# CHARACTERIZATION OF THE BOTTOM SEDIMENT VELOCITY-DEPTH RELATIONSHIP FOR THE SOMALI BASIN AND THE ARABIAN SEA

A DISSERTATION SUBMITTED TO THE GRADUATE DIVISION OF THE
UNIVERSITY OF HAWAII IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE DEGREE OF

DOCTOR OF PHILOSOPHY

IN

GEOLOGY AND GEOPHYSICS

MAY 1991

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ACKNOWLEDGMENTS

The author gratefully acknowledges the encouragement and support of the US Naval Oceanographic Office in this work and the help of many of the personnel of this organization who assisted in the acquisition and processing of the data. I thank the members of my committee for their time, patience and helpful suggestions. A special thanks to Dr. W. M. Adams who opened doors long closed and got me on track again.

ABSTRACT

Two relatively large ocean areas, the Somali Basin and the Arabian Sea, were sampled to determine the bottom sediment velocity versus depth relationship. The sampling method was that described by Clay and Rona (1965) and Le Pichon et al. (1968). This method employs a sonobuoy as the receiver and a ship towing a seismic source moving away at a constant speed and course. The method is known as the variable angle or the wide angle bottom reflection technique (WABR). The result is a series of layer thicknesses and associated layer average velocities. These interval thicknesses and velocities are then converted to instantaneous velocity-time functions relating velocity to one way travel time from the sediment surface and then to a velocity versus depth function in the manner described by Houtz et al. (1968,1970) and Bachman and Hamilton (1980). In each area, individual station instantaneous velocity-time curves are compared to each other to detect anomalous locations; then instantaneous velocity-time curves developed from groups of stations are used to determine curve variations in terms of compass direction or position. Velocity versus depth functions are derived from the instantaneous velocity-time functions and these also are examined for consistency of the function with respect to area or compass direction. From this analysis,

a minimum number of velocity versus depth functions are chosen to characterize the two large areas and these are compared to the results of previous investigators of specific areas to insure general agreement and consistency. These functions differ from each other in the sense that they describe the velocity-depth relationship of the sediments for specific depositional environments and indicate the gradients that might be expected for such areas. They may also be used to gain insight and to generalize on the velocity-depth relationship of the sediments in other ocean areas of similar depositional environment.

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# INTRODUCTION

## A. OBJECTIVES

The problem of accurately modeling the world's ocean areas is an overwhelming task requiring nearly unlimited resources and time. Given the resources and time available, the problem can be made tractable by determining the critical parameters in specific areas and then characterizing large areas of generally similar type. That is the approach used in this study. A number of velocity versus depth measurements, sufficient to uniformly cover the area of interest, were made using the sonobuoy technique as described by Clay and Rona (1965) and Le Pichon et al. (1968). The sonobuoy technique is refered to in this thesis as the Wide Angle Bottom Reflection method (WABR). WABR is particularly useful in this application due to the fact that it requires only one vessel, it can be done while underway and it is relatively inexpensive. The method requires minimal ship support, allowing numerous other oceanographic measurements to be made from the same vessel. Specific velocity-depth measurements are compared to each other for variation in the relationship with respect to distance and direction throughout the area of interest. In this manner, sub-areas of similar velocity-depth relationship can be determined and characterized by an average relationship for the sub-area. A large ocean area is then characterized by one or a minimum number of velocity-depth relationships.

NAVOCEANO employed a vessel, the USNS WILKES, for surveying in the Indian Ocean from the late 1970s to the mid 1980s. The availability of ship time on this vessel and general interest in the geology of the Arabian Sea and the Somali Basin made these two areas a natural choice for this study. The two areas, along with the bottom physiography and the WABR station locations, are depicted in figures 1 and 2. The WABR measurements are referred to as stations, even though the measurement is made over a distance of 9 to 10 nautical miles, for ease in cataloging and for giving specific locations for the measurement. The point used as a location for the measurement in this report is that point where the sonobuoy was deployed into the water.

## B. BACKGROUND

### Somali Basin

The Somali Basin is defined by the area bounded on the North by the Carlsberg Ridge, on the West by the east coast of Somali, Kenya and Tanzania, on the South by the Comoros Islands and Madagascar and on the East by the Seychelles and Mauritius Plateau.

Five cruise legs were devoted to the Somali Basin, during which a total of 70 usable stations were chosen so as to take advantage of the physiography and to provide for adequate coverage of the area. These stations are

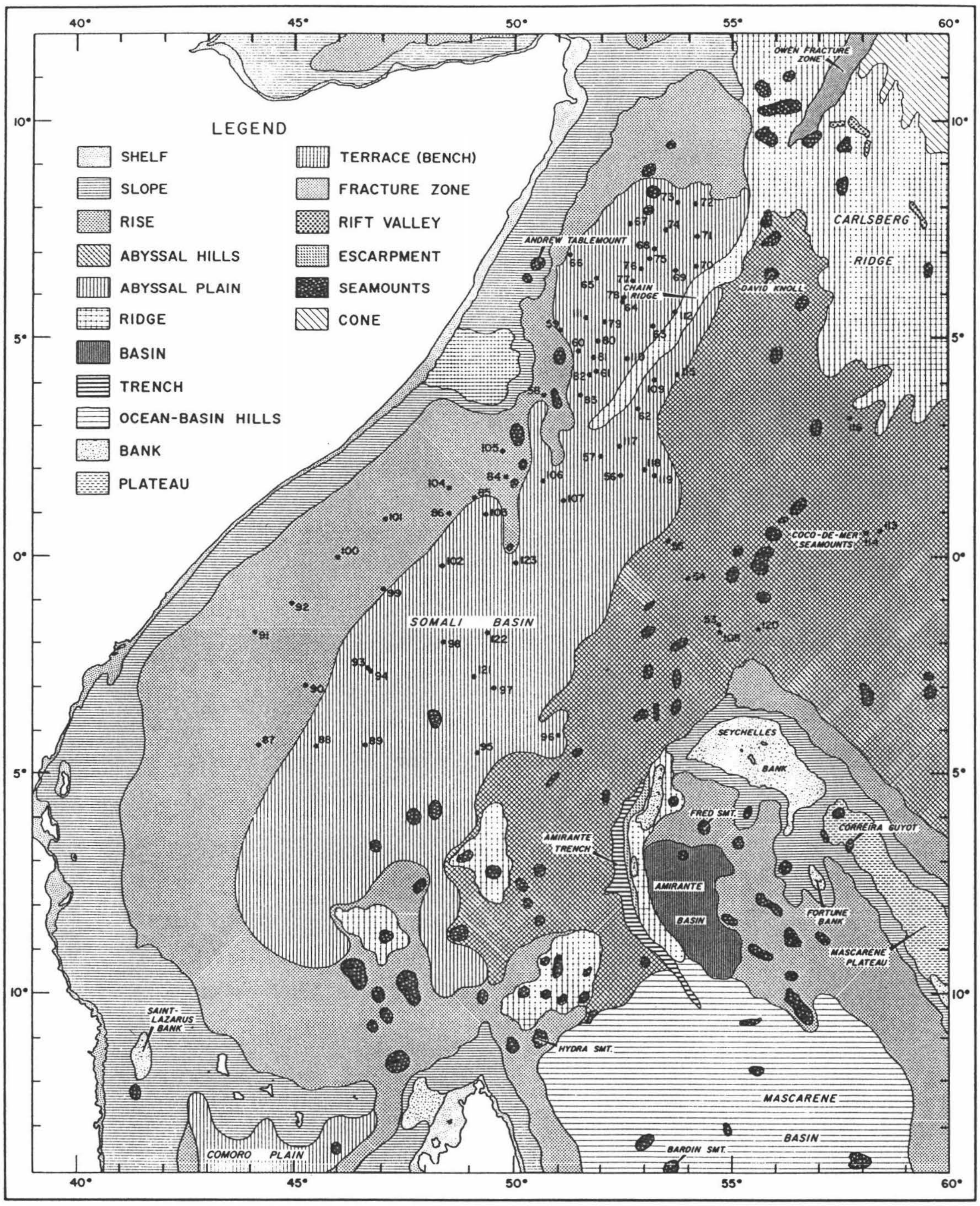



Figure 1. Somali Basin Physiography and Station Locations.

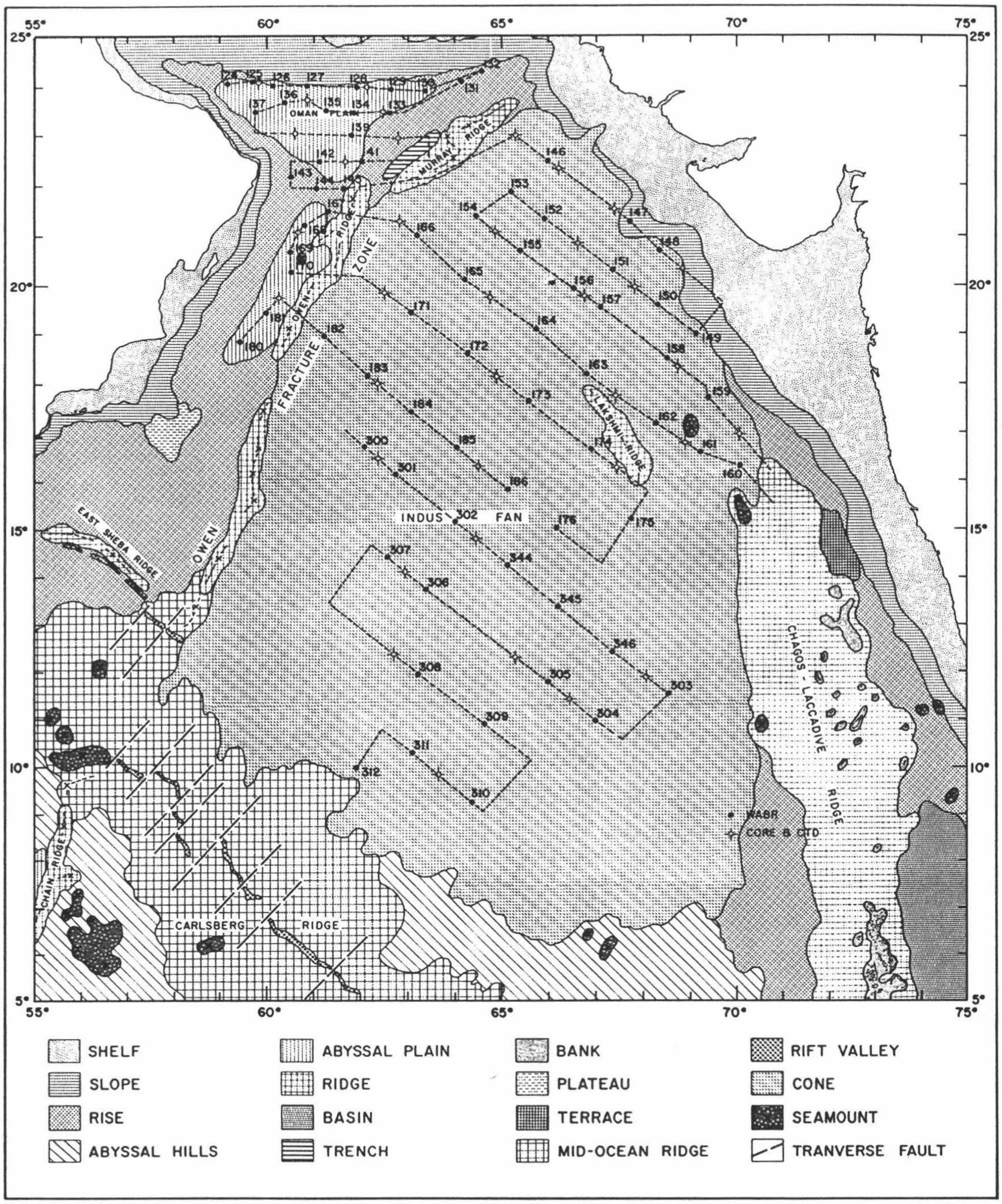



Figure 2. Arabian Sea Physiography and Station Locations.

superimposed on the physiography of the Somali Basin, as indicated in figure 1. Station numbers refer to successive wide angle bottom reflection stations taken by the US Naval Oceanographic Office. Along with the interval velocity measurements, 45 usable cores and 57 "sound velocity, salinity, temperature, depth" (SVSTD) measurements were made, and continuous seismic profiles were taken on each leg.

Considerable seismic profiling in the Somali Basin was conducted by Ewing et al. (1969) and Bunce et al. (1967) as well as refraction profiling by Francis et al. (1966); however, only a small amount of interval velocity measurements were previously available, as noted by Hamilton (1980). Good discussions of the area are given in Francis et al. (1966), Bunce et al. (1967) and Davies and Francis (1964). The physiography of the Somali Basin is illustrated in figure 1. The Somali Basin is made up of several relatively isolated abyssal plains, abyssal hills or swales, continental rise areas of the African Coast, the Mascarene Plateau and the Carlsberg Ridge. In the northern portion of the basin, Chain Ridge separates two abyssal plain areas and almost pinches out the western of the two plains against the African Continental Rise. A larger abyssal plain extends southward and a smaller abyssal plain with swales exists to the north and east of the Seychelles islands. Bunce et al. (1967) pointed out that the depth to basement abruptly changes at the southern edge of Chain Ridge at approximately 3° 30' S latitude, and that the northern and southern parts of the Basin are very different. The northern part has a deep basement covered with thick, mostly uniformly stratified terrigenous sediments, and it has a distinct geoid low and large negative gravity anomalies. This geoid low and the large gravity anomalies are believed to be the result of the superposition of a continental edge effect anomaly and the fracture zone effect (Cochran 1988).

The southern part of the Somali Basin has a shallow basement with high relief covered with stratified flat lying sediments filling the basement depressions, with isolated hills of basement material rising above the abyssal plain deposits. The basin is believed to have been formed during the southward movement of east Gondwanaland with the northern basin being the third of a series of oceanic basins, the other two being the Mozambique Basin and the Southern Basin, separated by long transform faults (Cochran 1988). According to Dutoit (1937) Madagascar was displaced from the African Coast in the large crustal movement in which India separated from Africa leaving the Seychelles Islands behind. Cochran (1988) suggested that the original Northern Basin was split apart by the movement cited by Dutoit and that Chain Ridge formed along the new boundary. In a study of sea floor age and fracture zone trends as constraints on continental reconstruction by Burroughs, mention is made that an investigator (Sowerbutts) relates developement of the East African Rifts with the southeastward movements of the continents out of the present day Somali Basin area (Burroughs 1977). Burroughs disputed the age relation, but not the concept. The developement of ridges, scarps and volcanoes cited by various investigators of the Somali Basin is typical of the present day development of these features in the East African Rift system, matching the definition of fracture zones by Menard and Chase (1970).

Burroughs (1977) suggested that turbidites make up a negligible portion of the sediments in the Somali Basin. However, other investigators have suggested that a large portion of the sedimentary section in both the Northern and Southern Basins is due to turbidite flows. Bunce et al. (1967) ran profiles in both basins, and attributed much of the sediment section to turbidity flows based on the clearly defined stratification in the uppermost sequence. This sequence occurs in both basins and is underlain by a generally acoustically transparent sequence, in turn underlain by a third sequence which shows some stratification. Navoceano seismic profiles are in complete agreement with the conclusions by Bunce (1967). Sediments in the Northern Basin are on the order of 2.0 seconds of two-way travel time thick and the uppermost section, thickly stratified, is on the order of 0.75 seconds thick. In the Southern Basin, the total sediment thickness is less than that of the Northern Basin, on the order of 1.5 seconds of two-way travel time. The uppermost sequence is about 0.5 seconds thick, which is about the same proportion relative to the deeper sediments as in the Northern Basin. The sediment section of the Continental Rise is considerably thicker than that in both of the Basins and heavily stratified sequences of 1 second or more of travel time are found here (see fig. 3). Thus, it is estimated that turbidity flows contribute at least 30% and possibly as much as 40% of the sedimentary section, with the African Coast considered to be the primary source of these sediments.

Arabian Sea

The Arabian Sea is bounded on the North by the southern extremes of Iran and Pakistan, on the East by India, on the West by the Arabian Peninsula and on the South by the Carlsberg Ridge. Four cruise legs were devoted to the study of the Arabian Sea area over a period of three years. The inadequacy of the wide angle bottom reflection method in shallow water, due to the strong over-riding multiples, precluded work on the continental shelf in this area, as in the Somali Basin. The intractability of the seismic methods in the ridge provinces, due to multipath returns, left only the deltaic fan and abyssal plain areas for study.

The physiography of the Arabian Sea is dominated by the huge Indus Cone, the deltaic outpouring of the Indus

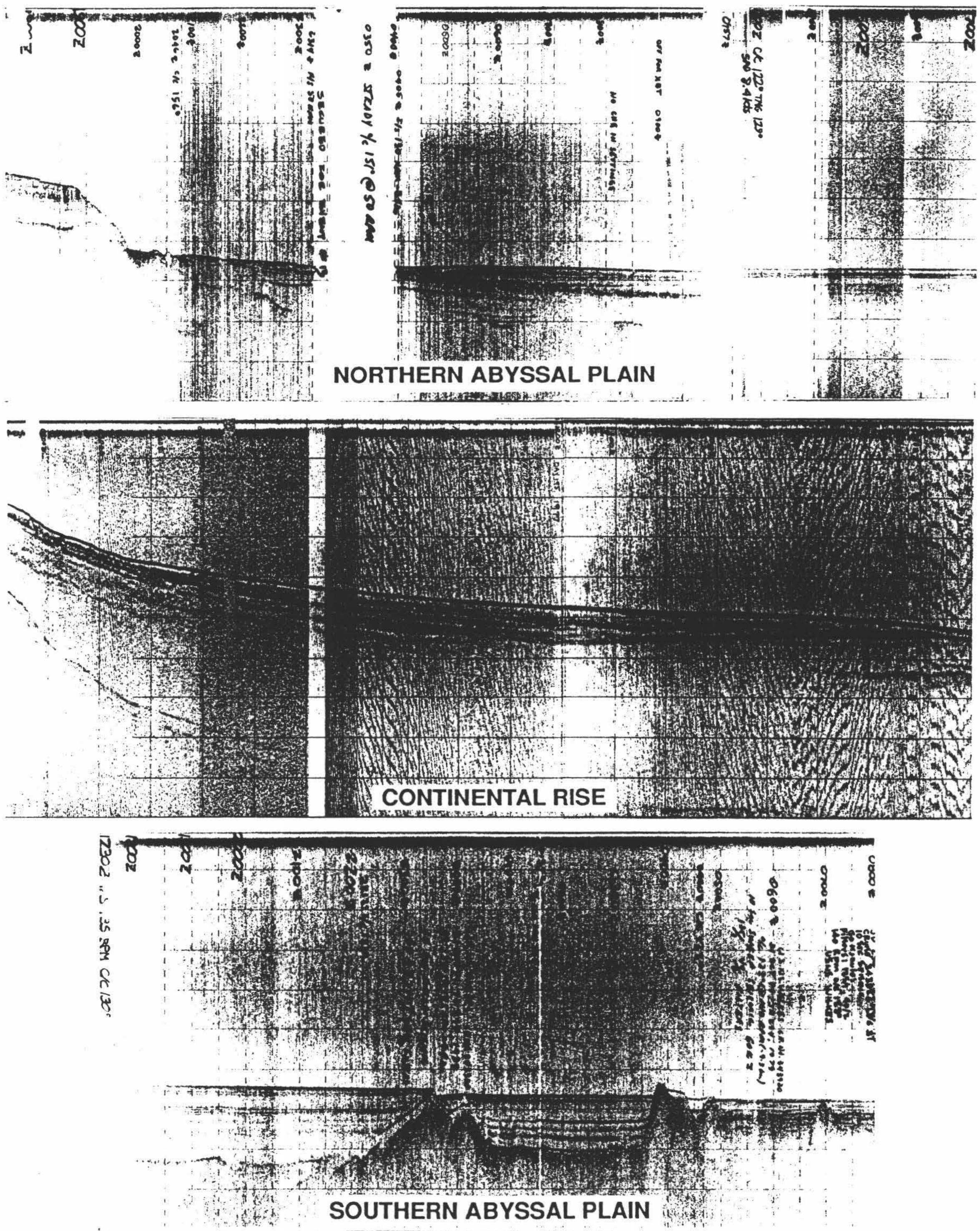



Figure 3. Illustration of Seismic Vertical Profile Records in Somali Basin.

River, the resting place for the erosion products from the highlands of India and Pakistan. Multichannel seismic investigations by Societe Nationale Elf Aquitain Petroleum have shown that there is a thickness of more than 35,000 feet (10,370m) of sediment at the head of the Indus Cone. The remainder of the basin includes a small triangular abyssal plain known as the Oman Abyssal Plain, a long narrow abyssal plain between the Murray Ridge-Owens Fracture Zone and the continental shelf of the Arabian Peninsula (known as the Owens Abyssal Plain), as well as surrounding ridges and the Chagos-Laccadive Plateau (see fig. 2). The southern edge of the Indus Cone is bounded by the Carlsberg Ridge, the northern extension of the Mid-Ocean Ridge. The western edge of the Cone is bounded by the Murray Ridge, extending from the shelf of Pakistan, and the Owen Fracture Zone, extending just to the east of Socotra. The eastern boundary of the cone is formed by the shelf of India and the Chagos-Laccadive Plateau. The continental shelves of Pakistan, Iran and Oman, along with the Murray Ridge, form the boundaries of the Oman Abyssal Plain. The two abyssal plains and the cone are the subject of study in this area.

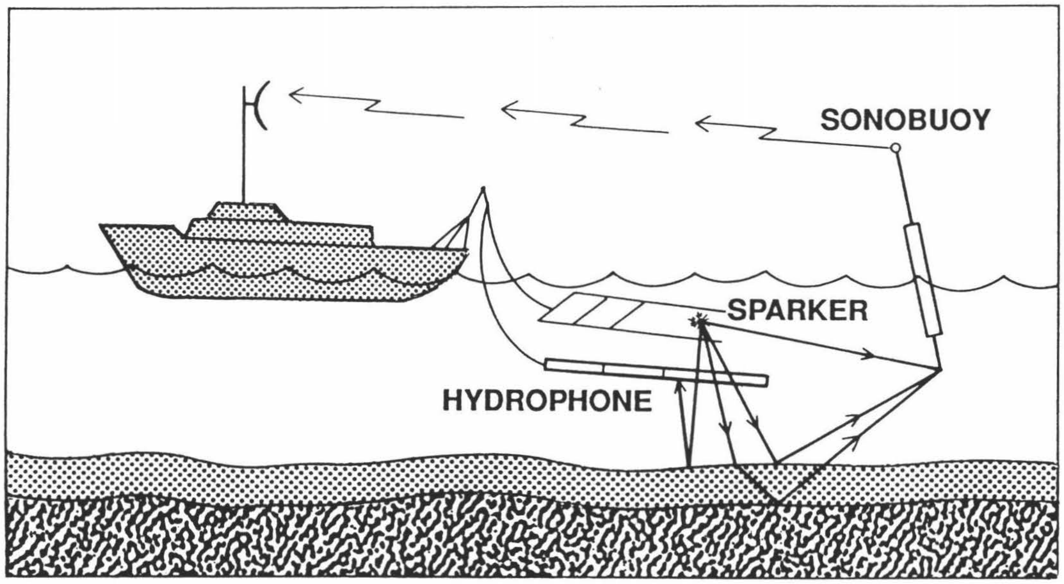
The Oman Abyssal Plain and the Owens Abyssal Plain are part of the Arabian Plate, while the Indus Fan is part of the Indian Ocean Plate. White and Ross (1979) demonstrated that the northern wall of the Oman Abyssal Plain is the frontal portion of a huge accretionary wedge of sediments resulting from the underthrusting of the Oceanic Plate. White and Klitgord (1976) have described the imbricated fold structure in this accretionary wedge and the continued filling in of the interfold basins by detritus from the Makran Coast. The basin itself is part of the Arabian oceanic plate thrusting northward. Their multichannel work show the basin to have a thick sequence, thickening to the north and abruptly terminating against the imbricated wedge. Our east-west seismic lines start just south of the frontal fold and progressed southward. Thus, our seismic records show only the flat lying abyssal plain deposits.

An exhaustive study of the Indus Fan was recently published by Kolla and Coumes (1987). Kolla extensively studied the Indus Cone for some time and some of the data used in his reports is from the cruises undertaken for this study. A definitive study of the surficial sediments of the Indus Cone was published by Kolla et al. (1981). In that study, they divide the fan into upper, middle and lower regions based on the 3.5 KHz and seismic profile characteristics. Two prominent features in the Indus Fan are the Lakshmi Ridge and the Chagos Lacadive Ridge. It was against the Lacadive Ridge that we delineated the eastern edge of our survey. Naini and Kolla (1981) note that there are somewhat higher velocity basal sedimentary layers following the structural trends of the basement in the upper and middle regions. They believe these layers are pelagic, while the upper sedimentary layers have been deposited by turbidity currents.

