs(p(i,i))
      a2=dabs(p(kk,i))
      if(a1-a2) 1020,1021,1021
1020  do 1200 iin=i,nq
      aa=p(kk,iin)
      p(kk,iin)=p(i,iin)
1200  p(i,iin)=aa
1021  if(a1-1.e-30) 1002,1002,1210
1210  do 1201 nm=ii,nq
1201  p(kk,nm)=p(kk,nm)-(p(i,nm)*p(kk,i)/p(i,i))
1002  continue
c     SOLVE MATRIX
      do 1005 k=1,ino
      i=nq-k
      ii=i+1
      x(i)=p(i,nq)
```

```
            if(i-ino) 1006,1050,1050
1006        do 1060 kx=ii,ino
1060        x(i)=x(i)-(p(i,kx)*x(kx))
1050        a1=dabs(p(i,i))
            if (a1-1.e-30) 1500,1500,1005
1005        x(i)=x(i)/p(i,i)
c FOR PRINTOUT IN=1 AND IND=1
            if(in-1) 1701,1701,4
1701        if(ind) 4,4,21
21          ddo=0.
            ok=ko
            write(iout,1902)
1902        format(/,3x,"DSQ(KM)",3x,"R2(SEC)",2x,"R2 COMPUTED",1x,
            "DIFFERENCE")
            do 1061 k=1,ko
            rr=0.d0
            if(d(k)) 9003,9004,9004
9003        ok=ok-1.0d0
            go to 1061
c COMPUTE PREDICTED TRAVEL TIME
9004        do 1062 i=1,ino
            if(i-1) 6006,6006,6007
6006        tx=x(i)
            go to 1062
6007        tx=x(i)*(d(k)**(i-1))
1062        rr=rr+tx
            dk=r(k)-rr
            ddo=ddo+dk**2
c SENSE SWITCH OPTION TO OMIT LISTING VALUES
             if(k.ne.1.and.issw1.eq.0) go to 1061
            if(dk.lt.-0.3) write(iout,1904) d(k),r(k),rr,dk
1904        format(1x,f9.3,2f10.3,2x,f9.3,"<")
            if(dk.ge.-0.3.and.dk.le.0.3) write(iout,1903) d(k),r(k),rr,dk
1903        format(1x,f9.3,2f10.3,2x,f9.3)
            if(dk.gt.0.3) write(iout,1905) d(k),r(k),rr,dk
1905        format(1x,f9.3,2f10.3,2x,f9.3,">")
1061        continue
c       SIGNIFICANCE CHECK FOR STANDARD DEVIATION
            if(ino.ge.ok) ddo=ok-ino
            ddo=dsqrt (ddo/(ok-in-1))
            k1=ko-ok
            write(iout,1802)ddo,k1,ko
1802        format(/," STANDARD DEVIATION=",f7.3,5x,"NEGATIVE D ",
            "VALUES DISCARDED ",i2," / ",i2)
            if(ino.ge.ok) write(iout,1803)
1803        format(1x," STANDARD DEVIATION NOT SIGNIFICANT, TOO FEW",
            " DATA POINTS")
            write(iout,1900) x(1),x(2),x(3),x(4),x(5)
1900        format(" COEFFICIENTS OF FITTED POLYNOMIAL:  INTERCEPT=",f7.4,
            "   X2=",f7.4,/," X3=",f7.4,"   X4=",f7.4,"   X5=",f7.4)
c       COMPUTE UNCERTAINTY
            std=ddo*ddo
            d11=0.d0
            d21=0.d0
            do 6 m=1,ko
            if(d(m))6,9010,9010
9010        d2=d(m)**2
            d21=d2+d21
            d11=d(m)+d11
6           continue
```

```
            d211=ok*d21-d11**2
            sx=std/d211
            svn=dsqrt(ok*sx/(x(2)**4))
            return
 1500       write(iout,1501)i,i
 1501       format(2hP(,i2,1h,,i2,25h)=0, PROBLEM UNDETERMINED)
 4          return
            end
```