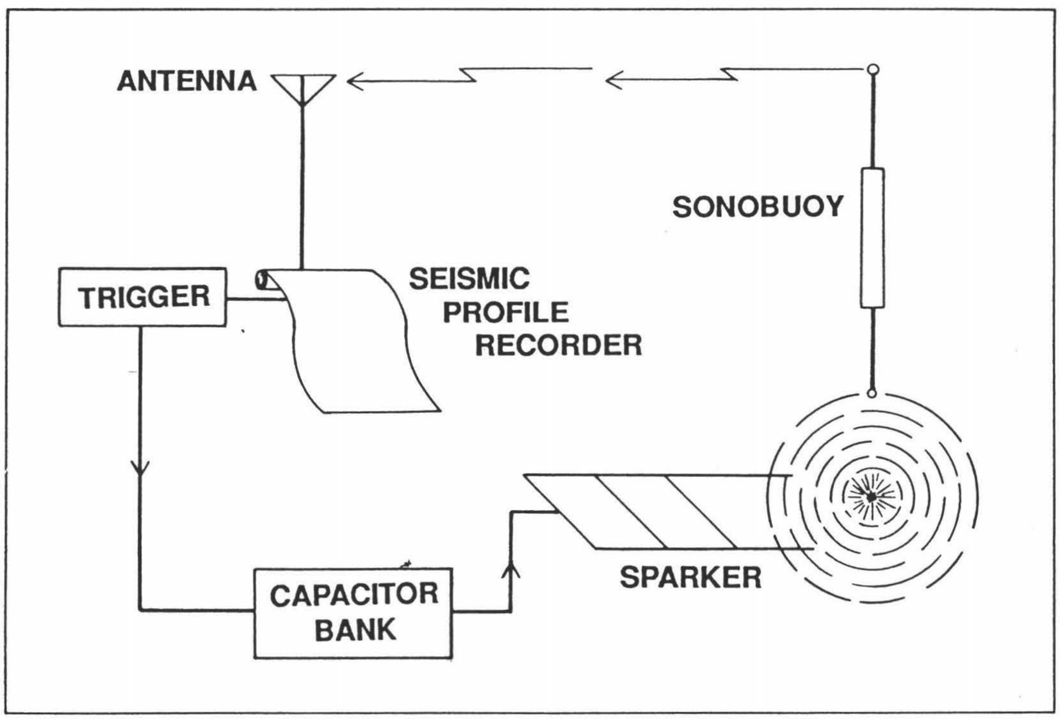
# CHAPTER I

## INSTRUMENTATION FOR DATA COLLECTION

The wide angle bottom reflection method (WABR), requires a ship-borne sound source, a sonobuoy to receive the reflected signals, a radio receiver to pick up the transmissions from the sonobuoy and a recording device to record the received data. The sound source used on the USNS WILKES was a 90 kilojoule sparker system consisting of three 30 kilojoule units fired simultaneously. The three sparkers were towed behind the ship, about 75 feet aft, with each individual sparker consisting of two plastic coated solid conductors in a ladder type arrangement held a foot apart by plastic spacers (see illustration figure 4). A hydrophone streamer was also towed behind the ship for simultaneous vertical seismic profiling. The sonobuoys used during most of the survey were US Navy type AN/SSQ-41A as depicted in figure 5. In later stages of the work, AN/SSQ57A type sonobuoys were used. The radio receiver in the system was a Watkins-Johnson model 8730 A with two band selections,0-30 MHz and 30-600 MHz, and a Yagi log periodic antenna with an antenna preamplifier. The raw data from the receiver were recorded on one FM and one AM channel of an Hewlett-Packard model 4968A precision instrumentation eight track tape recorder and paralleled to a Teledyne seismic amplifier model 24220. The filtered and amplified output was displayed on a Raytheon model 1811 line scan recorder. A second Raytheon recorder

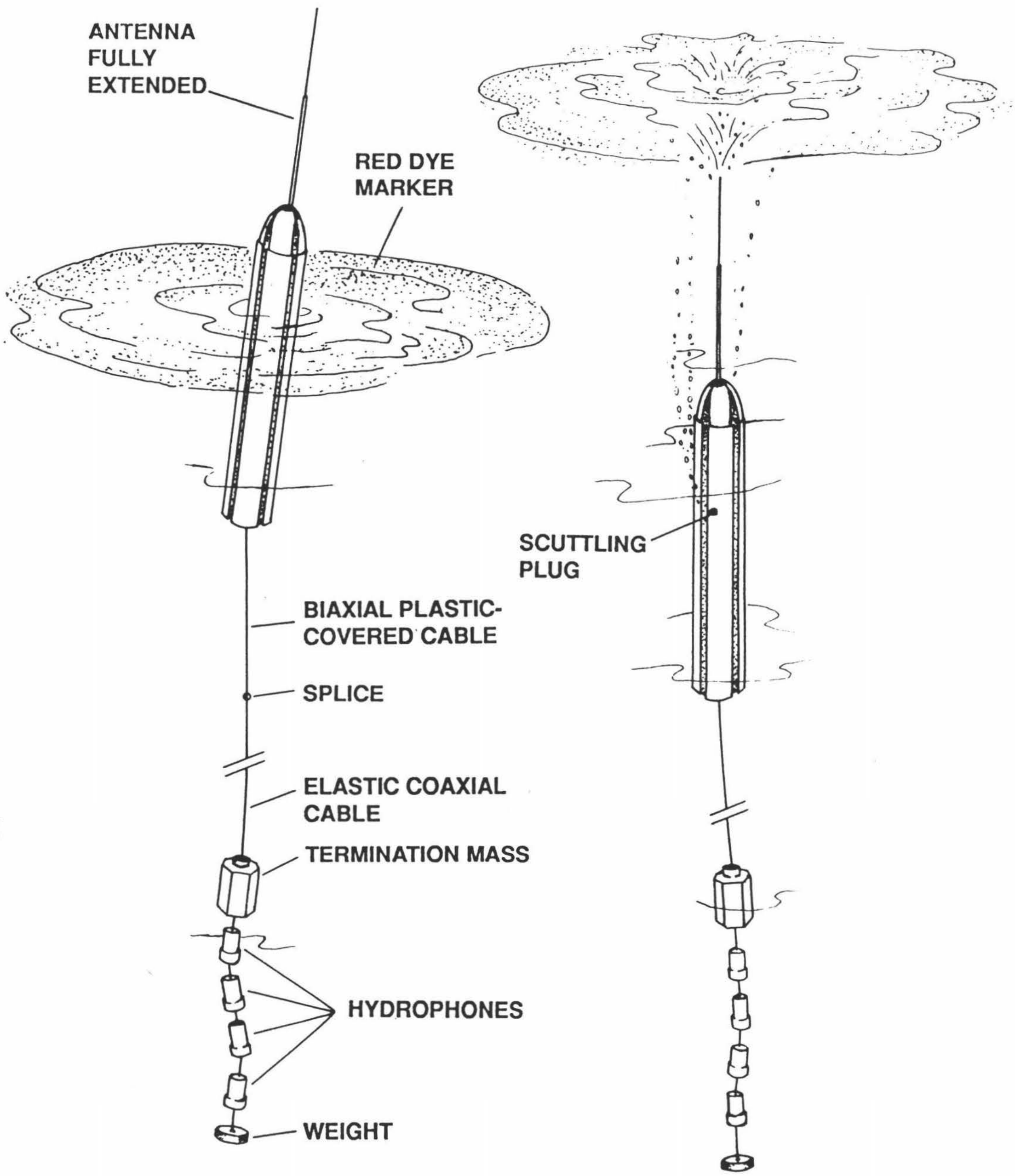



(a) Illustration of Both Vertical Profiling and Wide Angle Bottom Reflection.




(b) Block Diagram of a Typical System.

Figure 4. Illustration of Seismic Profiling System.




(a) In Operation (b) Scuttling

Figure 5. Illustration of Navy Sonobuoy Type AN/SSQ-41A.

recorded the vertical reflection profile data from the hydrophone streamer array during the wide angle bottom reflection measurement. Along with the wide angle bottom reflection system, the ship carried other types of instrumentation to obtain data to support the velocity-depth measurements. Navigation equipment included the Magnavox model 706 satellite receiver units, later these were replaced with Magnavox 1107 units. For water column data, a Bisset-Berman (Plessey) model 9040 sound velocity, salinity, temperature, depth (SVSTD) unit was used during the earlier part of the work, later replaced with a Neil Brown Model Mark 111 conductivity, temperature, depth (CTD) unit. Supporting core data were obtained with a 2000 pound modified Ewing corer with a twenty foot barrel. Underway total magnetic field intensity data were collected using a Geometrics model G801 marine proton precession magnetometer towed 250 meters behind the ship. Bathymetric measurements were continuously made underway employing a Harris model 853D 12 KHz Narrow Beam Echo Sounder manufactured by General Instruments Corporation. This system produces a beam pattern having a beam angle of 2 2/3 degrees and is pitch and roll stabilized electronically using the ship's Mark 19 gyrocompass for stable reference. A subbottom profile was obtained with an Edo 3.5 KHz unit. Expendable bathythermograph data (XBT) were collected periodically using XBT T-7 probes (750 meter depth) and a Sippican Mark 2A recorder.

The reliability of this system was enhanced by its simplicity and therefore it supplied a large quantity of data. The instrumentation used was standard throughout the industry and is returned to the manufacturer or to the Navoceano laboratories periodically for calibration and maintenance. A rigorous preventative maintenance program was carried on aboard the ship and the calibration of the instruments checked prior to each cruise. Most sonobuoys do not transmit true amplitudes and since travel times are the primary consideration in this study rather than amplitudes, the accuracy of the timing systems of the recorders is of prime importance. The recorders are controlled by crystal oscillators with an accuracy of five parts per million, and these were monitored by two rubidium frequency standards aboard the ship.

Data are easily reproducible from the raw data on magnetic tape, from the original visible recordings or from the 35 mm film copies made of all of the seismic records. The interval velocities and the thicknesses obtained for each station by the Dix (1955) method have been tabulated and are being published as a Navoceano Data Publication. This publication will include all of the stations taken through 1988.

## CHAPTER II

## DATA ACQUISITION AND PROCESSING

Several other methods of obtaining seismic velocity data were considered for this study. The two ship wide-aperture method was evaluated but was discarded due to the costs involved and the difficulty of obtaining two ships for a project over such large areas and requiring so much ship time. Multichannel reflection methods are highly desired for the increased detail and the much greater discrimination of layer thicknesses, but the level of effort and costs of using this method were beyond the means of the project. Also, since the bulk of the work was in water depths greater than 3000 meters, it was beyond the capabilities of the average multi-channel system. Refraction methods would have been as suitable as the WABR method as far as costs and ship time were concerned, but the requirement of large sources rich in low frequencies necessitates explosives, giving rise to a myriad of regulations and conditions aboard Navy ships. The availability of sonobuoys at minimal cost to NAVOCEANO and the need for only one ship made WABR the method of choice.

The data used for the characterization of the two ocean areas were acquired over a period from 1979 to 1985 and required nine cruise legs for the task. Cruise legs were multidisciplinary and the tracks were planned to accomodate other disciplines and the opportunity to take measurements in a systematic manner with stations located to take advantage of physiography. Wide angle reflection measurements were the primary purpose of the cruises in the Arabian Sea and the tracks were designed specifically for this purpose. A series of tracks were chosen to obtain uniform coverage of the region while maintaining tracks along depth contours to minimize the variation in water depth along the track.

The wide angle bottom reflection technique is a marine adaptation of the Dix (1955) $X^2$-$T^2$ method developed for land exploration. The $X^2$-$T^2$ method is used to determine interval velocities and thicknesses and has been discussed by Clay and Rona (1965), Le Pichon et al. (1968) and Houtz et al. (1968). During our underway data acquisition, the ship towed a sparker which fired every ten seconds. One or more hydrophone streamers were also towed, generally at a speed of eight to nine knots. Seismic vertical profile data were recorded on two analog paper recorders. One recorder, the primary recorder, was operated at a ten- second sweep recording data from the entire time period between shots to maintain a continuous unbroken record of the bottom when going from shelf areas to abyssal depths and vice versa. The second recorder was operated at a four- second sweep with a sweep delay eliminating most of the water column data but expanding the sub-bottom (See figure 6).

To make a wide angle measurement the ship is slowed

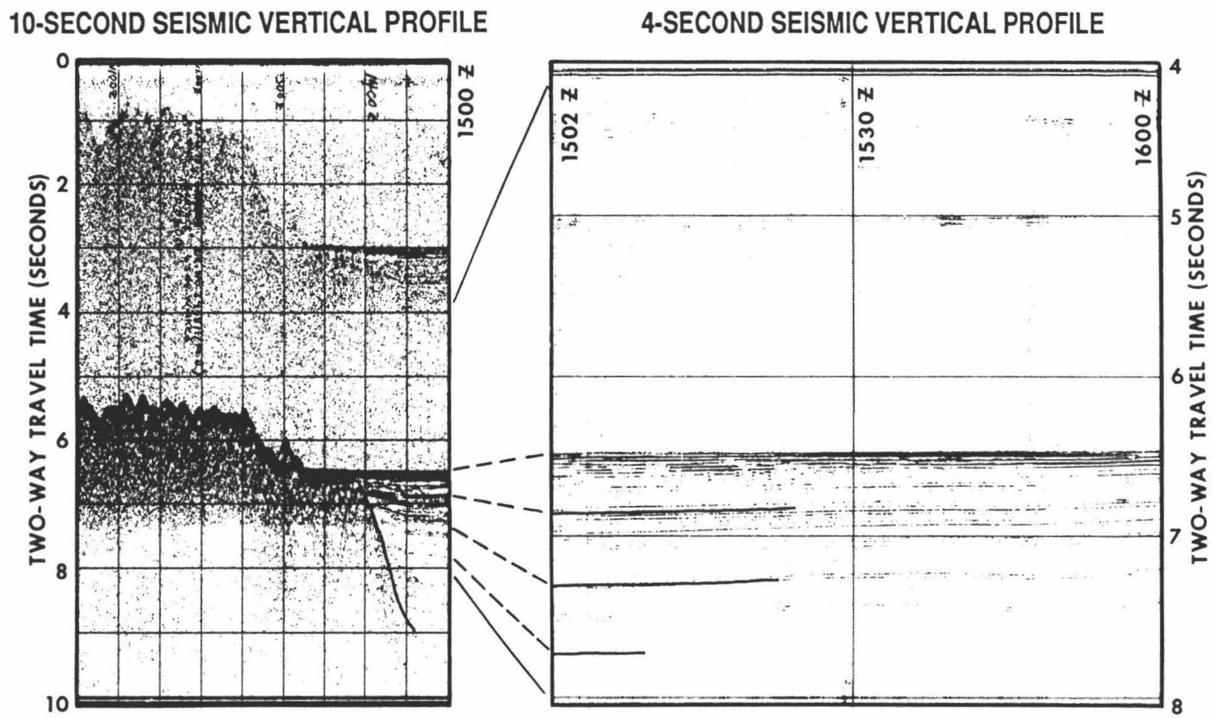



Figure 6. Illustration of 10 Second and 4 Second Vertical Profile Records.

to approximately five knots and the two seismic recorders are switched to a four-second sweep, firing the sparker at a four- second rate. The signal input to the second recorder is switched from the hydrophone streamer to the sonobuoy receiver output. In this manner, the first seismic recorder continues to record seismic vertical profile data while the second recorder now records data from the sonobuoy (fig. 7 ). A 4000 Hz reference signal from the second line scan recorder was put on an FM channel of the tape recorder and the sparker trigger pulse was put on an AM channel. A voice recorded header message was put on (AM) channel eight with information on the time, place and conditions of the WABR run. The ship is slowed to five knots in order to spread the wide angle reflection record over a longer time interval for a given distance covered and aids in picking horizons. The firing rate is increased to maintain data density with four seconds being the maximum firing rate of our system. The 3.5 KHz subbottom profiler is shut off to prevent interference, but the 12 KHz narrow beam echo sounder continues to operate. A sonobuoy is deployed over the fantail, and the ship is run at a constant speed and course for the duration of the measurement. The run is continued for an hour and a half to two hours depending on sonobuoy transmission quality for a distance of nine to ten nautical miles. The tape recorder was shut down after a voice annotation at the

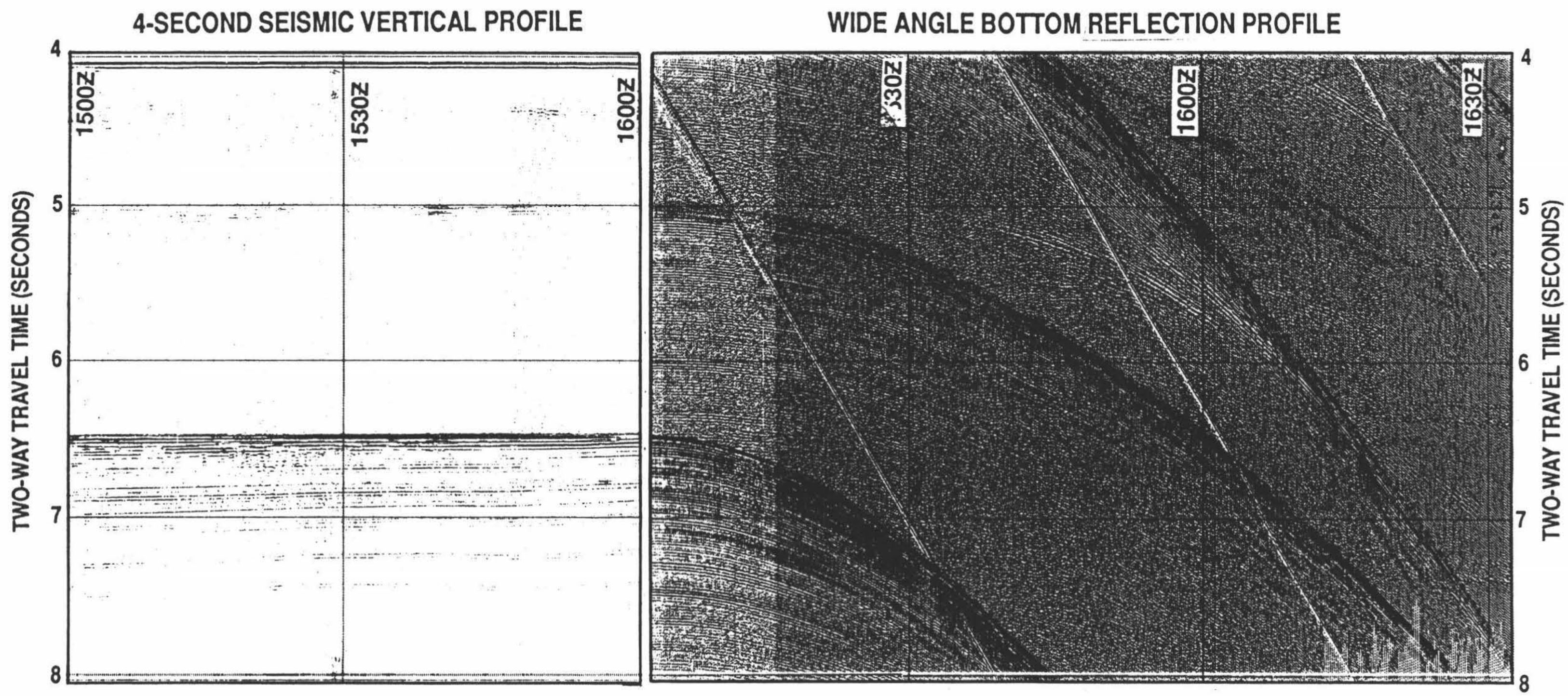



Figure 7. Illustration of WABR and Simultaneous Vertical Profile Records.

end of the run and the ship returned to normal underway operation.

Wide angle reflection measurements were often taken just prior to arrival on core station or immediately upon departure from a station so that the core and CTD data can be associated with the measurement. At sea, cores were cut to manageable lengths of four to five feet, x-rayed and velocity measurements were taken with a velocimeter, based upon study of the x-ray photographs, and measurements were made in two directions at right angles to each other with both measurements perpendicular to the length of the core. X-rays were taken of the cores in order to aid in determining layer boundaries and locate inclusions such as large shell fragments, pebbles, worm holes etc. Once boundary layers were determined,velocity measurements were taken at the top and bottom of the layer and uniformly throughout. All of these data were returned to the US Naval Oceanographic Office in Bay St. Louis, Mississippi, where the data processing was performed.

To keep from damaging or otherwise defacing the continuous seismic records, working paper records were made from the tapes. In rare cases where no tape recording was obtained or the tape recording was poor or faulty, full size photographs of the wide angle reflection record were made. Working reflection records were made by playing the tapes back through the same model seismic amplifier and line scan recorder as were used on the ship. The recorded 4000 Hz reference signal was used as a speed reference for the line scan recorder and the recorded trigger pulse was used to sychronize the line scan recorder to the tape recorder, just as the original line scan re-corder and tape recorder were synchronized on the ship. The resulting record is a duplicate of the original.

Processing to obtain velocities was done as follows: Using the seismic vertical profile record made during the station, coherent reflections were picked out and transferred to the working record. The trace of the direct wave and the trace of the arrivals from the reflections were enhanced with color pencil as shown in figure 8. Travel times of the direct wave and each of the reflected arrivals were measured from the record and tabulated on a form as illustrated in figure 9. The near surface water sound velocity, at the sparker depth and the sonobuoy hydrophone depth, were obtained from CTD data and used to calculate the distance from source to receiver based on the direct wave travel time. These data were input to a computer program written by Michael McGlaughlin of Navoceano and later slightly modified by the author (see appendix C). The program calculates the squares of the arrival times and distances, and uses the least-squares method to fit the best straight line to the plotted $X^2$-$T^2$ values. A coefficient of correlation (COC) calculated to determine the degree of fit was also found useful in determining "picking" errors and numerical transpositions

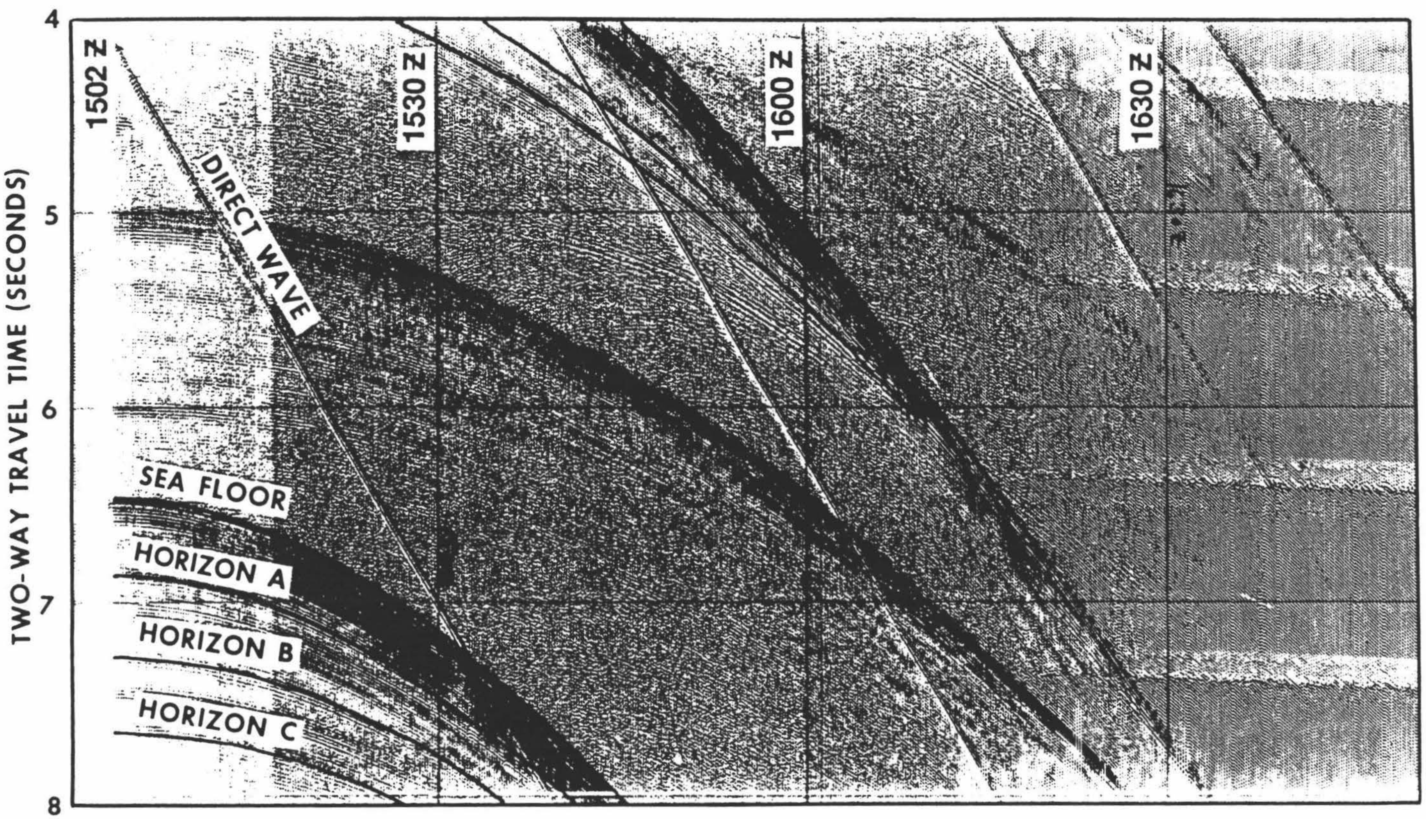



Figure 8. Illustration of Enhanced WABR Record.

# TRAVEL TIME TABULATION

STATION NO. 85

CRUISE NO. 343916 LEG NO. 30 JULIAN DATE 271 SHIP USNS WILKES

AREA INDIAN OCEAN LATITUDE 01° 21.5' N LONGITUDE 049° 06.3' E

SONOBUOY: CONSEC. NO. 30-36 REPORT NO.

| SHIP'S RUNNING TIME FROM SONOBUOY IN MINUTES | DIRECT WAVE TRAVEL TIME IN SECONDS (ONE-WAY) | DISTANCE SHIP TO SONOBUOY IN KM. | TWO-WAY REFLECTION TIME (SECONDS) | | | | |
|---|---|---|---|---|---|---|---|
| | | | SEA FLOOR | HORIZON A | HORIZON B | HORIZON C | HORIZON D |
| | t | x | t | t | t | t | t |
| 0.0 | 0.000 | | 6.248 | 6.503 | 6.905 | 7.260 | |
| 8.5 | 0.840 | | 6.296 | 6.550 | 6.957 | 7.313 | |
| 17.1 | 1.740 | | 6.482 | 6.732 | 7.120 | 7.457 | |
| 24.1 | 2.450 | | 6.717 | 6.960 | 7.322 | 7.660 | |
| 29.6 | 3.015 | | 6.955 | 7.177 | 7.527 | 7.853 | |
| 34.1 | 3.461 | | 7.170 | 7.389 | 7.733 | 8.033 | |
| 38.2 | 3.900 | | 7.385 | 7.605 | 7.945 | 8.215 | |
| 41.9 | 4.265 | | 7.600 | 7.810 | 8.112 | 8.395 | |
| 45.1 | 4.600 | | 7.792 | 8.000 | 8.295 | 8.563 | |
| 48.3 | 4.925 | | 8.000 | 8.200 | 8.485 | 8.740 | |
| 51.2 | 5.220 | | 8.190 | 8.395 | 8.660 | 8.905 | |
| 54.0 | 5.507 | | 8.385 | 8.577 | 8.838 | 9.070 | |
| 56.6 | 5.785 | | 8.568 | 8.755 | 9.008 | 9.228 | |
| 59.1 | 6.025 | | 8.740 | 8.928 | 9.172 | 9.375 | |
| 63.9 | 6.510 | | 9.085 | 9.252 | 9.490 | 9.675 | |
| 68.3 | 6.955 | | 9.425 | 9.595 | 9.805 | 9.970 | |
| 72.5 | 7.390 | | 9.765 | 9.930 | | | |
| 76.4 | | | | | | | |
| 80.1 | | | | | | | |
| 83.6 | | | | | | | |
| 87.0 | | | | | | | |
| 90.3 | | | | | | | |
| 93.5 | | | | | | | |

Figure 9. Travel Time Tabulation Sheet.

in entering the data into the computer. The correlation coefficient is defined as "the square root of the ratio of the explained variation to the total variation". It is a measure of the goodness of fit between the assumed equation and the data. If the Dix conditions of horizontal and parallel layers are met, the plot of the $X^2$-$T^2$ values is a straight line. The correlation coefficient would then be 1.0 and lower values indicate that either the conditions were not met or there are errors or noise in the data set. No fit of more than two data points is ever perfect, however, exceptionally good fits will achieve a COC of 0.99997 or 0.99998. As an example, an error of 0.2 seconds in arrival time will affect the fourth decimal place and result in a coefficient of 0.9996 or 0.9997. Checking the poor correlation coefficients most often resulted in detecting errors in picking travel times or transposition errors. Poor course maintenance or variations in speed show up as waves in the $X^2$-$T^2$ plot or bunching up of the data points. A disconcerting characteristic of our computer plotting routines is that COCs are rounded off at the fifth decimal place thus resulting in coefficients of 1.0. After establishing the straight line fit, the computer program then goes through the Dix calculations and determines interval velocities and interval thicknesses. The program outputs the $X^2$-$T^2$ plot and a tabulation of the input data with the resulting interval velocities and thicknesses as shown in figures 10 and 11. As noted earlier, the correlation coefficients indicated as 1.0000 in figure 11 have been rounded off at the fifth decimal and are actually on the order of 0.99998.

The velocimeter measurements made at sea are later corrected for temperature and pressure at Navoceano's core lab. The proceedure used for making the corrections is included as appendix B. The measurements for each core were averaged over a depth interval of thirty centimeters. In the tabulation of station layer thicknesses and layer velocities, the initial thickness (0.000) and associated velocity is that obtained from the core analysis.

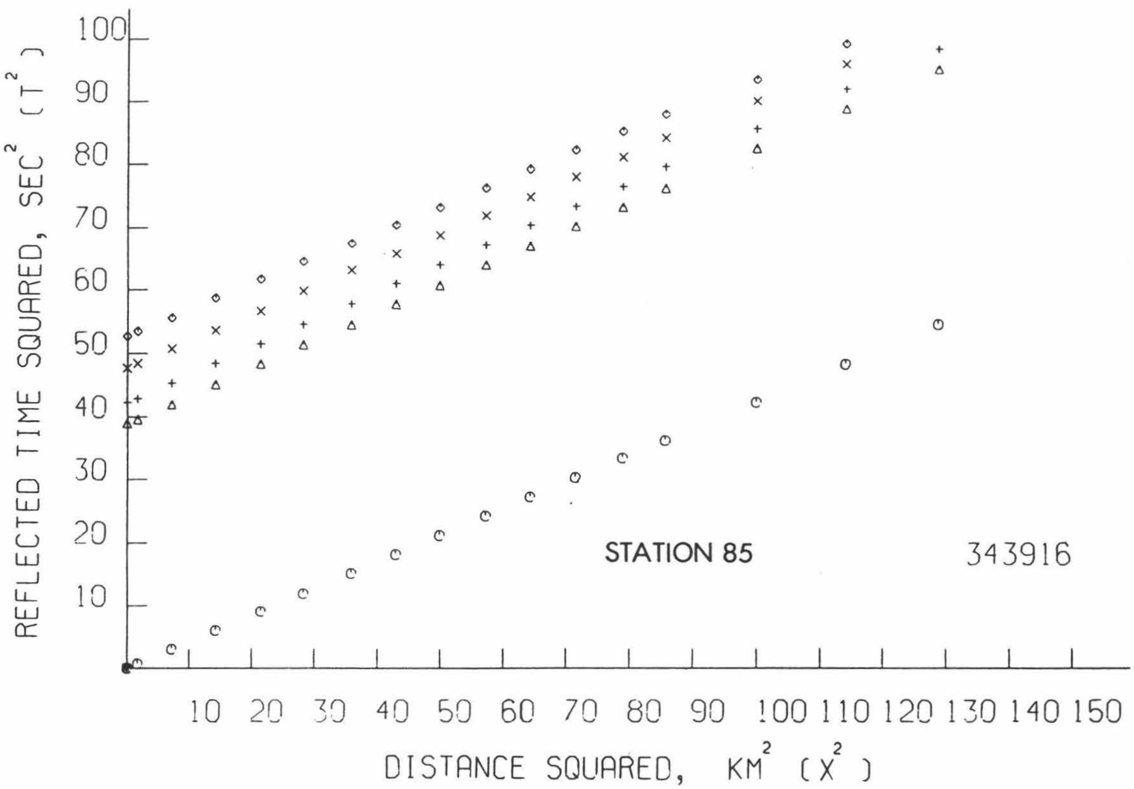



Figure 10. Computer Plot of $X^2$-$T^2$ Values.

SONOBUOY STATION NO. 85 AREA INDIAN OCEAN

SHIP WILKES 343916 LEG 30 DATE 271/79 LATITUDE 1.22 N LONGITUDE 49.06 E

| DIRECT WAVE TRAVEL TIME (ONE WAY) IN SECONDS | | DISTANCE SHIP TO SONOBUOY IN KM. | | 2-WAY REFLECTION TIME ( SECONDS) SEA FLOOR 1 | | HORIZON A 2 | | HORIZON B 3 | | HORIZON C 4 | | HORIZON D 5 | | HORIZON E 6 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| T | T^2 | X | X^2 | T | T^2 | T | T^2 | T | T^2 | T | T^2 | T | T^2 | T | T^2 |
| .000 | .000 | .000 | .000 | 6.248 | 39.038 | 6.503 | 42.289 | 6.905 | 47.679 | 7.260 | 52.708 | .000 | .000 | .000 | .000 |
| .840 | .706 | 1.289 | 1.663 | 6.296 | 39.640 | 6.550 | 42.903 | 6.957 | 48.400 | 7.313 | 53.480 | .000 | .000 | .000 | .000 |
| 1.740 | 3.028 | 2.671 | 7.134 | 6.482 | 42.016 | 6.732 | 45.320 | 7.120 | 50.694 | 7.457 | 55.607 | .000 | .000 | .000 | .000 |
| 2.450 | 6.002 | 3.761 | 14.143 | 6.717 | 45.118 | 6.960 | 48.442 | 7.322 | 53.612 | 7.660 | 58.676 | .000 | .000 | .000 | .000 |
| 3.015 | 9.090 | 4.628 | 21.419 | 6.955 | 48.372 | 7.177 | 51.509 | 7.527 | 56.656 | 7.853 | 61.670 | .000 | .000 | .000 | .000 |
| 3.461 | 11.979 | 5.313 | 28.224 | 7.170 | 51.409 | 7.389 | 54.597 | 7.733 | 59.799 | 8.033 | 64.529 | .000 | .000 | .000 | .000 |
| 3.900 | 15.210 | 5.986 | 35.838 | 7.385 | 54.538 | 7.605 | 57.836 | 7.945 | 63.123 | 8.215 | 67.486 | .000 | .000 | .000 | .000 |
| 4.255 | 18.190 | 6.547 | 42.860 | 7.600 | 57.760 | 7.810 | 60.996 | 8.112 | 65.805 | 8.395 | 70.476 | .000 | .000 | .000 | .000 |
| 4.600 | 21.160 | 7.061 | 49.858 | 7.792 | 60.715 | 8.000 | 64.000 | 8.295 | 68.807 | 8.563 | 73.325 | .000 | .000 | .000 | .000 |
| 4.925 | 24.256 | 7.560 | 57.152 | 8.000 | 64.000 | 8.200 | 67.240 | 8.485 | 71.995 | 8.740 | 76.388 | .000 | .000 | .000 | .000 |
| 5.220 | 27.248 | 8.013 | 64.203 | 8.190 | 67.076 | 8.395 | 70.476 | 8.660 | 74.996 | 8.905 | 79.299 | .000 | .000 | .000 | .000 |
| 5.507 | 30.327 | 8.453 | 71.457 | 8.385 | 70.308 | 8.577 | 73.565 | 8.838 | 78.110 | 9.070 | 82.265 | .000 | .000 | .000 | .000 |
| 5.785 | 33.466 | 8.880 | 78.854 | 8.568 | 73.411 | 8.755 | 76.650 | 9.008 | 81.144 | 9.228 | 85.156 | .000 | .000 | .000 | .000 |
| 6.025 | 36.301 | 9.248 | 85.532 | 8.740 | 76.338 | 3.928 | 79.709 | 9.172 | 84.126 | 9.375 | 87.891 | .000 | .000 | .000 | .000 |
| 6.510 | 42.380 | 9.993 | 99.857 | 9.085 | 82.537 | 9.252 | 85.600 | 9.490 | 90.060 | 9.675 | 93.606 | .000 | .000 | .000 | .000 |
| 6.955 | 48.372 | 10.676 | 113.975 | 9.425 | 88.831 | 9.595 | 92.064 | 9.805 | 96.138 | 9.970 | 99.401 | .000 | .000 | .000 | .000 |
| 7.390 | 54.612 | 11.344 | 128.578 | 9.765 | 95.355 | 9.930 | 98.605 | .000 | .000 | .000 | .000 | .000 | .000 | .000 | .000 |

VELOCITY (0 TO 1 ) 1.512 KM./SEC. COC = 1.0000
THICKNESS (0 TO 1) 4.722 KM.
VELOCITY (1 TO 2 ) 1.525 KM./SEC. COC = 1.0000
THICKNESS (1 TO 2) .194 KM.
VELOCITY (2 TO 3 ) 1.846 KM./SEC. COC = 1.0000
THICKNESS (2 TO 3) .371 KM.
VELOCITY (3 TO 4 ) 2.041 KM./SEC. COC = 1.0000
THICKNESS (3 TO 4) .362 KM.

Figure 11. Computer Data Tabulation Sheet.

# CHAPTER III

## DATA INTERPRETATION

The wide angle bottom reflection method estimates a velocity versus depth relationship where the depth is expressed in terms of layer thickness and the velocity is an average velocity for the layer. Investigators in this area prefer to express this as a parameterized relationship in terms of velocity versus one way travel time, called an instantaneous velocity function. Acoustic modelers prefer to work in terms of velocity versus depth. Thus, after obtaining the interval velocities and thicknesses for each of the WABR measurements, as described in the section on data acquisition and processing, the next step is to derive instantaneous velocity curves for each station. This is accomplished by making plots of the interval velocity data versus one way travel time, from the sediment surface, to the midpoint of the interval. A curve is then fit to the plotted data points. This method was discussed by Houtz et al (1968, 1970), Hamilton et al (1974) and Bachman and Hamilton (1980) and was closely followed in this work. As noted by these authors, interval velocity measurements have the drawback of modeling reality as constant velocity layers, thus yielding first order discontinuities that may not exist, leading to erroneous reflection coefficients. Hamilton et al. (1974), and Bachman and Hamilton (1980) have pointed out the importance of sediment surface velocities to the acoustic community and how these data provide anchor points in the velocity versus one way travel time plot. To provide these data in this study, sediment surface velocities were obtained from cores as noted earlier.

The process used to derive instantaneous velocity-time functions was to compute the one way travel time from the sediment surface to the midpoint of each layer, based on the average layer velocities obtained from each layer. These travel times are plotted versus the corresponding interval velocity. Two additional programs were written by Sara Windsor (pers. comm.), with some adaptation and modification by the author. One program converts individual layer thicknesses and velocities to velocity versus one-way travel time to layer midpoint, plots the data points, and fits each of three curves (linear, parabolic, exponential) to the points by the least squares method. Presently, both linear and parabolic curves are commonly used by modern investigators such as Houtz et al. (1968, 1970 ) and Bachman and Hamilton (1980). The exponential curve was tried because of the consideration that many geologic processes tend to be exponential in nature, such as erosion and deposition and that compaction might follow the same trend. A correlation coefficient was calculated for each curve fit so that the best fitting type of curve may be determined. The curve is forced through a sediment surface velocity point by weighting this data point (see appendix D). In the second program, data from several stations are then combined on the same graph and again fit with each of the three diferent curves and correlation coefficients calculated. Each curve is forced through the average surface sediment velocity of all of the stations included in the run (see appendix E). It should be noted that in spite of heavy weighting of the surface velocity data point, the best fit curve often resulted in a slightly different surface velocity due to skewing of the line or curve by the remaining data points. The author felt that this was acceptable, even though the surface velocity is a directly measured quantity, because of the possible errors involved in the core sample velocity measurements and a reasonable validity given to the other data points. An example of a single station plot and a group station plot is given in figure 12.

Of the 70 stations in the Somali Basin, 80% of the velocity versus one-way time data were fit best by a parabolic curve and the remaining 20% were fit best by a linear curve. The criteria for fit was the correlation coefficient. The coefficient of correlation is a measure of how well a linear or other equation describes the relationship between variables. A COC of 1.0 is a perfect fit. Of those stations fit best by a parabolic curve, the difference in the correlation coefficients between parabolic and linear fit was at the most 0.01 and

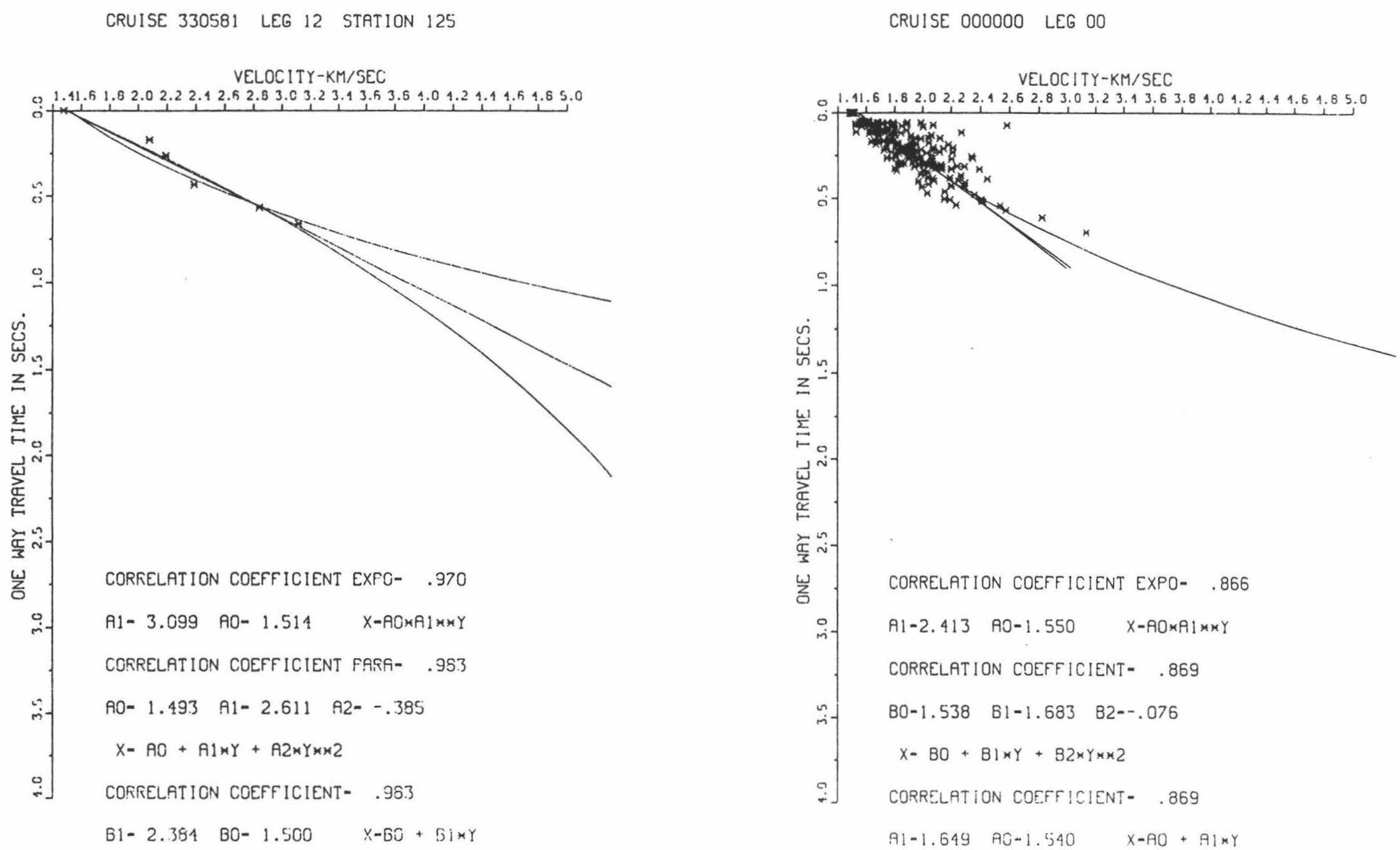



Figure 12. Example of Single and Group Station Data Plots and Curve Fits.

most often of the order of 0.005. Thus, it would be reasonable to assume a linear function for one- way travel time plots for the areas investigated. The exponential curve was the best fit by correlation coefficient in only one case out of all cases, and it was thus assumed that the speculation concerning the exponential nature of compaction was not justified.

Plotting the interval velocity at the midpoint of the layer is valid only if the layer has a constant velocity or if the velocity increases linearly with depth. If the best curve fit is parabolic, then the linear conditions are not met and the position in the layer at which the interval velocity is assigned must be corrected. Houtz et al. (1968) made an analysis of the error involved in placing the interval velocity at the layer midpoint when the velocity increases in the layer as a second order function. The error analysis determines that the correction for the interval velocity position in the layer is $E = Cdt^2/12$ where C is the constant in the parabolic curve fit given by $V=At^2+Bt+C$ and dt is the interval thickness in terms of one way travel time. Thus, when the correlation coefficient indicates that the parabolic fit is best, the position of the interval velocity in the layer is corrected by the factor E, replotted and refit with a parabolic curve for the resultant "Instantaneous Velocity Curve" of Houtz et al. (1968) and Hamilton et al. (1974). An example of instantaneous velocity curves derived using data from one station and data from numerous stations is presented in figure 12.

A function for depth in terms of one way travel time from the sediment surface is derived by integrating the instantaneous velocity function:

$$V=at^2+bt+c$$

$$\int V\,dt = D = et^3+ft^2+gt+H$$

where V is the velocity and the integral of velocity, D, is the depth from the sediment surface. The constant of integration H is zero since the depth must be zero at time equal zero. We now have expressions for velocity and depth in terms of one way travel time. These can be related by setting up a table for the values of velocity and depth obtained from the two equations when the same values of time are inserted into the equations and the values for V and D calculated.

| t | V | D |
|---|---|---|
| 0.1 | i | j |
| 0.5 | k | l |
| 1.0 | m | n |
| 1.5 | o | p |
| 2.0 | q | r |

Corresponding pairs of velocity and depth values (i,j;k,l;m,n;o,p) are plotted and fit with a curve by least squares resulting in a curve and function expressing the velocity in terms of depth.

$$V' = s + uD + wD^2$$

A listing of the program used to derive the velocity-depth function is given in appendix F. The estimate of error for the resultant velocity-depth function is the sum of the errors in each step of the process. The error in the WABR process has been estimated by Le Pichon et al. (1968) at ± 80m/s. The standard estimate of error in the Instantaneous Velocity process is of the order of 120 m/s and in the velocity-depth process is of the order of 10 m/s. Thus the cumulative error is approximately 210 m/s.

With very few exceptions, seismic penetration was about 1.2 seconds; therefore measurements and plots are limited to the upper 1000 to 1500 meters of the sediment. Some individual stations have only two data points; a surface velocity and one layer velocity. Other stations have as many as eight data points. For those stations with very few data points, it was not possible to derive a velocity-depth function without a great deal of speculation. Thus, groups of stations from an area were used to derive a velocity-depth function representative of that particular area. As an example, a velocity-depth function for the northernmost portion of the abyssal plain between Chain Ridge and the African Continental Rise was derived using stations 67 through 76; 40 or more data points to derive the representative velocity-depth function. The use of groups of stations for deriving velocity-depth functions was followed to derive functions for entire abyssal plains, portions of abyssal plains, east-west and north-south trending lines through abyssal plains and continental rise areas. These functions are compared to each other in order to determine whether or not significant differences exist between the velocity-depth functions of the various areas. A discussion of the two regions and the variations of their velocity structures follows.

A. SOMALI BASIN

A list of the stations in this area, along with layer interval velocities and thicknesses, is given in Table 3. There were insufficient data points to derive an instantaneous velocity function for three areas, namely: the continental rise north of 3° 30'S, the abyssal plain area east of Chain Ridge and the abyssal plain area to the north and east of the Seychelle Islands. Instantaneous velocity-time functions and velocity-depth functions were obtained for eight groupings of stations: 1) north-south line in the northern abyssal plain, 2) east-west line in the northern abyssal plain, 3) north-south line in the southern abyssal plain, 4) eastwest line in the southern abyssal plain, 5) all abyssal plain stations, 6) all continental rise stations, 7) all northern abyssal plain stations and 8) all southern abyssal plain stations. In comparing the north-south line to the east-west line in the northern abyssal plain, we find that the velocity gradient decreases with depth on the east-west line while the gradient is more nearly constant on the north-south line (figure 13). The same comparison in the southern abyssal plain ( figure 14 ) shows just the opposite of this situation, a decreasing gradient in the north-south line and a more nearly constant gradient in the east-west line. In the southern abyssal plain, both lines show the same initial gradients and velocities down to 400 meters where the curves begin to diverge. A comparison of all of the abyssal plain stations to all of the continental rise stations shows a similar feature (figure 15). Both curves are essentially the same down to a depth of about 600 meters at which point the curve for continental rise stations begins to show a greater decrease in gradient. A velocity-depth curve from a function derived using all 70 of the Somali Basin stations is also presented in figure 15 for comparison. A comparison of the velocity-depth curve and function for the northern abyssal plain stations to the southern abyssal plain stations indicates that both curves show essentially the same gradient to approximately 350 meters where the gradient for the northern abyssal plain begins to decrease more rapidly than does that for the southern abyssal plain. The two curves are slightly offset due to a small difference in surface sediment velocity. The velocity-depth curve for all of the abyssal plain stations of the Somali Basin is a composite of these two curves (see fig.16). Given that the overall estimate

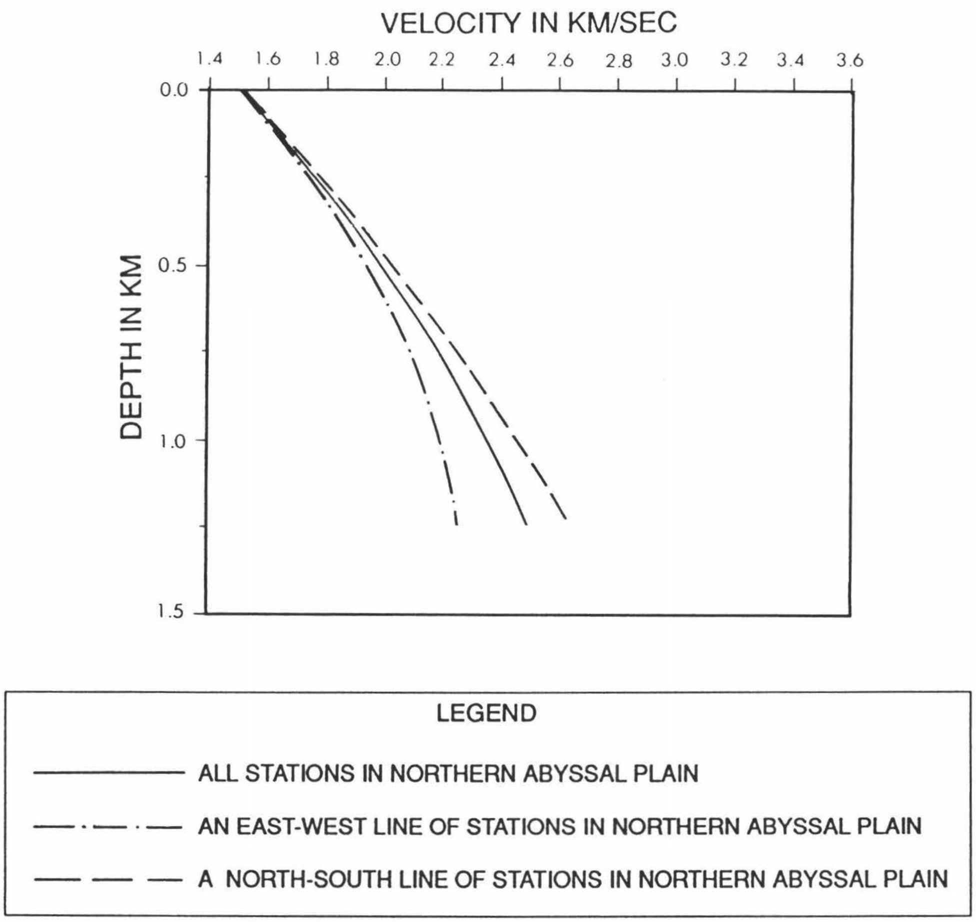



Figure 13. Velocity-Depth Curves For E-W Versus N-S Lines in the Northern Abyssal Plain.

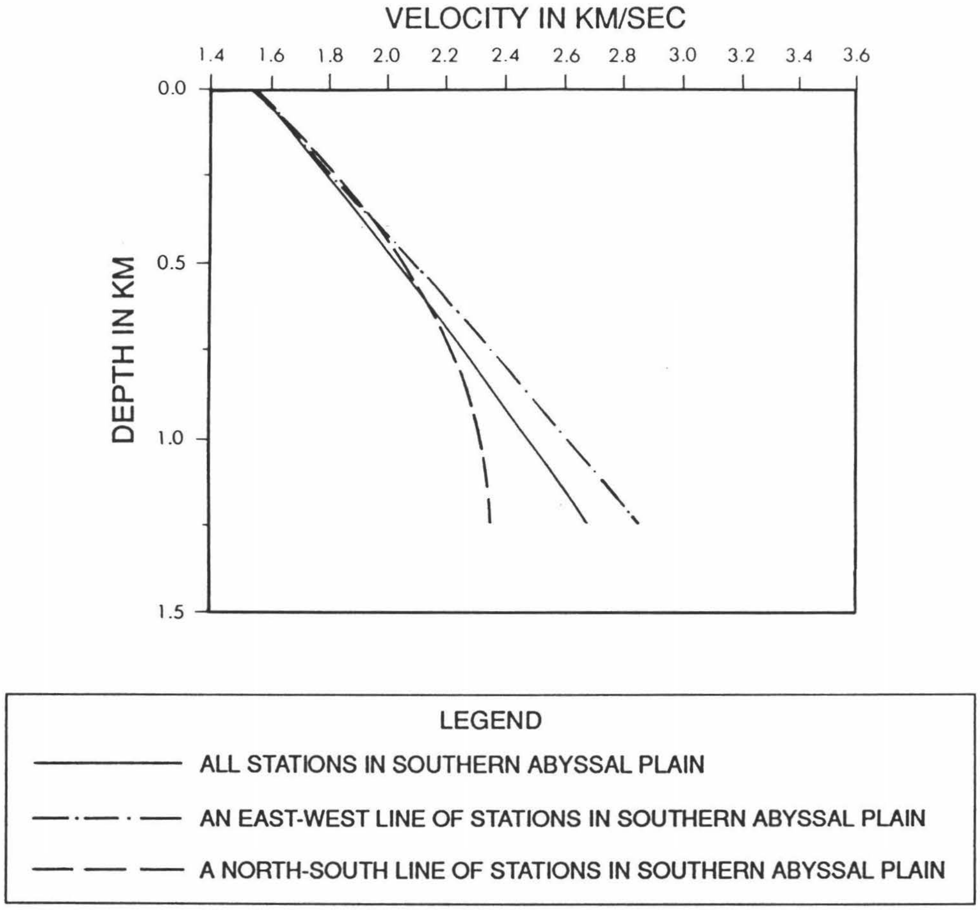



Figure 14. Velocity-Depth Curves For E-W Versus N-S Lines in the Southern Abyssal Plain.

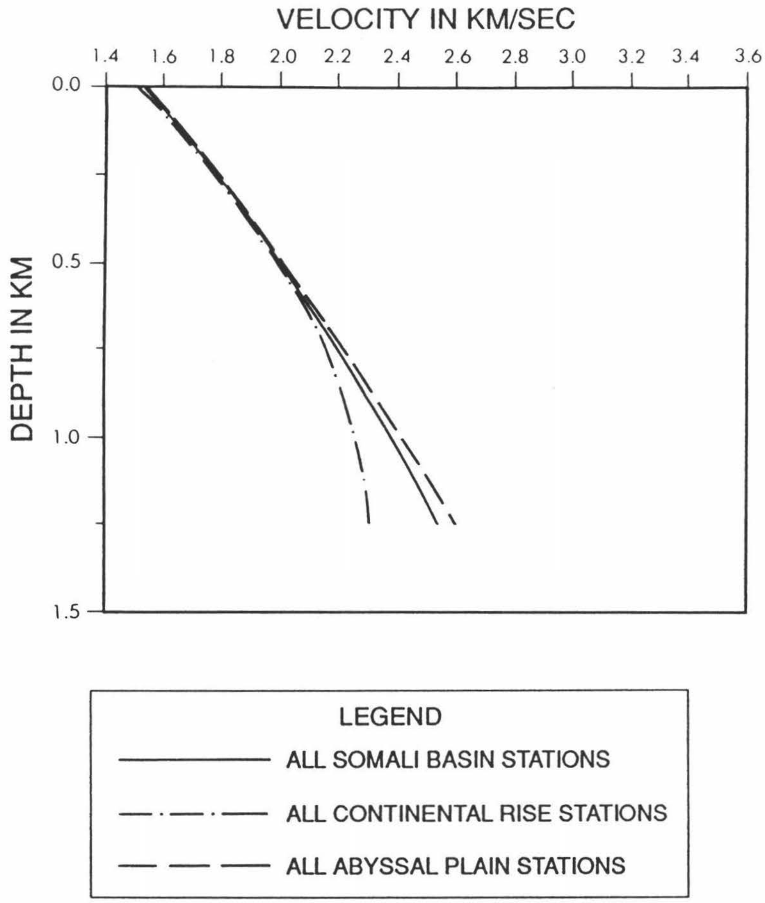



Figure 15. Velocity-Depth Curves for Abyssal Plain Versus Continental Rise in Somali Basin.