```
      subroutine kaus(l,zz,ik)
c STORED AS FILE KAUSS ON DISC
c SUBROUTINE TO COMPUTE REFLECTIONS FOR X2-T2 METHOD.
c L IS NUMBER OF LAYER, ZZ IS EMERGENCE ANGLE, IK IS INDEX
c  TO INDICATE FIRST POINT OF LAYER.
c PARAMETERS TRANSMITTED BY COMMON.  TR,DR,TI ARE RETURNED.
c     VERSION MAY 1967
      dimension to(15),hh(15),v(15),w(15),sw(15),cw(15),tw(15),d(75),
      r(75),zm(75),p(5,6),x(15), xx(15),y(5)
      common to,hh,v,w,tr,dr,sw,cw,tw,d,r,zm,p,c,svn,vh,y,ti,
       m,ind,ko
      double precision c,cox,cw,d,dr,hc,hh,hk,p,pp,q,r,rr,six,
       sixw,svn,sw,ti,tk,to,tr,tt,tw,u,v,vh,w,ww,x,xw,xx,y,zm,
       zz,zo,dsqrt,dsin,dcos,datan,darsin
      darsin(x)=datan(x/dsqrt(1.0d0-x*x))
      if(ik)9990,9990,9991
c     FIND THICKNESSES,COMPUTE SIN COS TAN
c     ON FIRST CALL TO KAUS FOR EACH LAYER
9990  do 1000 i=1,l
      sw(i)=dsin(w(i))
      cw(i)=dcos (w(i))
1000  tw(i)=sw(i)/cw(i)
      c=1.0d0
      if(l-1)1003,1003,1002
1002  l1=l-1
      ww=0.d0
      do 1001 i=1,l1
1001  ww=ww+w(i)
      c=dcos (ww)
c     FIND ANGLE CORRESPONDING VERTICAL REFLECTION
1003  i=l
      q=w(i)
      if(l-1)11,11,10
10    six=(v(i-1)/v(i))*dsin (q)
      cox=dsqrt (1.0d0-six*six)
      q=datan (six/cox)+w(i-1)
      i=i-1
      if(i-1)11,11,10
11    q=q-w(i)
      z0=q
      u=0.d0
      tt=0.d0
12    if(i-l)13,14,14
c     COMPUTE HH(I)
13    hc=hh(i)-u*dsin (w(i))
      six=dsin (q)
      cox=dcos (q)
      u=u*cw(i)+hc*six/cox
      tt=tt+hc/(v(i)*cox)
      sixw=v(i+1)*six/v(i)
      xw=darsin(sixw)
      q=xw-w(i+1)
      i=i+1
      go to 12
14    hc=(to(i)/2.0d0-tt)*v(i)
      hh(i)=hc+u*sw(i)
c     COMPUTE REFLECTIONS
c FIND ANGLES INCIDENCE FROM EMERGENCE ANGLE
9991  i=0
      xx(1)=zz+w(1)
```

```
 924    i=i+1
        if(l-i) 9252,9252,9250
 9250   six=dsin(xx(i))
        if(six-v(i)/v(i+1))9253,30,30
 9253   sixw=v(i+1)*six/v(i)
        xw=darsin(sixw)
        xx(i+1)=xw+w(i+1)
        go to 924
 9252   i=l+1
        x(l)=xx(l)
 926    i=i-1
        if(i-1)21,21,928
 928    six=dsin(x(i)+w(i))*v(i-1)/v(i)
        x(i-1)=darsin(six)
        go to 926
 c    MAIN COMPUTATION
 21     tt=0
        u=0
        i=0
 24     i=i+1
        hc=hh(i)-u*sw(i)
        six=dsin(x(i))
        cox=dcos(x(i))
        hk=hc*(six/cox)
        u=u*cw(i)    +hk
        tk=hc/(v(i)*cox)
        tt=tt+tk
        if(l-i)252,252,24
 252    i=l+1
        hk=hk/dcos (w(l))
        tr=tk
        dr=hk
        ti  =(hc/v(l))*2.0d0
        pp=u
 26     i=i-1
        rr=hh(i)-pp*tw(i)
        cox=dcos(xx(i)-w(i))
        hk=rr*dsin(xx(i))/cox
        pp=pp/cw(i)+hk
        tk=(rr*cw(i))/(cox*v(i))
        tt=tt+tk
        if(i-l)262,261,261
 261    dr=dr+hk
        tr=tr+tk
 262    if(i-1)27,27,26
 27     tr=tt-tr
        dr=pp-dr*c
        return
 30     dr=-1.d-4
        tr=0.d0
        ti=0.d0
        return
        end
```

```
      subroutine crnge
c PROGRAM STORED ON DISC AS CRNGS
c CRANGE  PROGRAM FOR COMPUTING MINUMUM RANGE OF REFRACTED WAVE
c   SLOWI VERSION      22 DEC 72
c   ASSUMES FLAT-LYING LAYERS
c
      common dummy(30),c,dumny(326),idumy(3),nlayr,h
      dimension c(15), h(15), sincr(15)
      double precision c,cr,dir,dummy,dumny,h,sincr,x,xx,dsqrt,dcos,
       datan,darsin
c
      darsin(x)=datan(x/dsqrt(1.0d0-x*x))
      iout=6
c
c DATA CHECKER
      if(c(nlayr).lt.8.0.and.c(nlayr).gt.0.8) go to 5
      write(iout,1002) nlayr,nlayr
      return
5     if(h(nlayr).lt.9.0.and.h(nlayr).gt.0.0) go to 6
      write(iout,1002) nlayr,nlayr
      return
1002  format(2x,"V(",i2,") OR THICK(",i2,") VALUE UNREASONABLE,",
      " COMPUTATION SKIPPED")
c
6     xx=0.d0
      sincr(nlayr)=1.0d0
      ij=nlayr+1
      ijk=nlayr-1
      do 10 ijkl=1,ijk,1
      i=ij-ijkl
      sincr(i-1)=c(i-1)/c(i)*sincr(i)
      if(sincr(i-1).gt.1.0d0) write(iout,1000) nlayr
      if(sincr(i-1).gt.1.0d0) return
1000  format(2x,"VELOCITY INVERSION IN UNDERLYING LAYER, NO ",
      "CRITICAL ANGLE FOR LAYER ",i2)
      cr=darsin(sincr(i-1))
10    xx=xx+h(i-1)*sincr(i-1)/dcos(cr)
      dir=xx/c(1)
      write(iout,1001) xx,dir,nlayr
1001  format(1x,f7.2," MINIMUM CRITICAL RANGE, ",f7.2," WATER ",
      "TRAVEL TIME FOR LAYER ",i2)
      return
      end
```

Appendix L

Listing of interpretation program SONOMODEL

This appendix contains a line numbered listing of the sonobuoy modelling program entitled sonomodel. The pathname of the program listing is:

>udd>Marine>JChilds>sonobuoy>sonomodel.fortran

The introductory comments prefacing the program describe the input required. All input is from file05 and all printer output goes to file06. Therefore, file attaches must be made to these files before executing the program. The fortran program has been compiled with Honeywell Multics fortran (release 4). The object segment has a pathname:

>udd>Marine>JChilds>sonobuoy>sonomodel

An example of the program, using the example input data contained in the comments, is contained in Appendix I.

```
c     **********    sonobuoy modelling program    **********
c
c       model employs ray tracing theory (a la brune).  method is to
c       calculate x and t values from the ray parameter p=sin(phi(i))/v(i)
c       for values of phi in 30 increments from 0 to critical phi.
c
c
c       input parameters required:
c         card 1
c                     id - label for model                 format(7a4)
c         card 2
c                     id - date                            format(7a4)
c         card 3
c            nl - number of layers in model                format(i3)
c            vh - horizontal water velocity of sound       format(f10.4)
c            v(nl+1) - velocity of material beneath
c                    deepest layer                         format(f10.4)
c         card 4
c            plotting parameters
c            xscal - constant to scale horizontal
c                    axis to desired length.  scales
c                    all x values.                         format(f10.3)
c            yscal - ibid for y axis                       format(f10.3)
c            ylen - length of the y axis (effect-
c                    ively the length of the time
c                    axis of the plot)                     format(f10.3)
c            deltat - initial time offest of plot          format(f10.3)
c         card 5
c            v(i) - velocity of layers (in km/sec)         format(10f8.3)
c         card 6
c            z(i) - thickness of layers (in km)            format(10f8.3)
c         note: if there are more than 10 layers in
c               the model, than the velocities and
c               thicknesses go on cards after 5 in
c               format(10f8.3)
c
c
c            SAMPLE INPUT DATA SET
c
c                This data set is designed to match an eight second
c            record, at a firing rate of 50 meters and a recorder
c            feed of 40 lines per inch.  In line 4, the first factor
c            scales the distance axis, while the second factor
c            scales the time axis.  For both axes, increasing the
c            factor "stretches" the axis, while decreasing the factor
c            "shrinks" the axis.
c
c
c
c      SONOBUOY TEST A
c        1 APRIL 1978
c   5     1.487     7.953
c      0.500     2.364     20.000     -0.100
c    1.500    2.040    2.411    3.761    6.712
c    3.755    1.042    1.272    1.811    6.207
c
c
c
           dimension x(10,30),t(10,30),v(11),z(10),tc(10),xc(10),xx(30),%
           yy(30),id(7),idate(7)
```