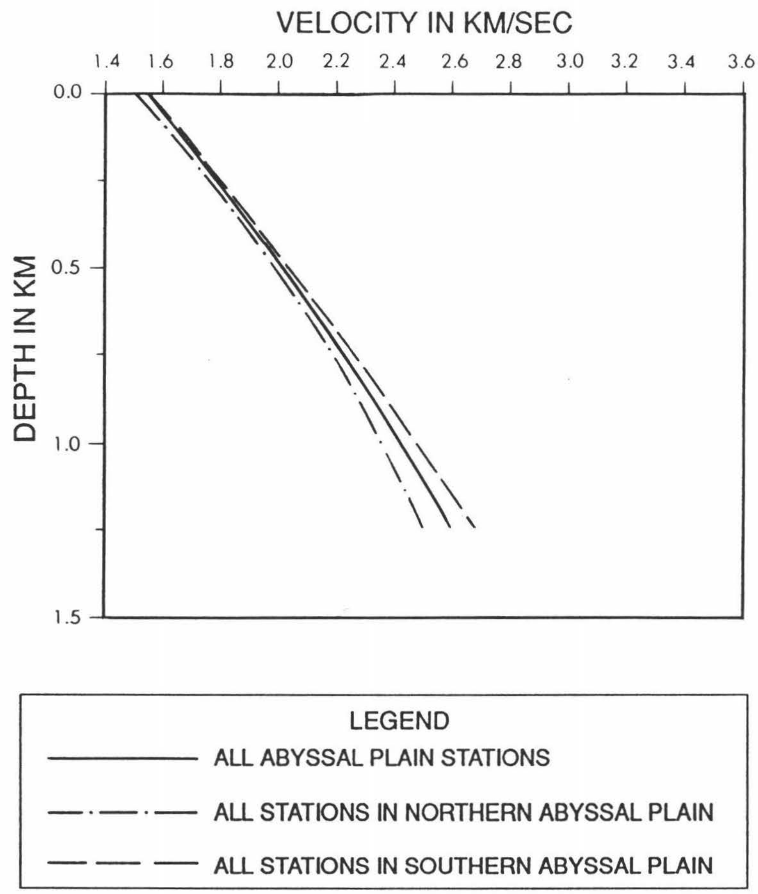



Figure 16. Velocity-Depth Curves for Northern Abyssal Plain Versus Southern Abyssal Plain.

of error in the velocity-depth curves is of the order of 200 m/s, the differences in the curves presented in the figures 13 to 16 is not much greater than the statistical error. The differences in the curves are differences in velocity gradient, which depends on factors such as depth, particle size, sorting, sediment type, etc. The station group curve is derived from the data of a number of stations sampling different portions of the basin. Thus, each group curve is the result of an average sampling of different portions of the basin which results in variations in the gradient of the curves.

If a general velocity-depth function for the entire Somali Basin as an entity is desired, the parabolic function derived using all 70 stations would be appropriate or the simpler linear function derived from the same data could also be used. A listing of the velocity-depth functions derived for this area is given in (A) of table 1 and a listing of the instantaneous velocity-time functions is given in (A) of table 2.

A fence diagram constructed of the interval velocities and thicknesses obtained by WABR measurements in the Somali Basin is presented in figure 17. The diagram was plotted to ascertain the uniformity or nonuniformity of velocities and thicknesses in the two central abyssal plain areas of the Somali Basin. Obviously, the thickness of layers is not consistent between the two abyssal plains

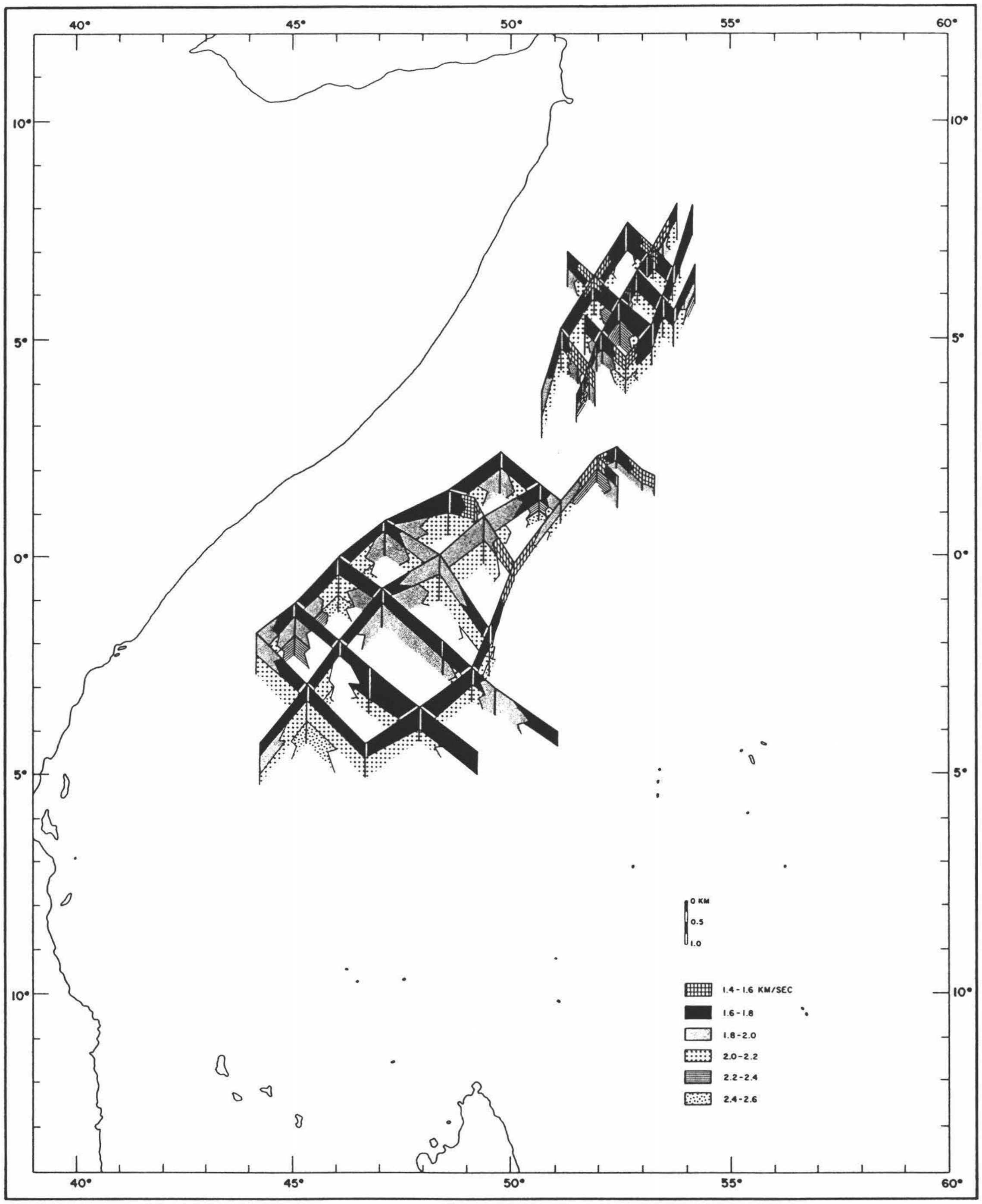



Figure 17. Fence Dilagram of Interval Velocities and Thickness in Somali Basin.

nor even within an individual abyssal plain itself. This may be due partially to the interpretor who picked the various reflectors. It was observed during the work, and may be verified by a study of Table 3, that particular reflectors could not be traced for more than a station or two at a time. The diagram indicates a variability of velocity and thickness throughout each abyssal plain.

While processing the Somali Basin data, we calculated the ratio of the sediment surface sound velocity, as determined from cores, to the bottom water sound velocity,as determined by SVSTD or CTD. During the calculations, it was noted that the ratio was always less than 1.0 despite the fact that Hamilton (1980) indicates that in some cases it should be greater than 1.0. This situation led me to plot the bottom sediment surface velocity versus location of the measurement on a chart of the area. I also plotted the bottom water sound velocity versus measurement location on another chart of the area. Both charts were contoured and one overlaid on the other. At those points where core velocity and bottom water velocity measurements coincided, the ratio of core velocity to bottom water velocity was taken and plotted in that position on a third chart. Intermediate ratio points for the third chart were obtained from the coincident contours of the previous two charts and by extrapolation guided by local sedimentology. This ratio chart was then contoured.

It should be noted that in addition to the velocities obtained by the WILKES, all available sediment surface velocities from the National Oceanographic Data Center were included in the plot. The three plots are presented in figures 18, 19, and 20. Consideration of figure 18, the contour plot of sediment surface velocities, indicates that the sediment surface velocities reflect the bathymetry or physiography to a considerable extent. Chain Ridge, though not well defined due to a lack of velocity measurements on the Ridge itself, is expressed by a high on either side. The highs on either side delineate the abyssal plains on the east and west sides of the Ridge. The sediment surface velocities generally increase with ocean depth. Consideration of figure 19, the bottom water velocity contour chart, shows as expected (Urick 1983) that the bottom water velocity is a function of depth and therefore controlled by physiography. In the northern and eastern portion of the Basin the bottom water velocity reflects the physiography to a large degree. In the western and southern portion of the Basin the bottom water velocities are not as high, particularly in the African Continental Rise area and the southernmost portion of the abyssal plain area, as those in the northern portion of the Basin, due to the shallower depth. In the southern portion of the Basin both sediment surface velocity and bottom water velocity do not reflect the physiography

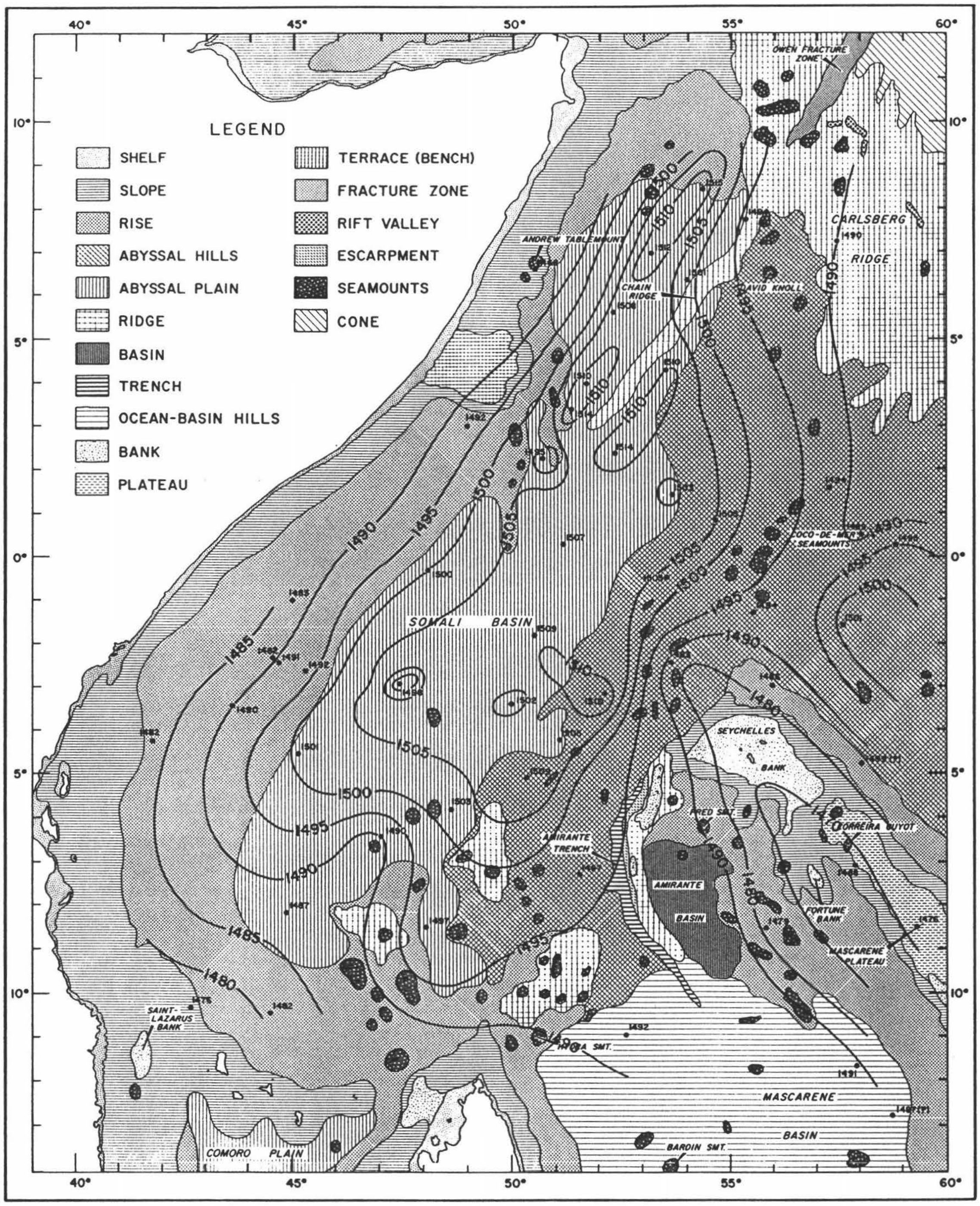



Figure 18. Somali Basin Sediment Surface Sound Velocity Contour Chart.

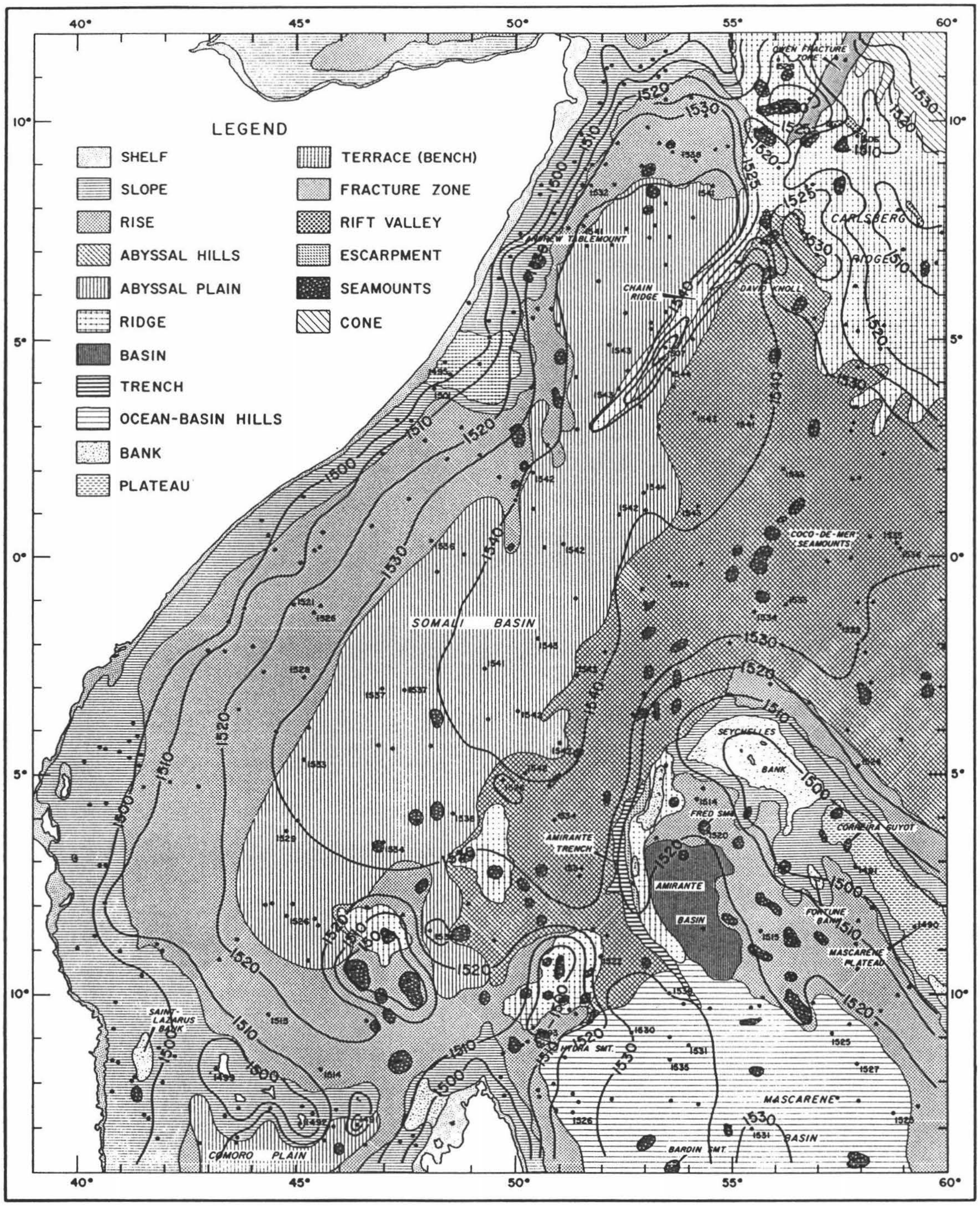



Figure 19. Somali Basin Bottom Water Sound Velocity Contour Chart.

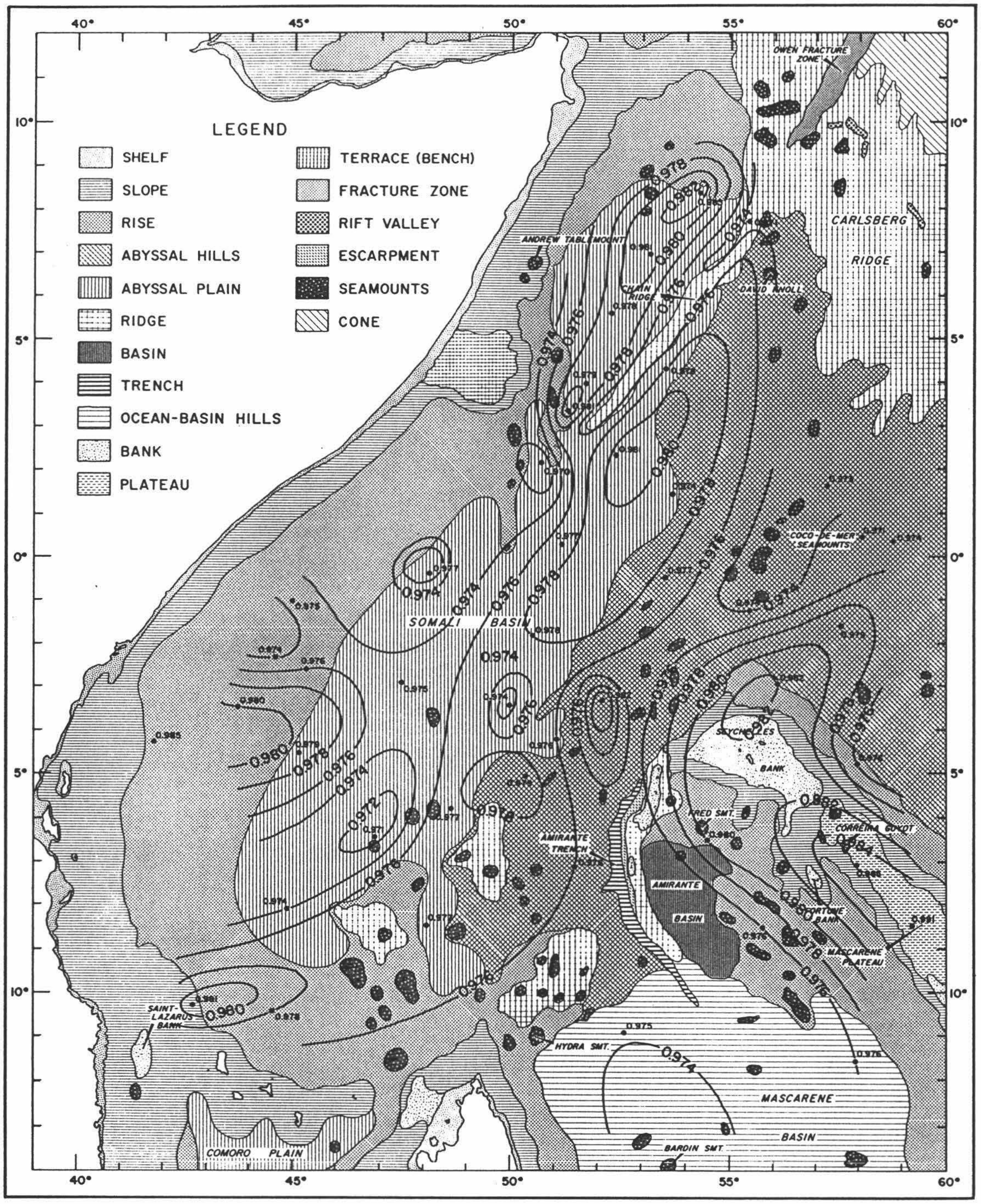



Figure 20. Sediment Surface To Bottom Water Sound Velocity Ratio Contour Chart for the Somali Basin.

nearly as well. This situation results in a profound effect on the sediment surface velocity/bottom water velocity ratio plot in figure 20. Consideration of this figure indicates that the ratio reflects physiography quite well in the northern and east-southeast portion of the Basin but has little relationship in the south and west. The ratio contour chart shows a high in the south-west and a low in the south central portion of the basin. This central low is the obvious result of the nose of low sediment velocities indicated in that area in figure 18. The reason for the nose of high ratio in the southwest is not apparent when considering figures 18 and 19.

## B. ARABIAN SEA

A list of the stations taken in this area, along with their interval velocities and thicknesses, is provided in table 4.

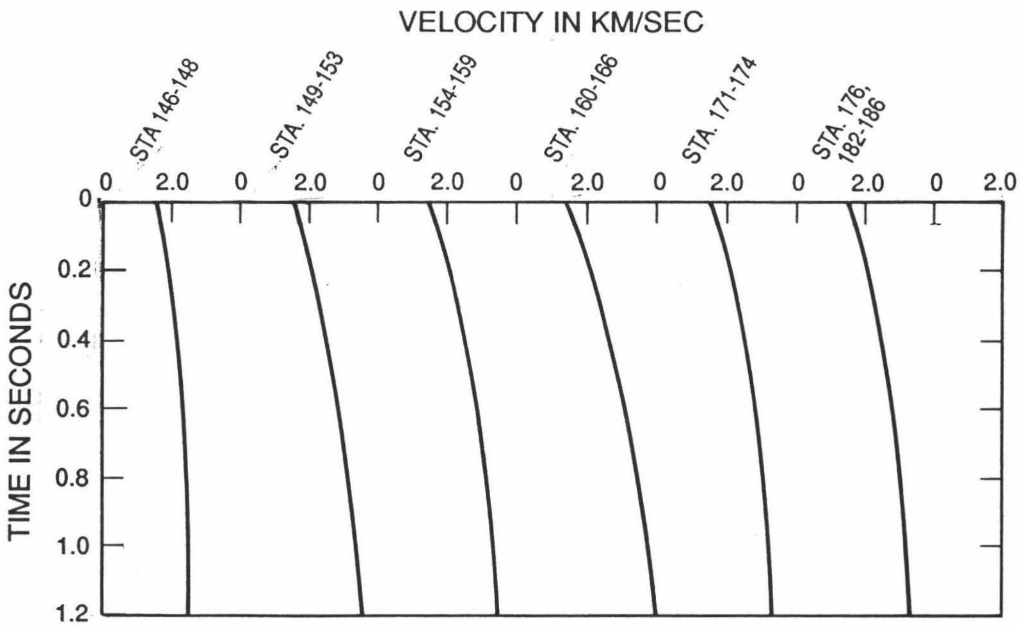
The general process used in this area was the same as that used in the Somali Basin. An instantaneous velocity-time curve was obtained for each station taken in the Oman Abyssal Plain. Individual stations were compared to each other to see if there were anomalous areas. In the Oman Abyssal Plain, it was thought that certain stations might be anomalous on the basis of their physiographic location. Stations 131 and 132 were two stations expected to be anomalous on the basis of their location in the northeast corner of the plain where the plain pinches down to somewhat of a trough. Stations 143, 144, and 145 were expected to be anomalous because of their position at the extreme south end of the plain where the bottom rises to the Murray Ridge. In the analysis, station 124 was found to have a higher gradient than most of the remainder and station 129 was found to have a lower gradient. However, both of these stations lacked velocities deeper in the sedimentary section and therefore the observation may not be significant. Stations 131 and 132 are very similar to each other and somewhat similar to station 124. Stations 143, 144 and 145 were quite similar to each other and to the bulk of the stations. In a comparison of the instantaneous velocity-time curves for each of the stations in the Oman Abyssal Plain, stations 124 and 129 were the only stations that seem to be somewhat anomalous in their gradients and they were suspect due to their lack of deeper velocities. Groupings of stations were used to look for any variations with direction but none were found. The end result of the analysis in the Oman Abyssal Plain was that two velocity-depth curves were derived for two separate conditions: 1) derived using all of the stations except 124 and 129; and 2) derived using all of the stations in the Abyssal plain. There was no difference between the curves. Groups of stations were plotted together and a velocity-depth curve obtained for them.

For example, the velocities from stations 124 through 130 and for stations 133 through 137 were plotted and curves obtained. The two curves were then compared for differences in gradient, etc. The velocities from a group of stations in a north-south line, stations 128, 134, 139, 141, 145, were similarly plotted and a curve obtained. This curve could be compared to the curve obtained from stations in an east-west line. In fact, two north-south lines were run for comparison to each other and for comparison with an east-west line of stations. This was to detect possible N-S variation with longitude.

The group of stations 167 through 170, 180 and 181, in the Owens Abyssal Plain which parallels the Arabian Coast, was then analyzed. These stations are located along the longitudinal axis of the plain and were analyzed for variations in that direction by comparing individual station velocity-depth curves. No anomalies were detected and all of the station curves were similar as expected.

The third group of stations analyzed is that group taken on the Indus Cone and consisted of stations 146 through 166, 171 through 176, 182 through 186, 300 through 312, and 344, 345, and 346. The wide grouping of station numbers is due to the fact that various legs were run in different years. The analysis of this group of stations was the most varied and also the most comprehensive due to the large number of stations and the geometric pattern of the stations allowing for great variety in the analysis. The instantaneous velocity-time curves were used to determine if there were any anomalous zones in the entire area. In this initial comparison, stations 146 and 149 are somewhat anomalous in that they have slightly higher velocity gradients than other stations. However, both of these stations have only two velocities, a surface velocity and one layer velocity, and therefore are not considered to be very reliable. In comparing all of the remaining stations, minor differences in initial velocity and minor differences in gradient are observed but all of the station curves are remarkably similar. Based on these results, the stations were arranged in various groupings. For example, all of the stations taken at the nose end of the cone in water less than 3,000 meters were put into one group, all of those in the mid cone area in water 3,000 to 4,000 meters in one group and all of the stations on the distal end of the cone in water 4,000 meters or more in a third group.

Another mode of analysis is to take each line of stations as a group, 146 through 148 or 149 through 153, and compare these composite curves to the curve for the adjacent line. Stations are plotted in a stepwise fashion with each line of the track down the entire cone (see fig. 21). A number of stations whose positions form a line




EACH CURVE REPRESENTS A NW-SE LINE OF STATIONS ON THE INDUS CONE.
LINES PROGRESS TOWARD THE DISTAL END OF THE CONE.

Figure 21. Instantaneous Velocity-Time Curves For the Indus Cone.

from north to south across the cone are assembled into two groups and composite curves are derived for stations at different longitudes to evaluate possible variations between the two north-south lines. Two east-west lines of stations were also chosen and curves obtained to check for variations in curves between east-west lines at different latitudes. Comparisons were made between the north-south lines and east-west lines. Other lines of stations at various angles around the compass were also used to derive instantaneous velocity-time curves and check for any radial variations throughout the area.

After all the comparisons and evaluations had been carried out with all of the various possibilities for groupings, velocity-depth curves were derived for a dozen of the significant groupings. These curves were used for the final evaluations. Three of the twelve pertained to the Oman Abyssal Plain Area and the Owens Abyssal Plain area. Only one velocity-depth function is needed for each of the two abyssal plain areas. The remaining nine velocity-depth functions are derived for the cone area to verify observations from the instantaneous velocity-time functions. The gradient is sufficiently low on the first line of stations (146-148) to justify its own velocity-depth function. All of the remaining lines of stations are found to be similar enough to be modeled by only one velocity-depth function.

Thus for the Arabian Sea, it is suggested that four separate velocity-depth functions apply. One for the Oman Abyssal Plain, one for the Owens Abyssal Plain, one for the upper reaches of the Indus Cone (within 160 Miles of shore) and one for the remainder of the Cone. The functions for these four areas are tabulated in Table 1(b) along with the variance and standard estimate of error for each function.

The velocity-depth function for the lower Indus Cone varies somewhat in gradient from that developed by Bachman and Hamilton (1980) from eight WABR stations taken in 1977 on the Indus cone by the Wilkes. In this work we have the benefits of a considerably greater number of stations, well spaced across the Cone and with supporting core data for surface sediment velocity, to ensure that our quantification of regional velocity-depth parameters are valid. A presentation and comparison of the two curves is made in a later chapter.

Fence diagrams constructed for the interval velocities and thicknesses obtained for the Arabian Sea are presented in figure 22. These diagrams indicate even greater variability than those for the Somali Basin, at least for the Indus Cone. The Oman Abyssal Plain does seem to have a fairly uniform section in the upper few hundred meters throughout most of the Plain. Only in the southernmost portion of the Plain triangle does it differ.

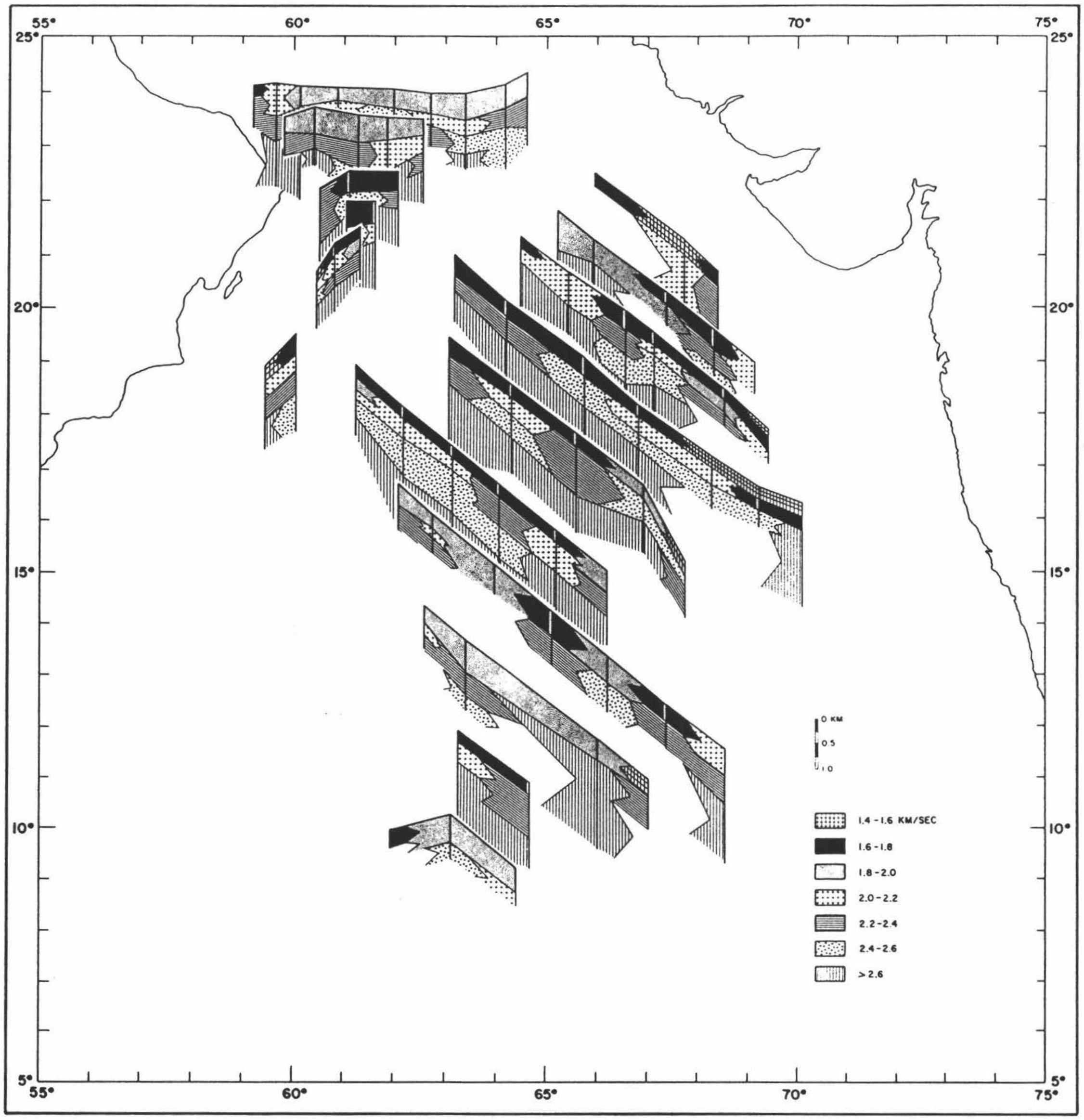



Figure 22. Fence Diagram of Interval Velocities and Thicknesses of the Arabian Sea.

The Owens Abyssal Plain shows the same uniformity as the Oman Abyssal Plain. On the Indus Cone, the lowermost section velocity seems to be fairly consistent throughout the Cone but successive sections above this show a considerable amount of variation.

Charts of the sediment surface sound velocity, bottom water sound velocity and the ratio of the sediment surface sound velocity to the bottom water sound velocity are presented as figures 23,24,and 25. Consideration of the sediment surface sound velocity chart in figure 23 shows a velocity increasing with distance from the source of deposition and, in consequence, with depth. A distortion of the smooth contour pattern of the upper section of the cone can be noted in the vicinity of the Lakshmi Ridge and is very likely due to a channeling of the sediments to the East of the Ridge as noted by Kolla and Coumes (1987). The bottom water sound velocity contour chart shown in figure 24, exhibits a considerable uniformity with the velocity again increasing with distance from the nose of the cone as depth increases. The chart showing the ratio of the sediment surface velocity to bottom water velocity is shown in figure 25. Considering the relative uniformity of the two previous charts, this chart is somewhat surprising. Aside from the ratio high in the upper portion of the Cone, the ratio generally decreases with distance from the source of the Cone. Obviously, the

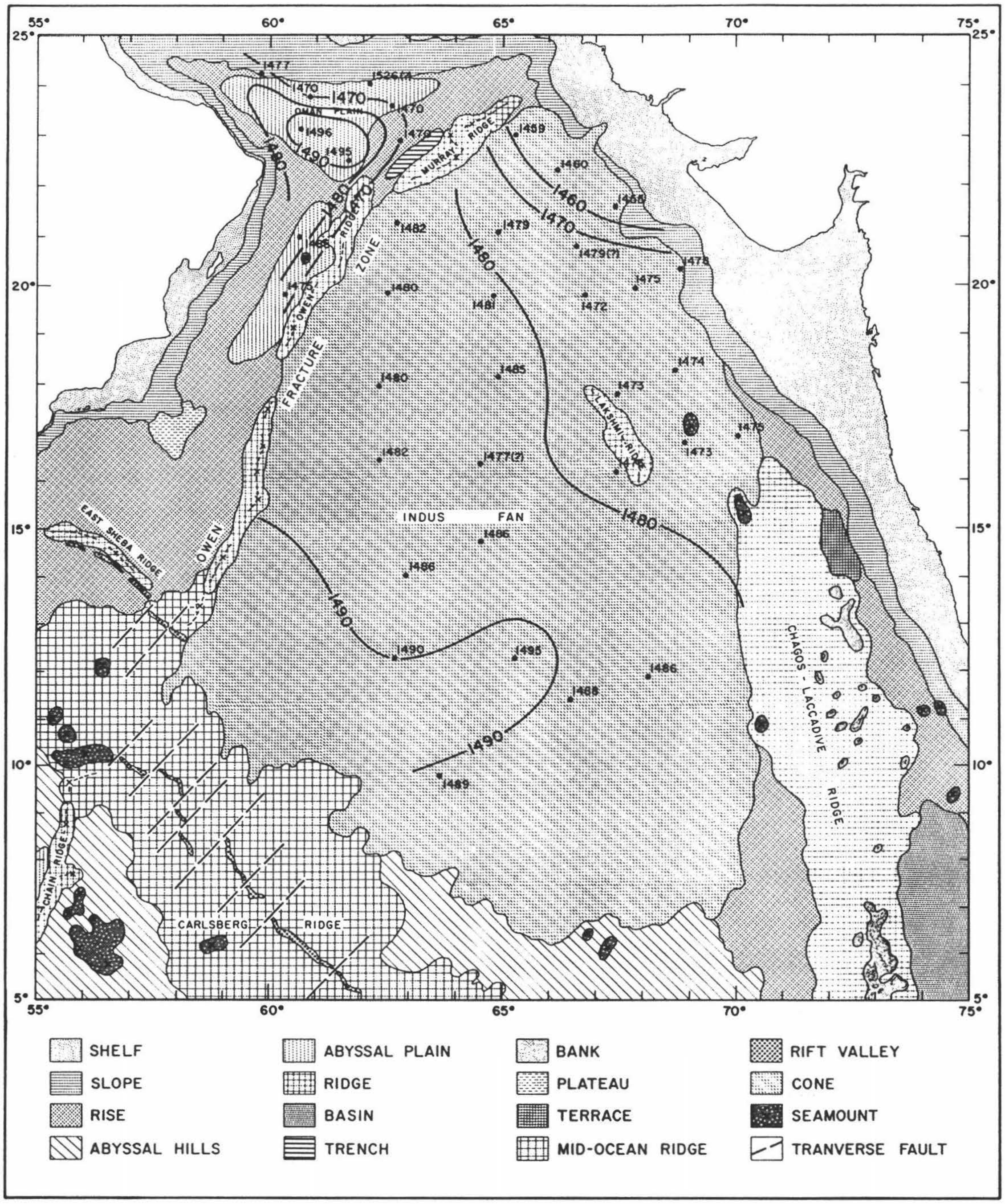



Figure 23. Arabian Sea Sediment Surface Sound Velocity Contour Chart.

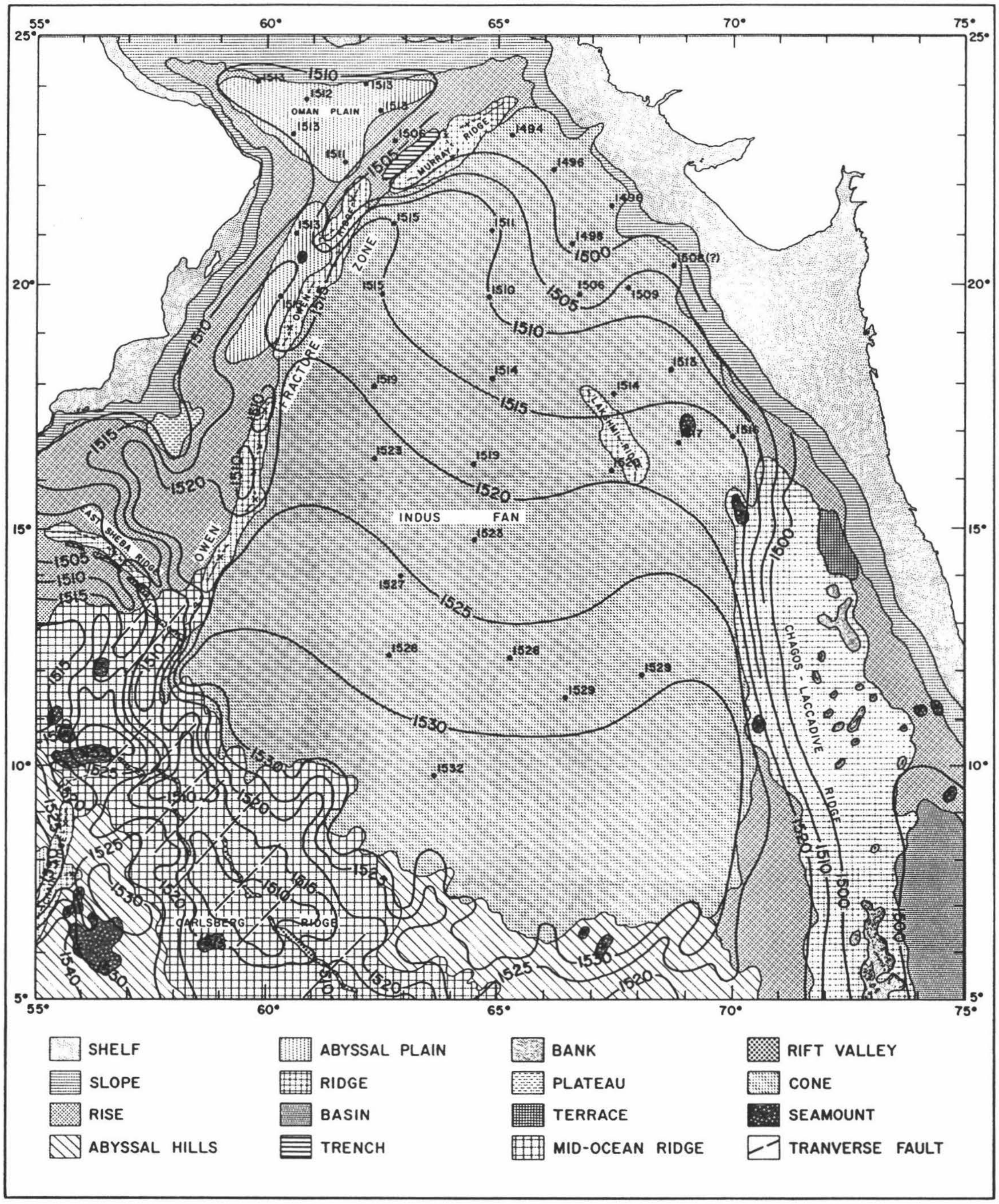



Figure 24. Arabian Sea Bottom Water Sound Velocity Contour Chart.

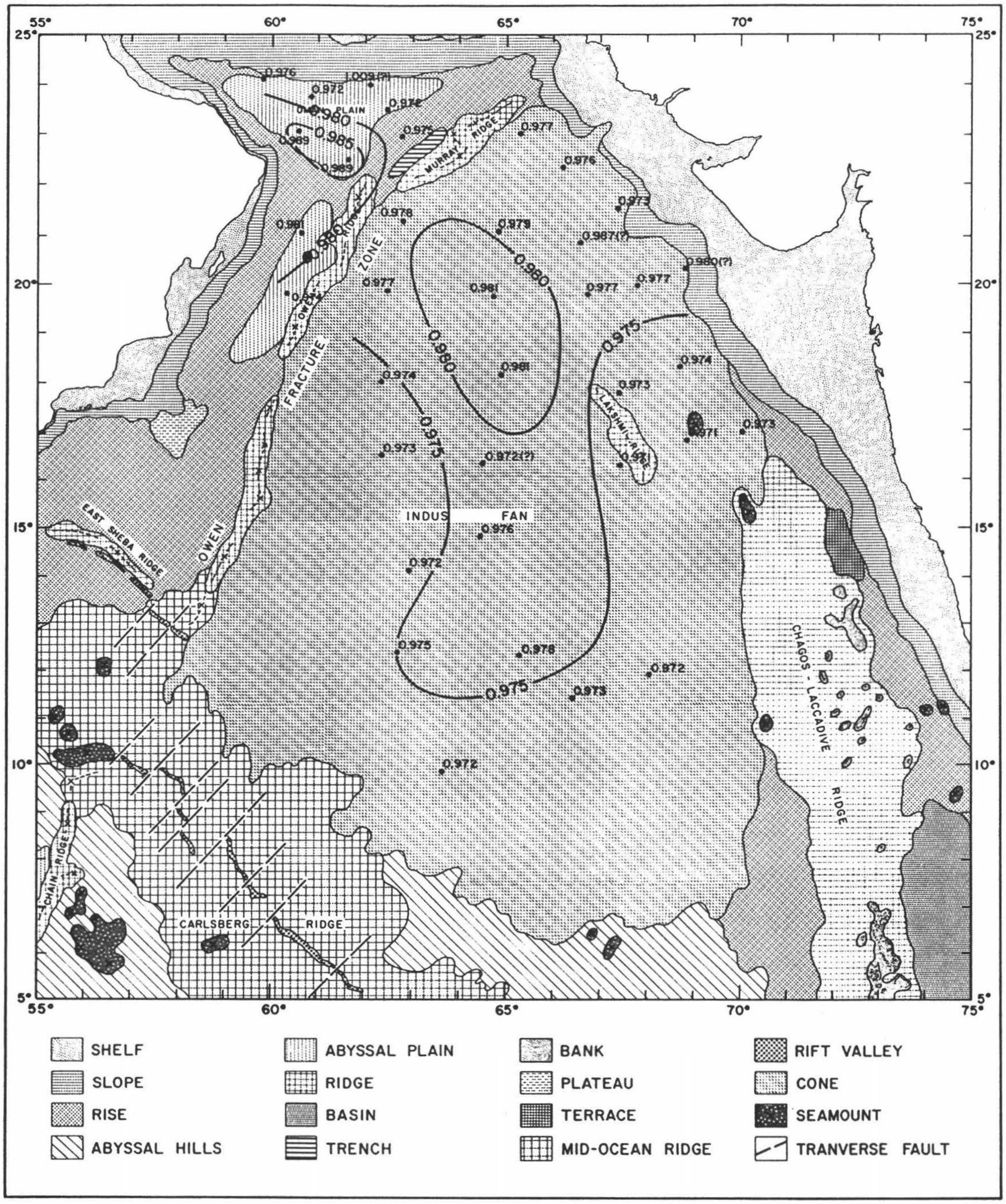



Figure 25. Sediment Surface to Bottom Water Sound Velocity Ratio Contour Chart of the Arabian Sea.

the nose of the Cone than does the sediment surface velocity. The implications of the fence diagrams and of the velocity contour diagrams of both the Somali Basin and the Arabian Sea are discussed in the following section.

# CHAPTER IV

# DISCUSSION

The construction of sound velocity contour charts for the sediment surface, the bottom water and the ratio of these two was detailed in the previous chapter. Some of the features noted in those charts are considered at this point. The most obvious feature in all of the contour charts was the relationship of the velocity to the physiography and depth. The relationship of the water sound velocity with depth is well known as noted by Urick (1983), and of interest to this discussion is the fact that the bottom water velocity varies linearly with depth beyond the main thermocline. This relationship varies minimally with seasons but the particular linear relationship does vary from ocean area to ocean area. The relationship of sediment surface velocity with depth suggested by the contour charts seems reasonable, when considering that the water content of the core samples in this study was in the range of 40% to 50% (pers. comm. NAVOCEANO CORE LAB) and the included water is the same bottom water. To test this observation, the sediment surface velocities were plotted versus water depth for both the Somali Basin and the Arabian Sea. A straight line was fit to the data by least squares for each case and a correlation coefficient determined to verify the relationship. The two plots are shown as figures 26 and

27. The particular bottom water velocity versus depth relationship for each area was determined by plotting the bottom water velocity measurements versus water depth and fitting with a straight line. These are included in the appropriate figures to facilitate comparison of the slopes of the linear fit. The correlation coefficient for the linear fit of the sediment surface velocities indicates a definite linear relationship in each area. The nearly identical slopes of the fit for sediment velocity and bottom water velocity in each case, indicate that the included water is a controlling factor.

Having noted the sediment surface velocity to water depth relationship, it was considered that this might be a factor in the differences noted in the velocity-depth functions of the sub areas of the Somali Basin and the Arabian Sea. The weighting given to the sediment surface velocity influences the derived instantaneous velocity-time function and in turn the velocity-depth function and might explain some of the differences in the functions of various sub areas. To test this hypothesis, the instantaneous velocity curves were recalculated with each station sediment surface velocity normalized to a common depth and therefore a common velocity using the linear fits of figures 25 and 26. This was done for four of the eight cases in the Somali Basin at a normalized depth of 4500m (1.490Km/s) and the four cases in the Arabian Sea were

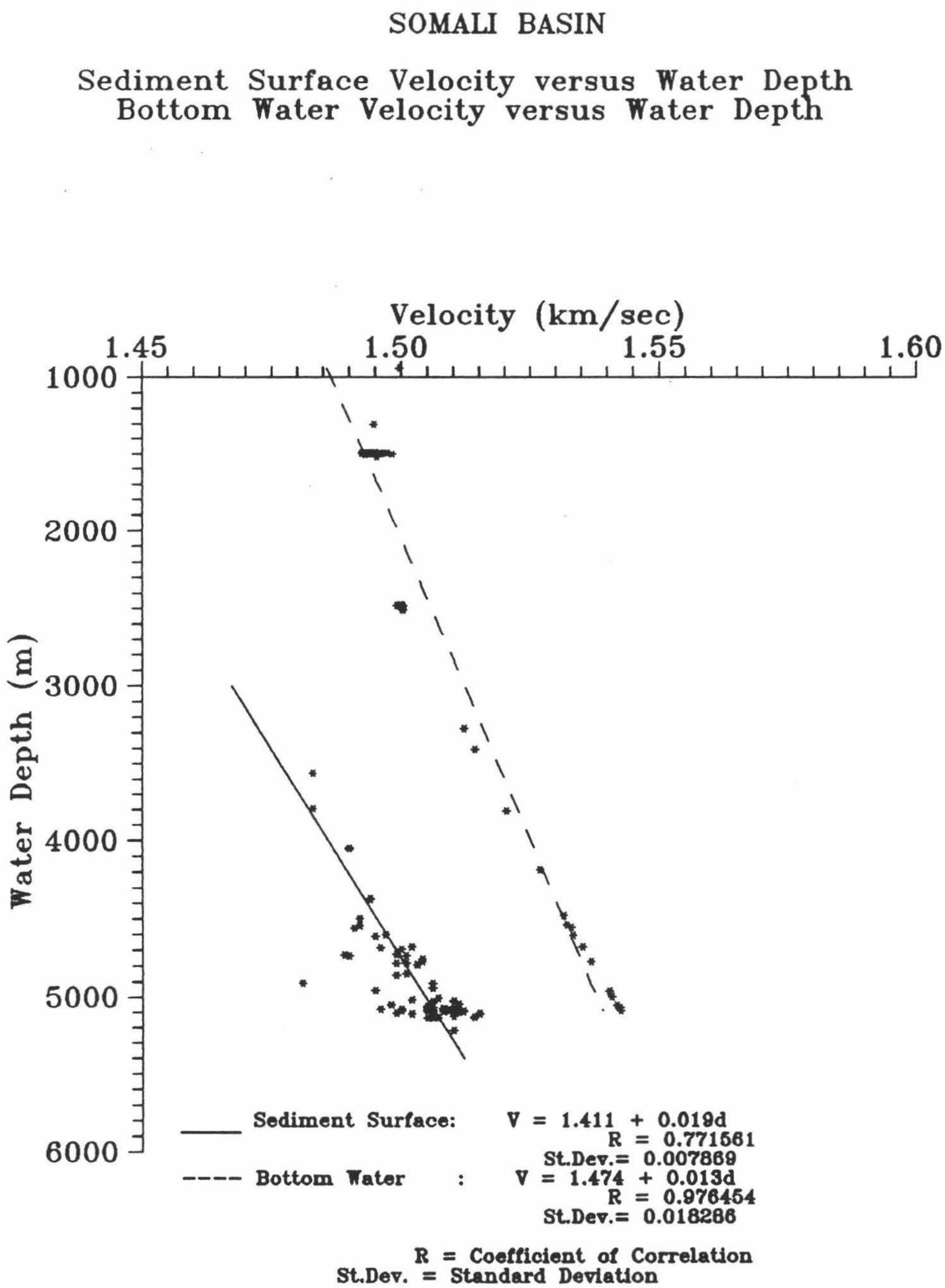



Figure 26. Sediment Surface Velocity Versus Water Depth in the Somali Basin.