```
61            arsin(x)=atan(x/sqrt(1-x**2))
62            read(5,8)  id
63            read(5,8) idate
64            read(5,10) nl,vh,v(nl+1)
65            read(5,14) xscal,yscal,ylen,deltat
66            read(5,11) (v(i),i=1,nl)
67            read(5,11) (z(i),i=1,nl)
68            write(6,9)  idate,id
69            write(6,16) vh
70            write(6,17) xscal,yscal,ylen,deltat
71            write(6,12)
72            do 15 i=1,nl
73      15    write(6,13) i,v(i),z(i)
74            i=nl+1
75            write(6,13) i,v(i)
76      8     format(7a4)
77      9     format(/," date:  ",7a4,/" model:  ",7a4,/)
78      10    format(i3,2f10.4)
79      11    format(10f8.3)
80      12    format(//" layer    velocity(km/sec)   thickness(km)",/
81            " -----    ---------------   -------------")
82      13    format(i3,9x,f5.3,15x,f6.3)
83      14    format(4f10.3)
84      16    format(/" horizontal velocity of sound=",f7.4)
85      17    format(" plot parameters are:",5x,"xscal=",f7.4,5x,"yscal=",f7.4,
86             5x,"ylen=",f7.2,/" ",26x," initial time offset=",f7.4)
87      c
88      c     set up the plot routine
89      c
90      c     we have interchanged the x and y axes in the plotting routines
91      c     and consequently, the variable labels may appear a little funny.
92      c
93                xlen=vh*ylen
94            call plot(0.0,1.0,-3)
95            call plot(50.0,28.0,+60)
96            call plot(-2.0,-2.0,-60)
97      c     The commands in lines 100,101,105,106,109 & 187 will
98      c     reduce the entire plot to page size.  The initial c
99      c     must be replaced with a blank and the program recompiled.
100     c         xscal=xscal/4
101     c         yscal=yscal/4
102               xscal=xscal*5.0
103               xlen=xlen/xscal
104           call plot(2.0,xscal,+20)
105     c     call plot(0.5,xscal,+20)
106     c     xlen=xlen/4
107               call axis(0.0,0.0,"kilometers",10,xlen,90.0,0.0,5.0)
108               xscal=xscal/5.
109     c     call plot(yscal,2.0,+20)
110           call plot(yscal,0.5,+20)
111           call axis(0.0,0.0,"seconds",-7,ylen,0.0,0.0,1.0)
112           call plot(yscal,xscal,+20)
113           ylen=ylen+1.00
114     c
115     c     offset plot by deltat, an initial time offset.  sign of deltat
116     c     is the same as lint or slowi convention.
117     c
118           call plot(-deltat,0.0,-3)
119     c
120     c     main loop for layers.  calculates hyperbolas, critical angle
```

```
c      and distance and plots both.
c      for each layer calculate the critical shooting angle, the point
c      at which the solution blows up (x and t go to infinity).
c      subtract a nominal sum (here .2 degrees) from this and divide
c      by an incremental number to determine a delta.
c
           do 35 i=1,nl
               phi=0.0
           cphi=1.570796
           if (i.ne.1) cphi=arsin(v(1)/v(i))
           cphi2=arsin(v(1)/v(i+1))
           delta=(cphi-0.000003490658)/30
               do 25 j=1,30
                    p=sin(phi)/v(1)
                    sum=0.0
                    summ=0.0
                    do 20 k=1,i
                         den=sqrt(1-(p*p*v(k)*v(k)))
                         sum=sum+z(k)*v(k)/den
 20                      summ=summ+z(k)/(v(k)*den)
                    x(i,j)=2*p*sum
                    t(i,j)=2*summ
               phi=phi+delta
               xx(j)=x(i,j)
 25            yy(j)=+t(i,j)
c
c      calculate the critical point from the critical angle, and
c      critical refraction at x=xlen.
c
           phi=cphi2
           p=sin(phi)/v(1)
                    sum=0.0
                    summ=0.0
                    do 30 k=1,i
                         den=sqrt(1-(p*p*v(k)*v(k)))
                         sum=sum+z(k)*v(k)/den
 30                      summ=summ+z(k)/(v(k)*den)
                    xc(i)=2*p*sum
                    tc(i)=+2*summ
c
c      plot the hyperbola and critical refraction line for each layer
c
               ndp=30
               if(i.eq.1)   ndp=26
               call line(yy,xx,ndp,1,0,0)
               if((ylen-tc(i)).le.0.0)  go to 35
               xend=xc(i)+(ylen-tc(i))*v(i+1)
               call spot(tc(i),xc(i),0.15,66,0.0)
               call plot(tc(i),xc(i),3)
               xtest=28.0/xscal
               if(xend.gt.xtest)  go to 34
               call plot(ylen,xend,2)
               go to 35
 34            xend=xtest
               yend=tc(i)+(xend-xc(i))/v(i+1)
               call plot(yend,xend,2)
 35        continue
c
c      calculate direct arrival and plot.
c
```

```
          dir=vh*ylen
              call plot(ylen,dir,3)
              call plot(0.0,0.0,2)
c
c     write a label and date on the plot
c
c         call plot(1.0,1.0,+20)
          call plot(0.25,0.25,+20)
          call symbol(4.0,12.0,0.5,id,90.0,28)
          call symbol(5.5,13.0,0.3,idate,90.0,28)
c
c     write out a table on the plot with the model parameters
c
          call symbol(9.0,19.0,0.4,"model",90.0,5)
          call plot(9.1,19.0,3)
          call plot(9.1,21.0,2)
          call symbol(10.0,12.0,0.3,"layer   velocity    thickness      dc       tc",90.0,44)
          xnum=10.5
          do 60 i=1,nl
              vel=v(i)
              thick=z(i)
              critd=xc(i)
              critt=tc(i)
              anl=i
              call number(xnum,12.6,0.25,anl,90.0,-1)
              call number(xnum,15.0,0.25,vel,90.0,2)
              if(i.eq.1)  call symbol(xnum,16.3,0.25,"km/sec",90.0,6)
              call number(xnum,18.7,0.25,thick,90.0,2)
              if(i.eq.1)  call symbol(xnum,20.0,0.25,"km",90.0,2)
              call number(xnum,22.0,0.25,critd,90.0,2)
              if (i.eq.1) call symbol(xnum,23.25,0.25,"km",90.0,2)
              call number(xnum,24.5,0.25,critt,90.0,2)
              if (i.eq.1) call symbol(xnum,25.75,0.25,"sec",90.0,3)
              xnum=xnum+0.5
60            continue
          anl=anl+1.0
          vel=v(nl+1)
          call number(xnum,12.6,0.25,anl,90.0,-1)
          call number(xnum,15.0,0.25,vel,90.0,2)
c
c      end plot
c
              call plot(0.0,0.0,999)
c
c     construct table of output values
c
          write(6,40)
40        format(" layer    phi      x(km)    t(sec)     critical distance  %
  critical travel time")
          do 50 i=1,nl
          j=1
          write(6,51) i,xc(i),tc(i)
          write(6,52) j,x(i,1),t(i,1)
          do 45 j=3,30,3
45        write(6,52) j,x(i,j),t(i,j)
          do 50 j=1,30
50        x(i,j)=x(i,j)/vh
c
c     construct and write an output data set compatible with slowi
c
```

```
      write(6,53)
      write(6,54) ((x(i,j),t(i,j),j=1,15,1),i=1,n()
51    format(i3,t45,f6.2,t66,f6.2)
52    format(8x,i3,4x,f6.3,4x,f6.3)
53    format(//" slowi formatted output",/)
54    format(10f8.3)
      stop
      end
```