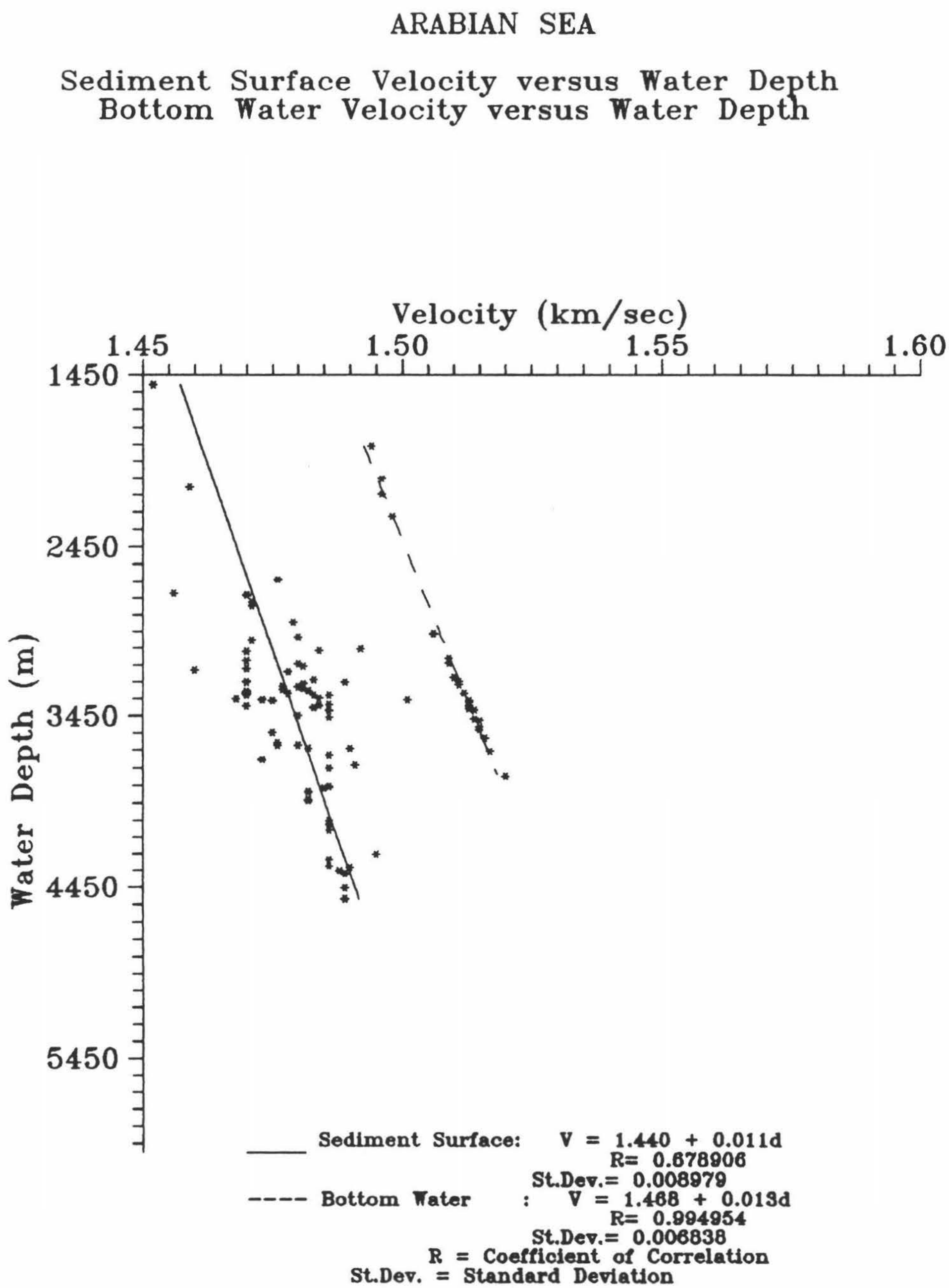



Figure 27. Sediment Surface Velocity Versus Water Depth in the Arabian Sea.

normalized to 3220m (1.476Km/s). The resulting functions continue to show the minor variations between the functions of different areas and were not significantly different from the original functions. A comparison of two normalized versus standard derived functions is presented in figures 28, and 29. As was the case in the original analysis, the curves obtained did not pass through the "normalized" origin point despite the heavy weighting of this point due to the normalization. This indicates that despite the control of water depth on sediment surface velocity, the velocity at depth in the sediments influences the initial velocity of the derived function to a considerable extent.

In the velocity contour charts of the Somali Basin, the high ratio in the southwest corner of the Basin is somewhat disconcerting given the smooth contours of the other two charts. The sediment surface velocity chart does not indicate a high at this point nor does the bottom water contour chart indicate a low to explain the ratio high. Neither the descriptions of DSDP Site 241 nor the seismic cross section of Francis et al. (1966) give any indication of an unusual sediment surface velocity high in this area which wasn't detected by our cores. The author concludes that it is a contouring artifact of the adjoining low just to the southeast.

In the velocity contour charts of the Arabian Sea, the ratio high in the upper portion of the Indus Cone in

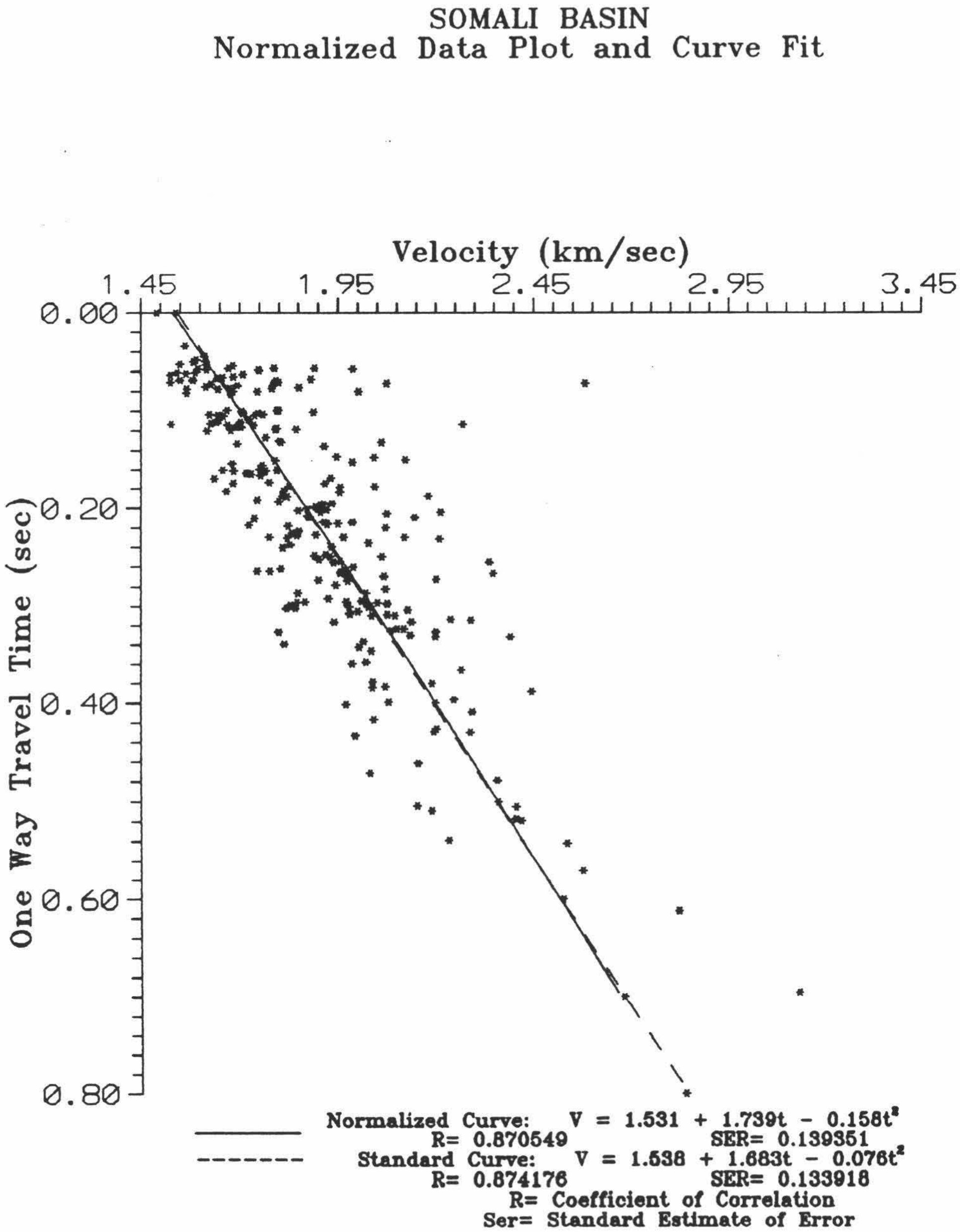



Figure 28. Instantaneous Velocity-Time Curves for Normalized Versus Standard Data in the Somali Basin.

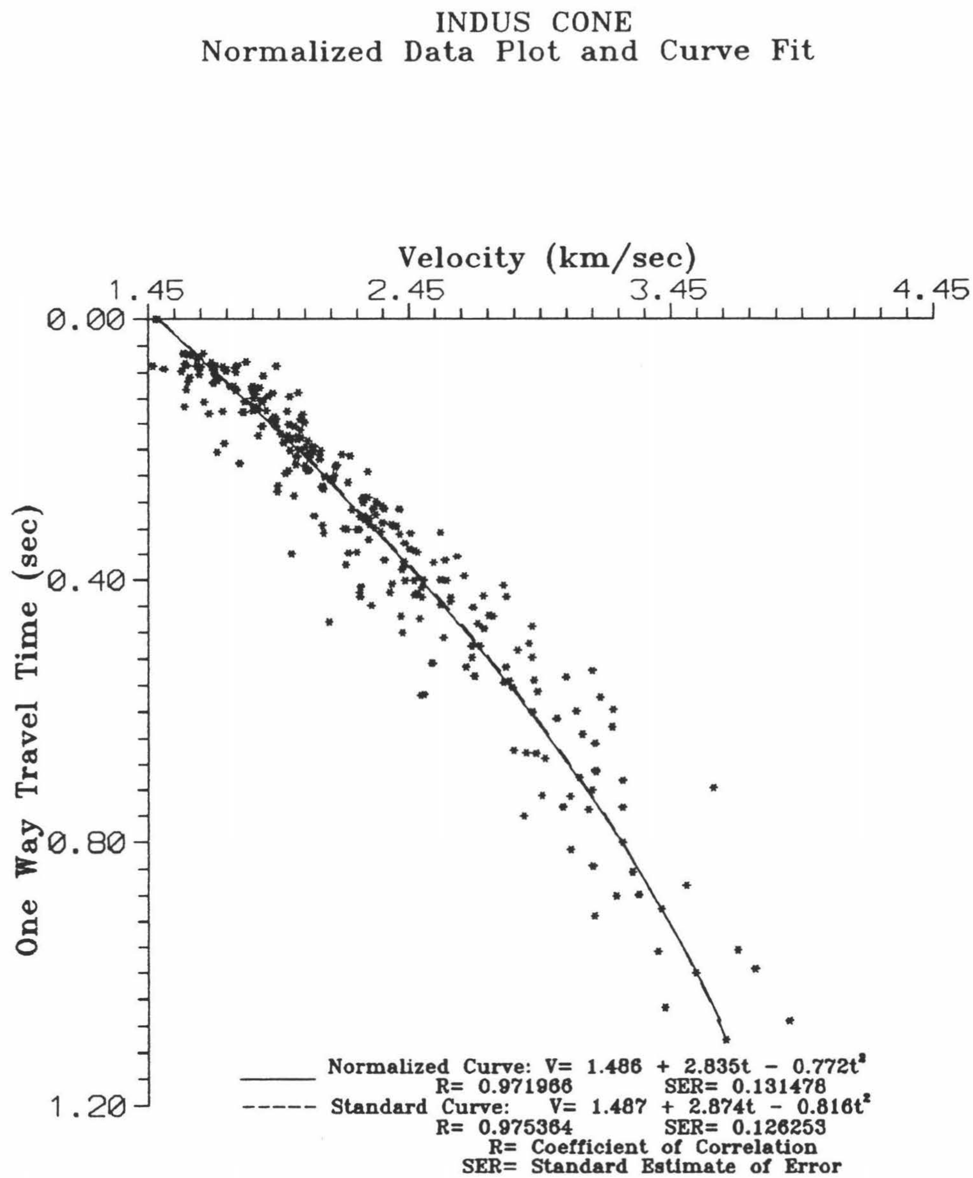



Figure 29. Instantaneous Velocity-Time Curves for Normalized Versus Standard Data in the Arabian Sea.

figure 25 is considered to be the result of the channeling effect of the Lakshmi Ridge on the sediment transport as well as the decrease of the ratio further down the Cone. The observation was made earlier that the bottom water velocity was increasing at a faster rate than the sediment surface velocity along the extent of the Cone. This is considered to be due to the transported sediments becoming finer with distance from the source at a higher rate than the increase of bottom water velocity with depth. The result is a general decrease in the ratio with increasing depth.

The fence diagram of the Somali Basin indicates a considerable amount of consistency in the sediment section of the norther basin between Chain Ridge and the African Coast. This is not surprising considering the limited nature of this portion of the Basin and its enclosure by coast and ridges. The southern portion of the Basin shows reasonable consistency considering its size. The major difference is in the very central portion of the southern fence diagram where slightly higher velocities occur nearer the surface. Despite the variation indicated by the fence diagrams, the individual station instantaneous velocity functions show little variation. This is presumed to be due to the smoothing effect of plotting curves through data points in which the layer velocity is assigned to the midpoint of the layer. The fence diagrams of the Arabian Sea show quite a similar situation. The Oman Abyssal Plain and the Owens Abyssal Plain both show considerable consistency as did the northern Somali Basin; presumably for the same reason. The Indus Cone fence diagram exhibits extensive variation throughout. Unfortunately, all of the DSDP and ODP sites taken in the Arabian Sea have been on the fringes of the Indus Cone along the Chagos Laccadive Ridge or the Owens Ridge. The author thus relies on the work of the two authors who have conducted the bulk of the investigation of the Indus Cone, B.R. Naini and V. Kolla. A basal layer following the structural trends of the basement cited by Naini and Kolla (1981) would correspond to the >2.6 km/s layer which seems to be fairly uniform throughout the fence diagram. The investigators believe the sediments in this basal layer were mainly influenced by pelagic sedimentation while the lower velocity sediments in the upper layers were mainly deposited by turbidite sedimentation. The considerable variation in the upper layers of the fence diagram are the result of the deposition by the three canyon complexes which migrated extensively across the fan as noted by Kolla and Coumes (1987).

The velocity ratio chart of figure 20 can be compared to a ratio chart whose ratios were obtained from the tables of Hamilton (1980) shown in figure 30. Core descriptions could be used to enter table 2b under the

TABLE IIB. Abyssal plain and abyssal hill environments; sediment densities, porosities, sound velocities, and velocity ratios.

| Environment | Density [a] (g/cm³) | | Porosity [a] (%) | | Velocity [a] (m/s) | | Velocity ratio [a] | |
|---|---|---|---|---|---|---|---|---|
| Sediment type | Av | SE | Av | SE | Av | SE | Av | SE |
| **Abyssal plain [b]** | | | | | | | | |
| Clayey silt | 1.454 | 0.022 | 74.2 | 1.58 | 1528 | 3 | 0.999 | 0.002 |
| Silty clay | 1.348 | 0.014 | 80.5 | 0.98 | 1515 | 2 | 0.991 | 0.001 |
| Clay | 1.352 | 0.037 | 80.0 | 2.20 | 1503 | 2 | 0.983 | 0.001 |
| **Bering Sea and Okhotsk Sea (siliceous-diatomaceous)** | | | | | | | | |
| Silt | 1.447 | ... | 70.8 | ... | 1546 | ... | 1.011 | ... |
| Clayey silt | 1.228 | 0.019 | 85.8 | 0.86 | 1534 | 2 | 1.003 | 0.001 |
| Silty clay | 1.214 | 0.008 | 86.8 | 0.43 | 1525 | 2 | 0.997 | 0.001 |
| **Abyssal hill** | | | | | | | | |
| **Deep-sea ("red") pelagic clay** | | | | | | | | |
| Clayey silt | 1.347 | 0.020 | 81.3 | 0.95 | 1522 | 3 | 0.995 | 0.002 |
| Silty clay | 1.344 | 0.011 | 81.2 | 0.60 | 1508 | 2 | 0.986 | 0.001 |
| Clay | 1.414 | 0.012 | 77.7 | 0.64 | 1493 | 1 | 0.976 | 0.001 |
| **Calcareous pelagic sediment** | | | | | | | | |
| Sand-silt-clay | 1.435 | 0.007 | 75.3 | 0.38 | 1556 | 2 | 1.017 | 0.001 |
| Silt-clay | 1.404 | 0.011 | 76.9 | 0.64 | 1536 | 1 | 1.004 | 0.001 |

[a] Laboratory values: 23 °C, 1 atm pressure; density: Saturated bulk density; porosity: Salt free; velocity ratio: Velocity in sediment/velocity in sea water at 23 °C, 1 atm, and salinity of sediment pore water; SE: Standard error of the mean.
[b] For approximate properties of thinner, coarser-grained layers in abyssal plain turbidities: See continental terrace Tables IA and IB in the fine sand to sand-silt-clay sizes (silt is most common).

Figure 30: Illustration of Hamilton's Table 2b.

heading of abyssal plain and obtain the appropriate ratio. Upon attempting this work, it was found that all of the cores for which velocity data were available had not yet been analyzed, and description of sediment types were not available. Of the cores taken by NAVOCEANO in the Somali Basin, only 13 had sufficient core analysis beyond velocity measurements for this purpose. Another 16 cores with suitable analysis were found in Burroughs (1977) and 6 cores from the Deep Sea Drilling Project (Fisher et al.,1974;Simpson et al.,1974). Using the physiographic location and the percentages of sand, silt, and clay to enter the tables, a velocity ratio for each of the 35 core locations was obtained and plotted. It is recognized that 35 data points is a limited number for contouring such a large area. However, this number of data points is sufficient to point out any obvious similarities or differences. It quickly became apparent that most of the sediments would fall into one table category (Hamilton 1980; Table IIB, Abyssal Hill, Calcareous Pelagic Sediment) and therefore all have the same velocity ratio. The result is shown in figure 31. Only two points can be made with any degree of confidence based on this comparison. First, the chart based on ratios from the table implies that the bulk of the area has a velocity ratio greater than one, while the measured ratio chart shows no ratio as great as one. Secondly, there is a general agreement between the two charts in

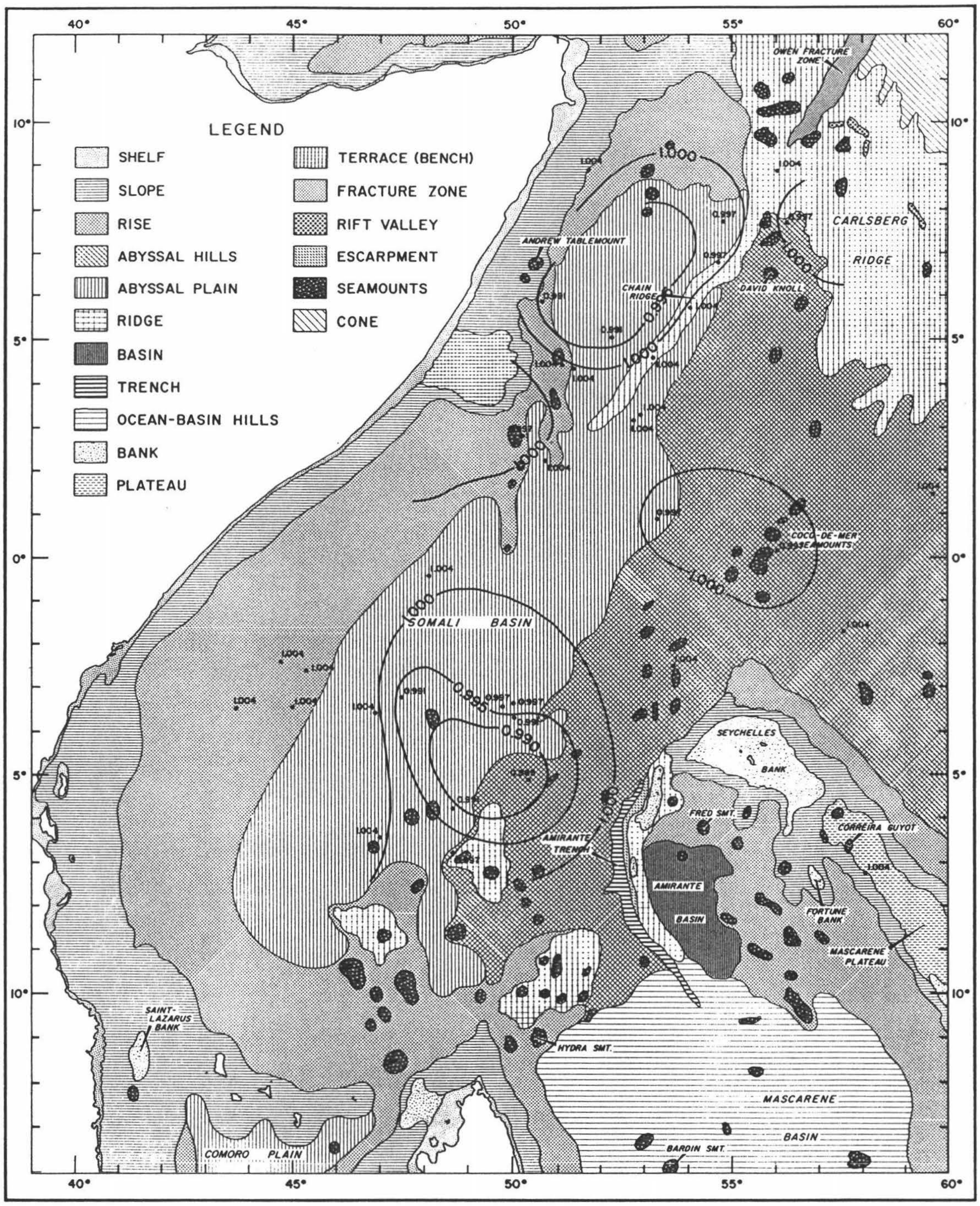



Figure 31. Velocity Ratio Contour Chart Using Hamilton's Tables.

that the velocity ratio in the southern portion of the basin is somewhat lower in general than that in the northern part of the basin. The explanation for the difference in the ratios obtained by Navoceano and those presented in the table is that those in the table are approximate values. In a phone discussion of this subject with Dr. Hamilton (pers.comm. 1983), his comment was "always go with the measured quantity".

To see what effect a difference in velocity ratios might have on the Rayleigh reflection coefficient, two coefficients were calculated for a central location in the Somali Basin using a ratio derived from Hamilton's tables and a NAVOCEANO derived ratio of 0.974. The bottom water density was obtained from CTD data and the surface sediment density from core data. The expression for the reflection coefficient is that for a liquid-liquid interface, given as:

$$R = \frac{( D_s / D_w ) \sin \theta - (( C_w / C_s )^2 - \cos^2 \theta )^{\frac{1}{2}}}{( D_s / D_w ) \sin \theta + (( C_w / C_s )^2 - \cos^2 \theta )^{\frac{1}{2}}}$$

where:

| | |
|---|---|
| Bottom Water Density ($D_w$) | 1.02782 g/cm |
| Surface Sediment Density ($D_s$)(Sta. 56) | 1.33 g/cm |
| Bottom Water Velocity ($C_w$ ) | taken from fig. 18 |

| | |
|---|---|
| Surface Sediment Velocity ($C_S$) | taken from fig. 17 |
| Grazing Angle (Θ) | variable |
| Hamilton's Table Ratio ( $C_S$ / $C_W$ ) | 1.004 |
| NAVOCEANO Ratio (Sta. 56) ( $C_S$ / $C_W$ ) | 0.974 |
| Location | 00° 30'N, 53° 30'E |

The results are given in figure 32.

A velocity ratio greater than one indicates that the sediment surface velocity is greater than the bottom water velocity. During this study, and in all other wide angle bottom reflection work in deep water, no velocity ratios greater than or equal to one were encountered.

The numerical difference between NAVOCEANO measured ratios and those derived from Hamilton's tables is small, but the significance of whether the ratio is less than or greater than 1 is important as can be noted in figure 32, particularly at small grazing angles.

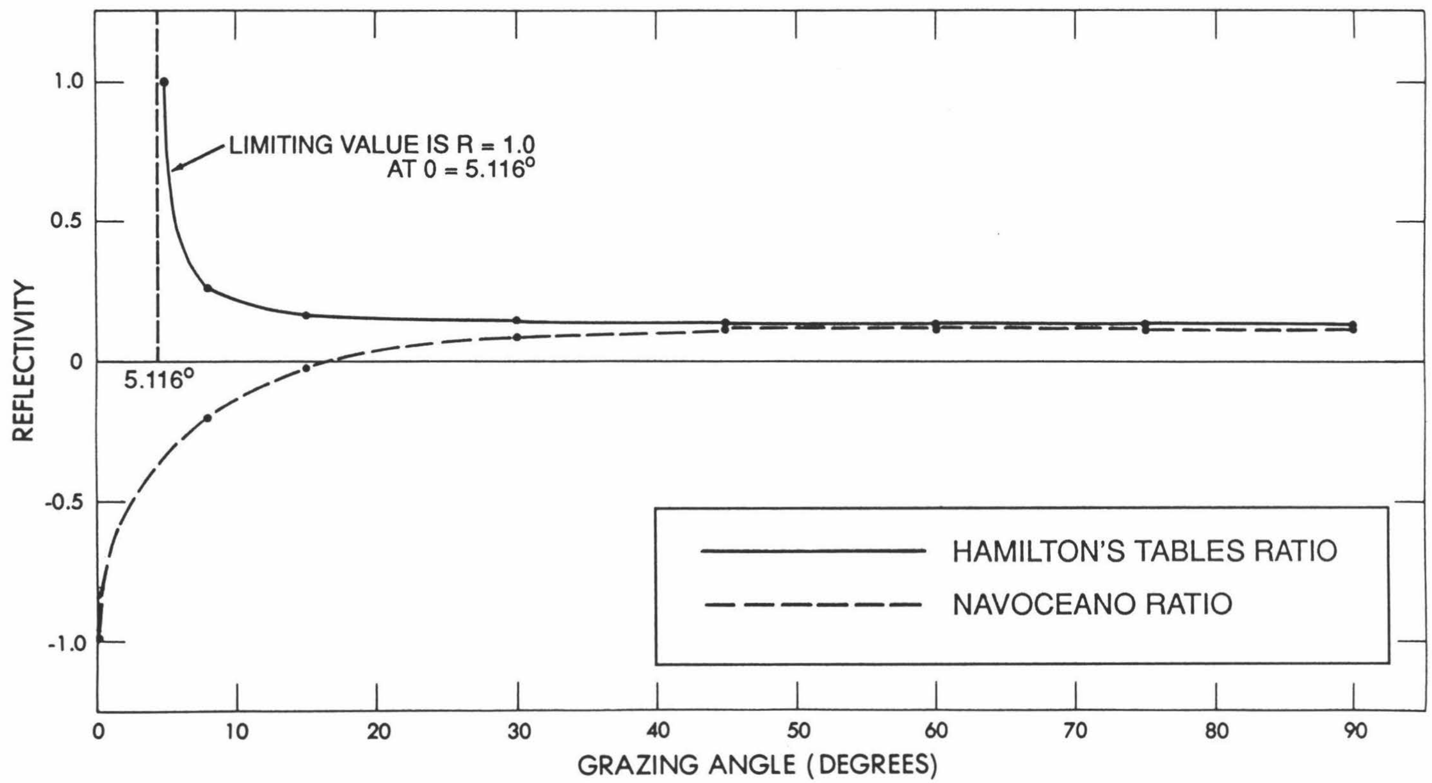



Figure 32. Plot of Reflection Coefficients Versus Grazing Angle.

# CHAPTER V

## CORRELATION WITH OTHER SEISMIC WORK

As mentioned earlier, considerable study of the Somali Basin has been carried on by various investigators such as Francis et al. (1966), Bunce et al. (1967), Davies and Francis (1964) and more recently by Coffin et al. (1986). Since Mombasa was a major port of operations during the International Indian Ocean Expedition, numerous tracks were made through the Basin. Unfortunately, many of the ships participating did not have seismic systems, and many of those with seismic systems took only seismic vertical reflection profiles. Aside from the refraction work by Francis et al (1966), only a limited amount of interval velocity measurements had been made until the measurements presented here and those recently published by Coffin et al (1986).

The general velocity-depth structure as obtained by this study and the refraction work of Francis et al. (1966) can be compared. Both studies agree that the sediment velocity increases gradually and smoothly with depth to at least 1500 meters beneath the sea floor, the limit of our penetration. We also agree on the velocity range of 1.50 km/sec to 1.80 km/sec in the upper 1500 meters.

It is possible to correlate to the work of Coffin et al. (1986) only to a limited extent, since the bulk of our stations in the Somali Basin were to the East of the

Coffin stations. Only eleven of our stations were in the continental rise area in the western portion of the Somali Basin, whereas all but 9 to 10 of their stations are on the Rise. Using only those stations taken on the rise, we derived a linear instantaneous velocity function given by V= 1.544+1.569t. Their results are similar, V= 1.577 + 1.655 t (where t is one way travel time).

In September of 1981, we received some preliminary global velocity data from Lamont-Doherty Geological Observatory (Houtz,pers. comm.). These velocity functions are given in the form V= V' + Kt where the sound velocity is expressed as a function of one way travel time t, V' is the sediment surface velocity and K is the vertical gradient of sound. For the Somali Basin, the Lamont function is V= 1.58 + 1.74t. An instantaneous velocity function from the data of all 70 Somali Basin stations in this study results in the function: V=1.540 + 1.649t. Our sediment surface velocity and velocity gradient are lower than that of Houtz, but in general the agreement is good (figure 33). For example, if you were to predict the velocity of sound in the sediment at a depth equivalent to 0.3 seconds of one way travel time, a velocity of 2.102 Km/sec would be obtained using the Houtz model and a velocity of 2.035 Km/sec according to the NAVOCEANO model. In the Somali Basin, near surface velocities derived from the Deep Sea Drilling Project are 1.47, 1.48, 1.53, 1.51 and 1.58 km/sec from DSDP sites 234,

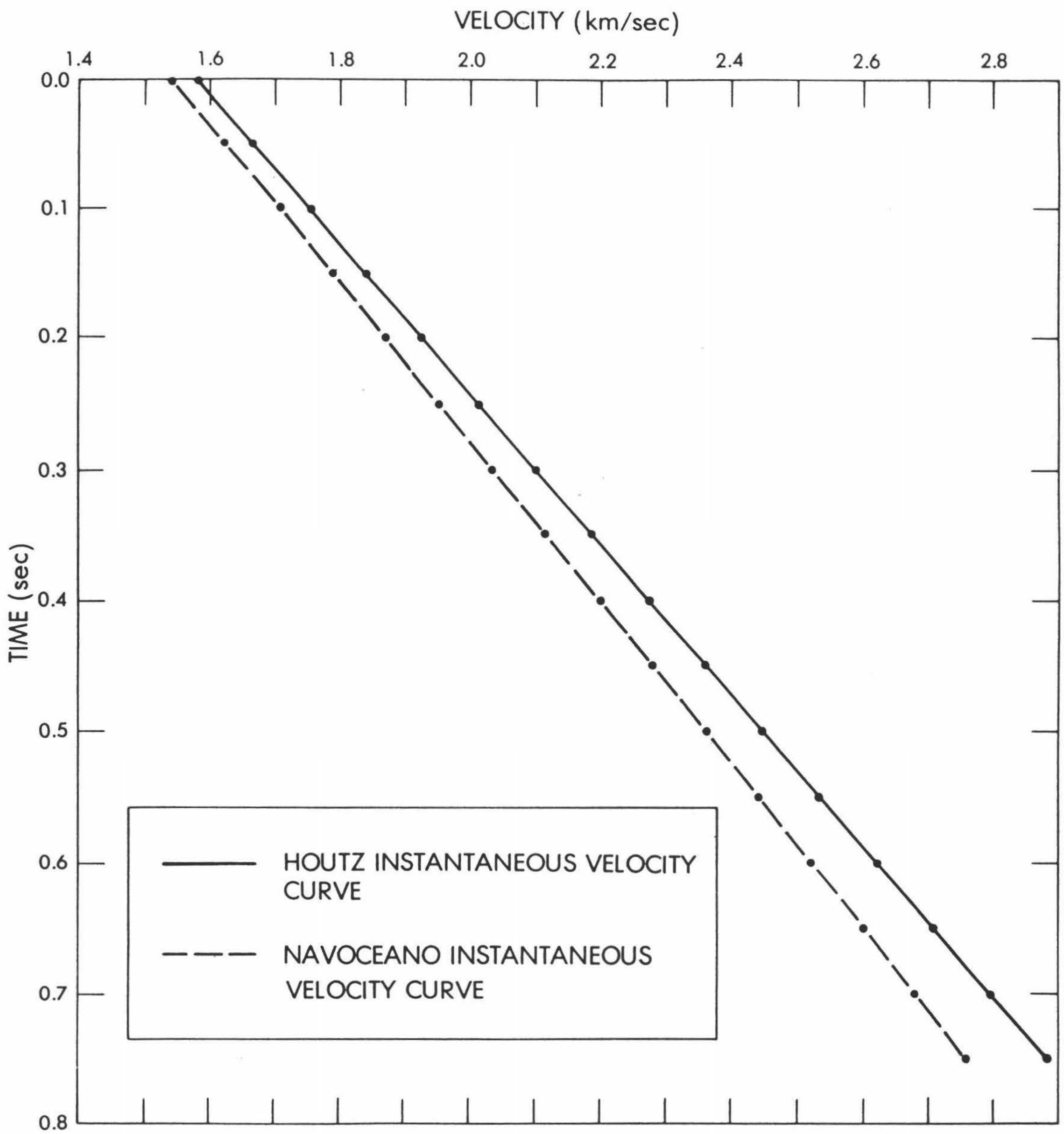



Figure 33. Instantaneous Velocity-Time Functions for the Somali Basin.

235, 236, 240 and 241 respectively (Fisher et al.,1974; Simpson et al., 1974). Our sediment surface velocity of 1.540 km/sec, obtained from our derived velocity function, falls within this range, and is close to their mean value. The surface velocity of 1.58 km/sec reported by Houtz agrees well with the velocity from DSDP site 241, located on the edge of the African Continental Rise, and may be more typical of a rise velocity (Simpson et al., 1974).

In the Arabian Sea, correlation to other data is minimal due to the paucity of available seismic data. Considerable work was done by White and Ross (1979) in the Gulf of Oman but, unfortunately, all but two of the lines were on the slope and shelf of Iran. The two lines extending into the Oman Abyssal Plain were taken with a single channel seismic system, while most of the other lines were taken with a multichannel system. The two abyssal plain lines run essentially north-south, and indicate a thick sediment sequence at the northern end, gradually thinning toward the southern end. Our lines were east-west, but each successive line progressed to the south and they indicate a thinning sequence as well. In the Owens Abyssal Plain, only the Deep Sea Drilling Program site 223 could be reasonably considered for correlation. Other DSDP sites were located on the Ridge and Ocean Drilling Program sites were also located on the Ridge or on the Arabian Continental Slope or Rise. Site

223 was located just west of the Ridge on the slope of the Ridge but velocities should be comparable. The velocities obtained by DSDP varied little from 1.55 km/sec in the upper 240 meters and from 1.60 to 1.75 km/sec in the next 220 meters(Whitmarsh et al., 1974). Below this velocities increase to 1.8 to 2.0 km/sec and our results are in good agreement with these.

In 1977, prior to the start of this study, a series of eight WABR stations were taken by Navoceano on the Indus Cone. Six of these stations ran in a north-south direction on the Cone and were analyzed and reported by Bachman and Hamilton (1980). Their reported velocity-depth function is $V= 1.510 + 1.200D -0.253D^2 +0.034D^3$. In this study, we characterized the Indus Cone by two velocity-depth functions, one for the upper portion of the cone (within 160 miles of shore) and one for the remainder of the cone. The function derived for the main portion of the cone is $V= 1.488 + 1.754D - 0.622D^2$ and is representative of the area from which Bachman's function was derived. A plot of each is shown for comparison in figure 34. The two functions differ considerably in gradient, with theirs indicating a higher gradient at depth. Our function is derived from the data of all but three of the stations taken on the cone and therefore is an averaging of the functions throughout the cone.

The instantaneous velocity function obtained by Naini and Talwani (1977) $V=1.534+1.965t$ is compared to the

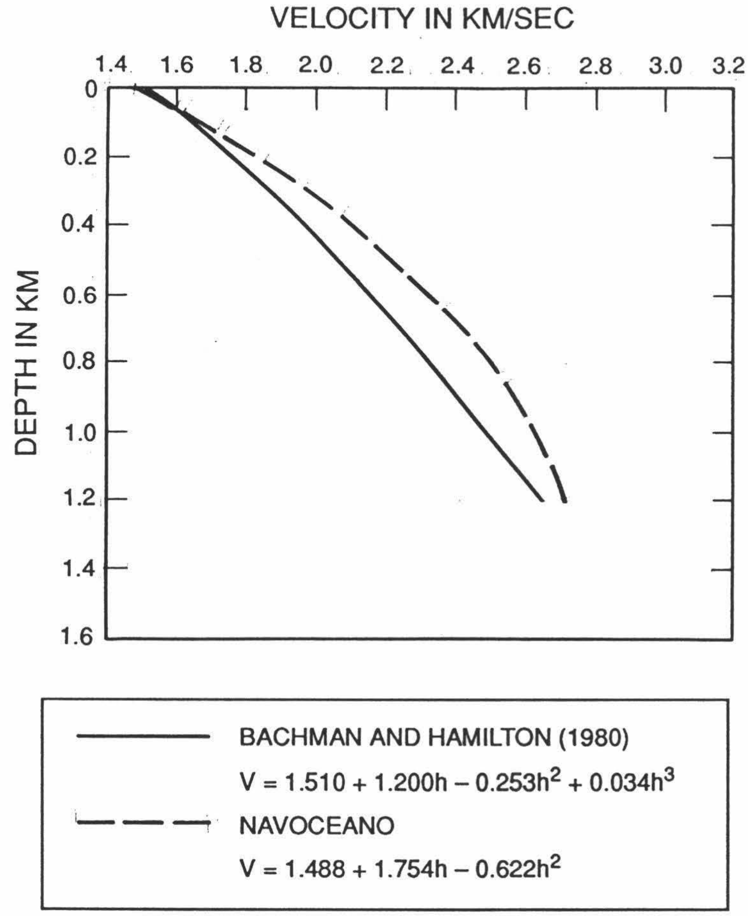



Figure 34. Velocity-Depth Functions for the Indus Cone.

instantaneous velocity function obtained for the middle Cone area in this study (V= 1.549 + 2.221t ), and the instantaneous velocity function derived by Bachman and Hamilton (V= 1.510 + 1.863t, 1980) is included in this plot for comparison (fig.35). Again, it is noted that our function is a synthesis of data from numerous stations and thus reflects the effects of considerable variation in sediment sections throughout the cone while the other two functions reflect only a limited portion.

Deep Sea Drilling Program site 221 lies at the south-eastern edge of the Cone and the uppermost velocity obtained from their coring was 1.41 km/sec and is some-what lower than the values we obtained in that area (Whitmarsh et al., 1974). The remainder of their cores had velocities from 1.45 to 1.74 km/sec and our values are in general agreement with these.

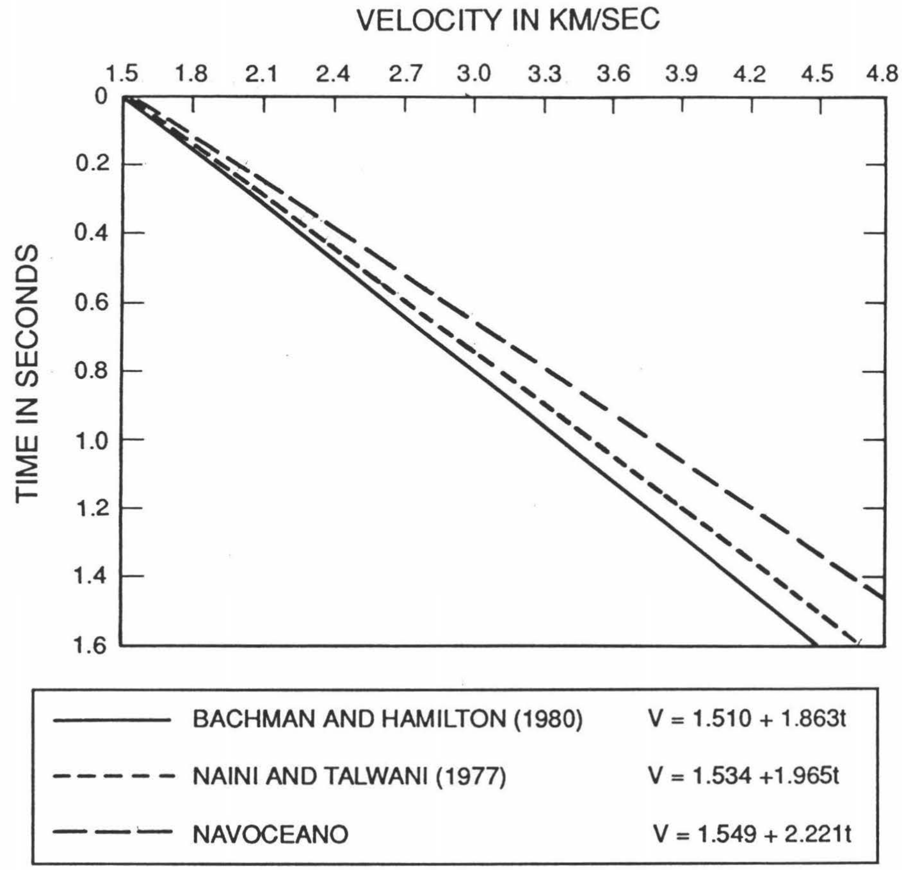



Figure 35. Instantaneous Velocity-Time Functions for the Indus Cone.

# CHAPTER VI

## SENSITIVITY ANALYSIS

There is an inherent factor in wide angle bottom reflection affecting the sensitivity of all measurements. That factor is the drift of the sonobuoy after it has been deployed. There are some extremely strong currents in the Somali Basin about five to fifty miles offshore. These currents can be most disrupting as was pointed out by Coffin et al (1986) where a considerable amount of their work was in that area. On the inshore portions of some of our cruise legs in this area we experienced currents on the order of 12 to 15 knots. Fortunately, none of our WABR measurements were taken in this area but were taken some 300 miles or more out to sea where the drift of the sonobuoys was almost negligible over the period of the measurement. The same was true of the measurements made in the Arabian Sea.

As noted earlier, the wide angle bottom reflection method is based on the Dix method developed for land reflection seismic exploration. In land exploration, the distance between source and receiver is small compared to the distances encountered in marine work and ray parameters (or slowness), or apparent velocity, are zero. Generally, in land work, the distance between the source and the furthest receiver is only a few thousand feet, whereas at sea this distance approaches 10 nautical miles. In the Dix method, the refraction or bending of rays between source and reflector is not considered and simple straight line geometry is assumed for the reflections when plotted $X^2$-$T^2$. In land work the refraction effect is minimal, except where very strong velocity gradients are detected. In marine WABR work, this refraction effect shows up as a slight amount of curvature in the distal end of the $X^2$-$T^2$ plot giving rise to some problems in curve fitting. In this study, the limitations of the source level allowed a penetration of the sediments only on the order of 1200 to 1500 meters and the generally small gradual increase in velocity with depth caused little refraction at interfaces, and the assumption of straight line geometry is reasonable. This assumption is reflected in the lack of or the minimal amount of curvature in the distal ends of the $X^2$-$T^2$ plots.

Other investigators have developed a rule-of-thumb in that intervals between horizons chosen for study should not be less than 1/12 the depth of the water column. In general, this rule of thumb was followed in this study except in cases of unusually good reflecting horizons giving rise to intervals slightly less than 1/12 the water depth in thickness. Jim Matthews of the Naval Ocean Research and Development Agency studied the sensitivity of the factors involved in the wide angle reflection method and concluded that the method was not particularly sensitive to the interval thickness as long as noise is not a major factor ( personal communication, 1990).

A major point of sensitivity in the overall method arises in conversion of the interval velocity versus one way travel time from the sediment surface to an instantaneous velocity-time function. In water depths of 4000 to 5000 meters, using the rule of thumb, the first interval thickness is from 300 to 400 meters. When plotting the interval velocity at the midpoint of the interval, this point is from 150 to 200 meters from the sediment surface. After all of the interval velocities have been plotted at the midpoints of the intervals, a curve is fit to the data points. The point of sensitivity arises from the fact that without a data point at the sediment surface, there is no curve origin point to control the least squares fit, thus placing no limits on the initial velocity gradient. It is important, as pointed out by Hamilton (1974), to obtain a sediment surface velocity and force the curve through this point.

The methods used in this study to acquire and process the data have been used by investigators such as Houtz et al. (1968) and Bachman and Hamilton (1980) for some time and are sensitive primarily to attention to detail in the method of acquisition and to the detail and accuracy in reading travel times. Routine calibration of the acquisition components is necessary for the validity of the travel time data. The sensitivity of the analysis is predominantly in the comparison of instantaneous velocity functions and the detection of whether anomalous instantaneous velocity functions are true anomalies or reflecting problems in the acquisition and processing of that particular station. A check of the raw data and reflection profile will generally determine if there was a problem in the acquisition or processing of the data. If this is not the case, then other measurements must be taken in the same location to verify that the measurement was truly anomalous. A simultaneous vertical reflection profile during the WABR run is most helpful in assuring that the critical assumption of flat bottom and parallel layers is met.

# CHAPTER VII

# CONCLUSIONS

The primary conclusion of this study is that a velocity-depth function representative of the sediment velocity-depth relationship throughout a large ocean area can be derived from an adequate velocity-depth sampling in that area. The derived function will not describe the precise velocity-depth relationship in the sediments of any specific site, but is representative of that relationship. In this study, the derived function describes the velocity-depth relationship in the upper 1200 to 1500 meters of the sediment section with a possible calculated error of 210 m/sec.

For the areas considered in this study, these functions are:

A. SOMALI BASIN

$V= 1.539 + 1.010d - 0.166d^2$

B. ARABIAN SEA

1. Oman Abyssal Plain

   $V= 1.513 + 1.696d - 0.649d^2$

2. Owens Abyssal Plain

   $V= 1.483 + 1.465d - 0.401d^2$

3. Upper Indus Cone

   $V= 1.460 + 1.581d - 0.907d^2$

4. Lower Indus Cone

   $V= 1.488 + 1.754d - 0.622d^2$

The area in which each of the above Arabian Sea functions applies is indicated in figure 36. These functions describe the velocity profiles of the upper 1200 to 1500 meters of the sediment section in the individual areas. In the Somali Basin, Oman Abyssal Plain and Owens Abyssal Plain, the velocity/depth functions describe a condition of terrigenous sedimentation and an upper sediment section consisting largely of turbidite flows. The Indus Cone velocity/depth functions describe a condition of voluminous terrigenous deposition primarily from one source with a mechanical segregation of material progressing away from the source and turbidite flows overall.

In other areas of the world's oceans of similar depositional environment where little or no data are available, the results obtained in this study may be used to derive generalized functions. Sediment surface velocity from core data can be used as the initial data point for a linear instantaneous velocity function of the Houtz type. The gradient for this function could be obtained from one of the functions derived for an area of similar depositional environment described in this study. The function so obtained could then be developed into a velocity/depth function in the manner described earlier.

A second conclusion reached in this study is that the sediment surface velocity of deep water sediments is linearly related to water depth. This appears to be due

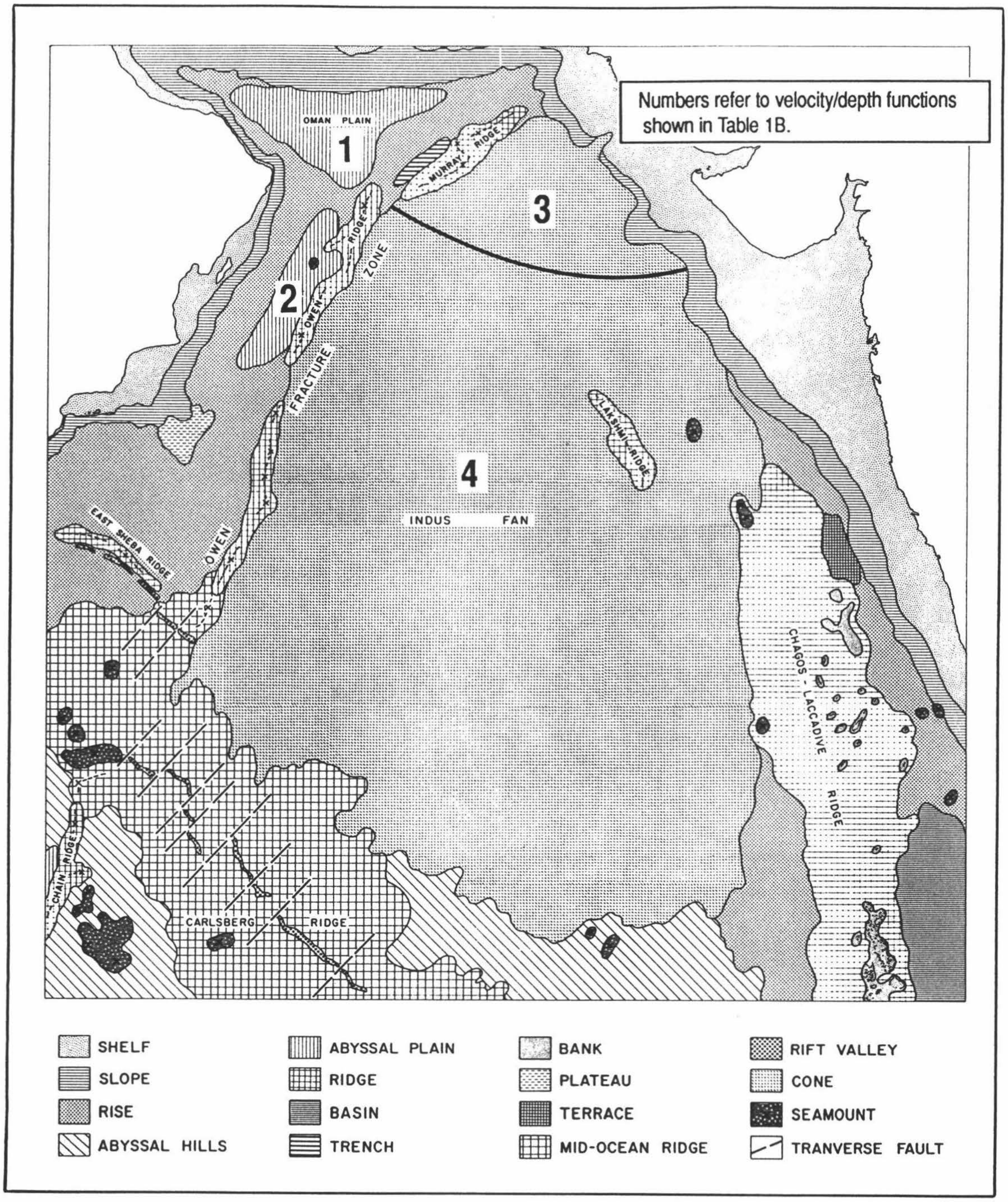



Figure 36. Illustration of Areas of Application for Various Velocity-Depth Functions in Arabian Sea.

to the included bottom water of the surface sediments. This conclusion was reached in the course of an effort to chart the sediment surface sound velocity to bottom water sound velocity ratio for the areas under investigation. As a consequence of this effort, the author also reached the conclusion that this velocity ratio, in deep water, is generally less than 1.0. All of the velocity ratios determined in this study and in all subsequent work by the author have supported this conclusion. This conclusion is in line with the observation of Fry and Raitt (1961) that sediment surface velocities are generally 2% lower than the bottom water velocities in the Pacific Ocean.

# CHAPTER VIII

## RECOMMENDATIONS FOR FUTURE WORK

Considering the primary conclusion reached in this study, it would only be consistent to recommend that other suitable large ocean areas be characterized in the same manner as the two areas in this study. In fact, work is underway to do just that in large areas of the South Atlantic Ocean.

One deficiency in the wide angle bottom reflection method was cited earlier. The first data point, other than a surface sediment measurement from a core, occurs at depths of 150 to 200 meters or more because our source and receiver are far away from the boundary of interest. Those interested in modeling higher frequencies are interested in greater detail in the upper few hundred meters, which cannot be obtained using this method. If such detail is needed, it is recommended that a similar sampling arrangement to the one in this study be carried out with a system such as the "Deep Towed Array Geophysical System" (DTAGS). This system, developed by the Naval Oceanographic and Atmospheric Research Laboratory (NOARL), consists of a deep towed source and multichannel array. It collects multichannel data in the upper few hundred meters and has definition on the order of meters. These data could define the velocity structure of the upper few hundred meters in detail and could be used to adjust or modify the upper portion of the velocity/depth curve obtained by WABR methods.

The processing method used in this study for obtaining interval velocities and thicknesses is very labor intensive. At the moment, WABR records are read by hand and the travel times recorded on tabulation sheets before being entered into the interval velocity computer program. The work is tedious and requires approximately 3 to 4 hours per record from initial setup to tabulation sheet by an experienced person. During this process, there are numerous opportunities for the introduction of errors such as errors in the reading of travel times or the errors produced by the transposition of digits during the recording of the travel times on the travel time sheets. I recommend that this process be modernized by acquiring the data digitally and processing digitally for velocities and thicknesses, as is commonly done in the oil industry. Presently, work is underway at Navoceano to do this. A digital acquisition system was purchased and has been taken to sea to acquire data. The data are recorded on nine track tape with three tapes being required for each WABR run. During a cruise in which fifteen to twenty WABR runs are made, a considerable amount of tape is expended and results in additional storage and shipping problems. To alleviate this problem, a disc storage system for the recording of the data will be installed in the near future. It is planned to use a technique employing a velocity analysis module to compute the trace to trace coherence of events as a function of normal incidence travel time and obtain stacking velocities to derive interval velocities and thicknesses.

# APPENDIX A

## TABLES OF VELOCITIES AND VELOCITY FUNCTIONS

### TABLE 1

A. VELOCITY-DEPTH FUNCTIONS FOR THE SOMALI BASIN

1. All Somali Basin Stations:
   $$V=1.539 + 1.010d - 0.166d^2$$
   var. =0.000016 $S_{x,y}=0.0052$

2. All Abyssal Plain Stations:
   $$V=1.545 + 0.991d - 0.199d^2$$
   var.=0.000012 $S_{x,y}=0.0037$

3. All Continental Rise Stations:
   $$V=1.517 + 1.200d - 0.451d^2$$
   var.=0.00016 $S_{x,y}=0.0124$

4. Northern Abyssal Plain Stations:
   $$V=1.501 + 1.078d - 0.220d^2$$
   var.=0.000052 $S_{x,y}=0.0073$

5. Southern Abyssal Plain Stations:
   $$V=1.541 + 1.025d - 0.088d^2$$
   var.=0.0000042 $S_{x,y}=0.0021$

B. VELOCITY/DEPTH FUNCTIONS FOR ARABIAN SEA

1. Oman Abyssal Plain:
   $$V=1.513 + 1.696d - 0.649d^2$$
   var.=0.00004 $S_{x,y}=0.0064$

2. Owens Abyssal Plain:
   $$V=1.483 + 1.465d - 0.401d^2$$
   var.=0.00001 $S_{x,y}=0.0033$

3. Upper Cone:
   $$V=1.460 + 1.581d - 0.907d^2$$
   var.=0.00004 $S_{x,y}=0.0063$

4. Main Portion of Cone:
   $$V=1.488 + 1.754d - 0.622d^2$$
   var.=0.000039 $S_{x,y}=0.0062$

var.= Variance
$S_{x,y}$= Standard Estimate of Error

TABLE II

INSTANTANEOUS VELOCITY FUNCTIONS

A. SOMALI BASIN:

| | | |
|---|---|---|
| 1. | Linear for Somali Basin | $V=1.540 + 1.649t$ |
| 2. | All Basin Stations<br>$S_{x,y}=0.1339$ | $V=1.538 + 1.683t - 0.076t^2$<br>var.=0.01792 |
| 3. | All Abyssal Plain<br>$S_{x,y}=0.1181$ | $V=1.545 + 1.612t + 0.199t^2$<br>var.=0.0202 |
| 4. | All Continental Rise<br>$S_{x,y}=0.1072$ | $V=1.514 + 2.180t - 1.450t^2$<br>var.=0.0125 |
| 5. | North Abyssal Plain<br>$S_{x,y}=0.0925$ | $V=1.500 + 1.799t - 0.291t^2$<br>var.=0.0186 |
| 7. | South Abyssal Plain<br>$S_{x,y}=0.1387$ | $V=1.540 + 1.622t + 0.469t^2$<br>var.=0.01799 |

B. ARABIAN SEA:

| | | |
|---|---|---|
| 1. | Oman Abyssal Plain<br>$S_{x,y}=0.1761$ | $V=1.505 + 2.857t - 1.128t^2$<br>var.=0.01975 |
| 2. | Owens Abyssal Plain<br>$S_{x,y}=0.1172$ | $V=1.483 + 2.303t - 0.144t^2$<br>var.=0.01376 |
| 3. | Upper Cone<br>$S_{x,y}=0.0702$ | $V=1.458 + 2.962t - 0.986t^2$<br>var.=0.00462 |
| 4. | Main Portion of Cone<br>$S_{x,y}=0.1262$ | $V=1.487 + 2.874t - 0.816t^2$<br>var.=0.01592 |

$S_{x,y}$= Standard Estimate of Error
var.= Variance

TABLE 3

SOMALI BASIN

| STATION | LAYER | VELOCITY (m/sec) | LAYER THICKNESS (m) | WATER DEPTH (m) | LOCATION LAT. | LOCATION LONG. |
|---|---|---|---|---|---|---|
| 53 | | 1492 | 000 | 4543 | 01°35'S | 54°42'E |
| | A | 1562 | 105 | | | |
| | B | 2269 | 210 | | | |
| | A&B | 2001 | 320 | | | |
| 54 | | 1501 | 000 | 4778 | 00°30'S | 53°59'E |
| | A | 1851 | 282 | | | |
| 55 | | 1506 | 000 | 4938 | 00°21'N | 53°31'E |
| | A | 1792 | 249 | | | |
| 56 | | 1510 | 000 | 5072 | 01°51'N | 52°26'E |
| | A | 1750 | 206 | | | |
| | B | 1988 | 566 | | | |
| | A&B | 1921 | 773 | | | |
| 57 | | 1511 | 000 | 5079 | 02°17'N | 51°59'E |
| | A | 1582 | 219 | | | |
| | B | 2212 | 291 | | | |
| | A&B | 1915 | 517 | | | |

TABLE 3 (cont.)

SOMALI BASIN

| STATION | LAYER | VELOCITY (m/sec) | LAYER THICKNESS (m) | WATER DEPTH (m) | LOCATION LAT. | LOCATION LONG. |
|---|---|---|---|---|---|---|
| 58 | | 1499 | 000 | 4858 | 03°44'N | 50°40'E |
| | A | 1894 | 858 | | | |
| | B | 2152 | 219 | | | |
| | A&B | 1944 | 1079 | | | |
| 59 | | 1495 | 000 | 4953 | 05°08'N | 51°08'E |
| | A | 1616 | 189 | | | |
| | B | 2043 | 244 | | | |
| | C | 2075 | 299 | | | |
| | A&B | 1844 | 436 | | | |
| | B&C | 2061 | 543 | | | |
| 60 | | 1502 | 000 | 5015 | 04°44'N | 51°27'E |
| | A | 1542 | 189 | | | |
| | B | 1969 | 556 | | | |
| | A&B | 1850 | 749 | | | |
| 61 | | 1512 | 000 | 5089 | 04°17'N | 51°53'E |
| | A | 1527 | 344 | | | |
| | B | 1867 | 261 | | | |
| | A&B | 1666 | 608 | | | |
| 62 | | 1510 | 000 | 5124 | 03°24'N | 52°50'E |
| | A | 1736 | 397 | | | |

TABLE 3 (cont.)

SOMALI BASIN

| STATION | LAYER | VELOCITY (m/sec) | LAYER THICKNESS (m) | WATER DEPTH (m) | LOCATION LAT. | LOCATION LONG. |
|---|---|---|---|---|---|---|
| 63 | | 1506 | 000 | 5085 | 05°16'N | 53°11'E |
| | A | 1683 | 181 | | | |
| | B | 1762 | 191 | | | |
| | C | 2035 | 379 | | | |
| | A&B | 1723 | 372 | | | |
| | B&C | 1939 | 572 | | | |
| 64 | | 1508 | 000 | 5073 | 05°50'N | 52°30'E |
| | A | 1701 | 378 | | | |
| | B | 2391 | 518 | | | |
| | A&B | 2071 | 908 | | | |
| 65 | | 1496 | 000 | 5079 | 06°24'N | 51°53'E |
| | A | 1584 | 158 | | | |
| | B | 1685 | 206 | | | |
| | C | 2117 | 429 | | | |
| | A&B | 1640 | 365 | | | |
| | B&C | 1965 | 639 | | | |
| 66 | | 1481 | 000 | 4910 | 06°58'N | 51°16'E |
| | A | 1786 | 263 | | | |
| | B | 1973 | 481 | | | |
| | A&B | 1905 | 745 | | | |

TABLE 3 (cont.)

SOMALI BASIN

| STATION | LAYER | VELOCITY (m/sec) | LAYER THICKNESS (m) | WATER DEPTH (m) | LOCATION LAT. | LOCATION LONG. |
|---|---|---|---|---|---|---|
| 67 | | 1499 | 000 | 5104 | 07°39'N | 52°39'E |
| | A | 1739 | 363 | | | |
| | B | 1777 | 195 | | | |
| | A&B | 1752 | 558 | | | |
| 68 | | 1511 | 000 | 5097 | 07°06'N | 53°12'E |
| | A | 1525 | 217 | | | |
| | B | 1745 | 170 | | | |
| | C | 2075 | 239 | | | |
| | A&B | 1618 | 388 | | | |
| | B&C | 1930 | 410 | | | |
| 69 | | 1506 | 000 | 5095 | 06°35'N | 53°41'E |
| | A | 1683 | 269 | | | |
| | B | 2050 | 557 | | | |
| | A&B | 1922 | 830 | | | |

TABLE 3 (cont.)

SOMALI BASIN

| STATION | LAYER | VELOCITY (m/sec) | LAYER THICKNESS (m) | WATER DEPTH (m) | LOCATION LAT. | LOCATION LONG. |
|---|---|---|---|---|---|---|
| 70 | | 1500 | 000 | 5079 | 06°41'N | 54°10'E |
| | A | 1672 | 186 | | | |
| | B | 1684 | 212 | | | |
| | C | 1901 | 135 | | | |
| | D | 2265 | 262 | | | |
| | A&B | 1678 | 399 | | | |
| | B&C | 1738 | 342 | | | |
| | C&D | 2134 | 398 | | | |
| 71 | | 1505 | 000 | 5086 | 07°23'N | 54°22'E |
| | A | 1595 | 181 | | | |
| | B | 1776 | 212 | | | |
| | C | 1979 | 294 | | | |
| | D | 1993 | 207 | | | |
| | A&B | 1691 | 394 | | | |
| | B&C | 1891 | 507 | | | |
| | C&D | 1985 | 501 | | | |
| 72 | | 1512 | 000 | 5090 | 08°05'N | 54°09'E |
| | A | 1708 | 348 | | | |
| | B | 1745 | 211 | | | |
| | A&B | 1722 | 560 | | | |

TABLE 3 (cont.)

SOMALI BASIN

| STATION | LAYER | VELOCITY (m/sec) | LAYER THICKNESS (m) | WATER DEPTH (m) | LOCATION LAT. | LOCATION LONG. |
|---|---|---|---|---|---|---|
| 73 | | 1511 | 000 | 5044 | 08°06'N | 53°45'E |
| | A | 1624 | 334 | | | |
| | B | 2094 | 431 | | | |
| | A&B | 1874 | 771 | | | |
| 74 | | 1511 | 000 | 5092 | 07°31'N | 53°28'E |
| | A | 1567 | 243 | | | |
| | B | 1934 | 324 | | | |
| | C | 2037 | 249 | | | |
| | A&B | 1767 | 570 | | | |
| | B&C | 1978 | 574 | | | |
| 75 | | 1512 | 000 | 5091 | 06°52'N | 53°06'E |
| | A | 1799 | 256 | | | |
| | B | 2021 | 582 | | | |
| | A&B | 1950 | 839 | | | |
| 76 | | 1510 | 000 | 5092 | 06°31'N | 52°50'E |
| | A | 1704 | 394 | | | |
| | B | 2137 | 361 | | | |
| | A&B | 1898 | 760 | | | |

TABLE 3 (cont.)

SOMALI BASIN

| STATION | LAYER | VELOCITY (m/sec) | LAYER THICKNESS (m) | WATER DEPTH (m) | LOCATION LAT. | LOCATION LONG. |
|---|---|---|---|---|---|---|
| 77 | | 1509 | 000 | 5091 | 06°09'N | 52°37'E |
| | A | 1550 | 160 | | | |
| | B | 1717 | 206 | | | |
| | C | 2085 | 424 | | | |
| | A&B | 1642 | 366 | | | |
| | B&C | 1956 | 633 | | | |
| 78 | | 1508 | 000 | 5095 | 05°56'N | 52°31'E |
| | A | 1627 | 366 | | | |
| | B | 2200 | 445 | | | |
| | A&B | 1915 | 819 | | | |
| 79 | | 1500 | 000 | 5088 | 05°22'N | 52°04'E |
| | A | 1659 | 347 | | | |
| | B | 2127 | 399 | | | |
| | A&B | 1892 | 750 | | | |
| 80 | | 1505 | 000 | 5091 | 04°57'N | 51°55'E |
| | A | 1759 | 364 | | | |
| | B | 1846 | 329 | | | |
| | A&B | 1800 | 693 | | | |

TABLE 3 (cont.)

SOMALI BASIN

| STATION | LAYER | VELOCITY (m/sec) | LAYER THICKNESS (m) | WATER DEPTH (m) | LOCATION LAT. | LOCATION LONG. |
|---|---|---|---|---|---|---|
| 81 | | 1508 | 000 | 5077 | 04°36'N | 51°49'E |
| | A | 1565 | 193 | | | |
| | B | 1753 | 149 | | | |
| | C | 1971 | 340 | | | |
| | A&B | 1644 | 343 | | | |
| | B&C | 1902 | 490 | | | |
| 82 | | 1512 | 000 | 5094 | 04°12'N | 51°43'E |
| | A | 1795 | 354 | | | |
| | B | 1849 | 328 | | | |
| | A&B | 1821 | 683 | | | |
| 83 | | 1515 | 000 | 5107 | 03°44'N | 51°30'E |
| | A | 1643 | 220 | | | |
| | B | 1932 | 133 | | | |
| | C | 2347 | 296 | | | |
| | A&B | 1747 | 355 | | | |
| | B&C | 2209 | 431 | | | |
| 84 | | 1501 | 000 | 4733 | 01°50'N | 49°48'E |
| | A | 1549 | 215 | | | |
| | B | 1964 | 354 | | | |
| | A&B | 1795 | 574 | | | |

TABLE 3 (cont.)

SOMALI BASIN

| STATION | LAYER | VELOCITY (m/sec) | LAYER THICKNESS (m) | WATER DEPTH (m) | LOCATION LAT. | LOCATION LONG. |
|---|---|---|---|---|---|---|
| 85 | | 1499 | 000 | 4722 | 01°22'N | 49°06'E |
| | A | 1525 | 194 | | | |
| | B | 1846 | 371 | | | |
| | C | 2041 | 362 | | | |
| | A&B | 1729 | 568 | | | |
| | B&C | 1940 | 734 | | | |
| 86 | | 1496 | 000 | 4681 | 01°00'N | 48°31'E |
| | A | 1657 | 530 | | | |
| 87 | | 1494 | 000 | 4371 | 04°20'S | 44°11'E |
| | A | 1656 | 217 | | | |
| | B | 1954 | 203 | | | |
| | C | 2034 | 453 | | | |
| | A&B | 1794 | 421 | | | |
| | B&C | 2009 | 656 | | | |
| 88 | | 1502 | 000 | 4678 | 04°21'S | 45°29'E |
| | A | 1616 | 170 | | | |
| | B | 1986 | 184 | | | |
| | C | 2337 | 269 | | | |
| | A&B | 1799 | 355 | | | |
| | B&C | 2145 | 445 | | | |

TABLE 3 (cont.)

SOMALI BASIN

| STATION | LAYER | VELOCITY (m/sec) | LAYER THICKNESS (m) | WATER DEPTH (m) | LOCATION LAT. | LOCATION LONG. |
|---|---|---|---|---|---|---|
| 89 | | 1504 | 000 | 4769 | 04°20'S | 46°37'E |
| | A | 1745 | 280 | | | |
| | B | 2021 | 543 | | | |
| | A&B | 1922 | 825 | | | |
| 90 | | 1494 | 000 | 4368 | 02°56'S | 45°15'E |
| | A | 1694 | 250 | | | |
| | B | 2067 | 501 | | | |
| | C | 2405 | 613 | | | |
| | A&B | 1934 | 754 | | | |
| | B&C | 2247 | 1118 | | | |
| 91 | | 1483 | 000 | 3560 | 01°44'S | 44°05'E |
| | A | 1806 | 473 | | | |
| | B | 2038 | 473 | | | |
| | A&B | 1919 | 948 | | | |

TABLE 3 (cont.)

SOMALI BASIN

| STATION | LAYER | VELOCITY (m/sec) | LAYER THICKNESS (m) | WATER DEPTH (m) | LOCATION LAT. | LOCATION LONG. |
|---|---|---|---|---|---|---|
| 92 | | 1483 | 000 | 3792 | 01°03'S | 44°56'E |
| | A | 1645 | 255 | | | |
| | B | 1955 | 388 | | | |
| | C | 2358 | 593 | | | |
| | A&B | 1826 | 645 | | | |
| | B&C | 2190 | 985 | | | |
| 93 | | 1503 | 000 | 4788 | 02°33'S | 46°41'E |
| | A | 1647 | 360 | | | |
| | B | 1799 | 387 | | | |
| | C | 2190 | 330 | | | |
| | A&B | 1724 | 747 | | | |
| | B&C | 1970 | 720 | | | |
| 94 | | 1504 | 000 | 4753 | 02°36'S | 46°45'E |
| | A | 2119 | 972 | | | |
| | B | 2534 | 424 | | | |
| | C | 3131 | 434 | | | |
| | A&B | 2238 | 1401 | | | |
| | B&C | 2820 | 863 | | | |
| 95 | | 1507 | 000 | 5006 | 04°30'S | 49°10'E |
| | A | 1757 | 546 | | | |

TABLE 3 (cont.)

SOMALI BASIN

| STATION | LAYER | VELOCITY (m/sec) | LAYER THICKNESS (m) | WATER DEPTH (m) | LOCATION LAT. | LOCATION LONG. |
|---|---|---|---|---|---|---|
| 96 | | 1505 | 000 | 5060 | 04°06'S | 51°00'E |
| | A | 1678 | 277 | | | |
| 97 | | 1506 | 000 | 5027 | 03°00'S | 49°32'E |
| | A | 1812 | 658 | | | |
| 98 | | 1506 | 000 | 4908 | 01°58'S | 48°23'E |
| | A | 1627 | 238 | | | |
| | B | 1842 | 573 | | | |
| | A&B | 1776 | 812 | | | |
| 99 | | 1497 | 000 | 4601 | 00°43'S | 47°01'E |
| | A | 1748 | 202 | | | |
| | B | 1830 | 666 | | | |
| | A&B | 1810 | 868 | | | |
| 100 | | 1490 | 000 | 4051 | 00°00'N | 46°00'E |
| | A | 1791 | 421 | | | |
| | B | 2199 | 423 | | | |
| | C | 2406 | 373 | | | |
| | A&B | 1986 | 849 | | | |
| | B&C | 2294 | 797 | | | |

TABLE 3 (cont.)

SOMALI BASIN

| STATION | LAYER | VELOCITY (m/sec) | LAYER THICKNESS (m) | WATER DEPTH (m) | LOCATION LAT. | LOCATION LONG. |
|---|---|---|---|---|---|---|
| 101 | | 1490 | 000 | 4047 | 00°52'N | 47°03'E |
| | A | 1708 | 216 | | | |
| | B | 2079 | 1135 | | | |
| | A&B | 2014 | 1355 | | | |
| 102 | | 1499 | 000 | 4778 | 00°12'S | 48°22'E |
| | A | 1882 | 256 | | | |
| | B | 2003 | 824 | | | |
| | A&B | 1974 | 1081 | | | |
| 103 | | 1501 | 000 | 4846 | 00°59'N | 49°22'E |
| | A | 1946 | 569 | | | |
| | B | 2195 | 598 | | | |
| | A&B | 2070 | 1169 | | | |
| 104 | | 1495 | 000 | 4608 | 01°35'N | 48°32'E |
| | A | 1636 | 554 | | | |
| | B | 2031 | 539 | | | |
| | A&B | 1820 | 1099 | | | |
| 105 | | 1500 | 000 | 4692 | 02°25'N | 49°44'E |
| | A | 1782 | 276 | | | |
| | B | 1814 | 667 | | | |
| | A&B | 1805 | 943 | | | |

TABLE 3 (cont.)

SOMALI BASIN

| STATION | LAYER | VELOCITY (m/sec) | LAYER THICKNESS (m) | WATER DEPTH (m) | LOCATION LAT. | LOCATION LONG. |
|---|---|---|---|---|---|---|
| 106 | | 1502 | 000 | 5110 | 01°44'N | 50°39'E |
| | A | 1668 | 329 | | | |
| | B | 2201 | 330 | | | |
| | C | 2445 | 202 | | | |
| | A&B | 1916 | 666 | | | |
| | B&C | 2290 | 533 | | | |
| 107 | | 1506 | 000 | 5134 | 01°17'N | 51°07'E |
| | A | 1890 | 212 | | | |
| | B | 2180 | 326 | | | |
| | A&B | 2060 | 539 | | | |
| 108 | | 1491 | 000 | 4560 | 01°45'N | 54°44'E |
| | A | 2580 | 374 | | | |
| 109 | | 1510 | 000 | 5216 | 04°05'N | 53°12'E |
| | A | 1987 | 228 | | | |
| | B | 2074 | 373 | | | |
| | A&B | 2041 | 602 | | | |

TABLE 3 (cont.)

SOMALI BASIN

| STATION | LAYER | VELOCITY (m/sec) | LAYER THICKNESS (m) | WATER DEPTH (m) | LOCATION LAT. | LOCATION LONG. |
|---|---|---|---|---|---|---|
| 110 | | 1509 | 000 | 5080 | 04°34'N | 52°35'E |
| | A | 1566 | 258 | | | |
| | B | 2000 | 560 | | | |
| | C | 2574 | 643 | | | |
| | A&B | 1851 | 824 | | | |
| | B&C | 2289 | 1213 | | | |
| 111 | | 1498 | 000 | 5049 | 05°28'N | 51°38'E |
| | A | 1681 | 513 | | | |
| | B | 2070 | 321 | | | |
| | C | 2233 | 352 | | | |
| | A&B | 1822 | 838 | | | |
| | B&C | 2154 | 673 | | | |
| 112 | | 1505 | 000 | 5134 | 05°36'N | 53°41'E |
| | A | 1670 | 380 | | | |
| | B | 2100 | 399 | | | |
| | A&B | 1878 | 784 | | | |
| 113 | | 1490 | 000 | 4733 | 00°34'N | 58°23'E |
| | A | 1612 | 145 | | | |

## TABLE 3 (cont.)

### SOMALI BASIN

| STATION | LAYER | VELOCITY (m/sec) | LAYER THICKNESS (m) | WATER DEPTH (m) | LOCATION LAT. | LOCATION LONG. |
|---|---|---|---|---|---|---|
| 114 | | 1489 | 000 | 4728 | 00°31'N | 58°04'E |
| | A | 1674 | 259 | | | |
| | B | 1905 | 186 | | | |
| | A&B | 1767 | 446 | | | |
| 115 | | 1510 | 000 | 5093 | 04°12'N | 53°44'E |
| | A | 1614 | 242 | | | |
| | B | 1926 | 549 | | | |
| | A&B | 1824 | 794 | | | |
| 116 | | 1510 | 000 | 5023 | 03°09'N | 52°41'E |
| | A | 2073 | 297 | | | |
| 117 | | 1514 | 000 | 5132 | 02°31'N | 52°25'E |
| | A | 1614 | 161 | | | |
| | B | 1791 | 179 | | | |
| | C | 1830 | 137 | | | |
| | A&B | 1705 | 341 | | | |
| | B&C | 1808 | 316 | | | |
| 118 | Deleted | | | | | |

TABLE 3 (cont.)

SOMALI BASIN

| STATION | LAYER | VELOCITY (m/sec) | LAYER THICKNESS (m) | WATER DEPTH (m) | LOCATION LAT. | LOCATION LONG. |
|---|---|---|---|---|---|---|
| 119 | | 1507 | 000 | 5135 | 01°49'N | 53°08'E |
| | A | 1684 | 219 | | | |
| | B | 1913 | 249 | | | |
| | A&B | 1802 | 469 | | | |
| 120 | | 1492 | 000 | 4498 | 00°41'S | 55°32'E |
| | A | 1591 | 153 | | | |
| | B | 2121 | 225 | | | |
| | A&B | 1888 | 381 | | | |
| 121 | | 1506 | 000 | 5036 | 02°45'S | 49°05'E |
| | A | 1788 | 202 | | | |
| | B | 2027 | 494 | | | |
| | A&B | 1955 | 697 | | | |
| 122 | | 1506 | 000 | 5067 | 01°40'S | 49°28'E |
| | A | 1694 | 451 | | | |
| | B | 2021 | 370 | | | |
| | C | 2419 | 337 | | | |
| | A&B | 1834 | 824 | | | |
| | B&C | 2202 | 710 | | | |
| 123 | | 1505 | 000 | 5068 | 00°08'S | 50°01'E |
| | A | 1588 | 195 | | | |

TABLE 4

ARABIAN SEA

(Oman Abyssal Plain, Stations 124-145)

| STATION | LAYER | VELOCITY (m/sec) | LAYER THICKNESS (m) | WATER DEPTH (m) | LOCATION LAT. | LOCATION LONG. |
|---|---|---|---|---|---|---|
| 124 | | 1473 | 000 | 3351 | 24°04'N | 59°08'E |
| | A | 1667 | 183 | | | |
| | B | 2235 | 251 | | | |
| | C | 2361 | 395 | | | |
| | A&B | 1975 | 439 | | | |
| | B&C | 2311 | 647 | | | |
| 125 | | 1477 | 000 | 3293 | 24°08'N | 59°40'E |
| | A | 2079 | 706 | | | |
| | B | 2388 | 449 | | | |
| | C | 3117 | 840 | | | |
| | A&B | 2194 | 1157 | | | |
| | B&C | 2840 | 1299 | | | |
| 126 | | 1470 | 000 | 3392 | 24°02'N | 60°06'E |
| | A | 1925 | 407 | | | |
| | B | 2335 | 378 | | | |
| | C | 2549 | 599 | | | |
| | D | 3446 | 836 | | | |
| | A&B | 2113 | 789 | | | |
| | B&C | 2464 | 978 | | | |

TABLE 4 (cont.)

ARABIAN SEA

| STATION | LAYER | VELOCITY (m/sec) | LAYER THICKNESS (m) | WATER DEPTH (m) | LOCATION LAT. | LOCATION LONG. |
|---|---|---|---|---|---|---|
| 127 | | 1470 | 000 | 3323 | 24°03'N | 60°50'E |
| | A | 1836 | 277 | | | |
| | B | 2085 | 234 | | | |
| | C | 2530 | 539 | | | |
| | D | 2944 | 468 | | | |
| | A&B | 1946 | 512 | | | |
| | B&C | 2386 | 776 | | | |
| | C&D | 2715 | 1010 | | | |
| 128 | | 1470 | 000 | 3304 | 24°02'N | 61°53'E |
| | A | 1815 | 402 | | | |
| | B | 2400 | 288 | | | |
| | C | 2940 | 1742 | | | |
| | A&B | 2040 | 697 | | | |
| | B&C | 2856 | 2035 | | | |
| 129 | | 1470 | 000 | 3248 | 23°58'N | 62°37'E |
| | A | 1836 | 250 | | | |
| | B | 1969 | 162 | | | |
| | C | 2021 | 176 | | | |
| | D | 2334 | 431 | | | |
| | A&B | 1887 | 412 | | | |
| | B&C | 1996 | 338 | | | |
| | C&D | 2238 | 608 | | | |

TABLE 4 (cont.)

ARABIAN SEA

| STATION | LAYER | VELOCITY (m/sec) | LAYER THICKNESS (m) | WATER DEPTH (m) | LOCATION LAT. | LONG. |
|---|---|---|---|---|---|---|
| 130 | | 1470 | 000 | 3169 | 23°56'N | 63°21'E |
| | A | 1941 | 538 | | | |
| | B | 2180 | 379 | | | |
| | C | 2412 | 292 | | | |
| | D | 2804 | 296 | | | |
| | A&B | 2037 | 919 | | | |
| | B&C | 2278 | 672 | | | |
| | C&D | 2602 | 589 | | | |
| 131 | | 1470 | 000 | 3123 | 24°07'N | 64°08'E |
| | A | 1907 | 454 | | | |
| | B | 2201 | 325 | | | |
| | C | 2506 | 356 | | | |
| | D | 2575 | 520 | | | |
| | A&B | 2025 | 781 | | | |
| | B&C | 2355 | 682 | | | |
| | C&D | 2547 | 876 | | | |
| 132 | | 1470 | 000 | 3066 | 24°19'N | 64°34'E |
| | A | 1972 | 422 | | | |
| | B | 2307 | 555 | | | |
| | C | 2438 | 447 | | | |
| | A&B | 2156 | 980 | | | |
| | B&C | 2364 | 1003 | | | |

TABLE 4 (cont.)

ARABIAN SEA

| STATION | LAYER | VELOCITY (m/sec) | LAYER THICKNESS (m) | WATER DEPTH (m) | LOCATION LAT. | LOCATION LONG. |
|---|---|---|---|---|---|---|
| 133 | | 1477 | 000 | 3275 | 23°29'N | 62°36'E |
| | A | 1813 | 300 | | | |
| | B | 2140 | 296 | | | |
| | C | 2387 | 461 | | | |
| | D | 2680 | 592 | | | |
| | A&B | 1969 | 598 | | | |
| | B&C | 2287 | 758 | | | |
| | C&D | 2548 | 1055 | | | |
| 134 | | 1484 | 000 | 3345 | 23°30'N | 61°50'E |
| | A | 1896 | 479 | | | |
| | B | 2184 | 613 | | | |
| | C | 2934 | 1276 | | | |
| | A&B | 2053 | 1094 | | | |
| | B&C | 2665 | 1907 | | | |
| 135 | | 1483 | 000 | 3325 | 23°33'N | 61°15'E |
| | A | 1931 | 565 | | | |
| | B | 2316 | 549 | | | |
| | C | 2524 | 487 | | | |
| | D | 3119 | 778 | | | |
| | A&B | 2112 | 1118 | | | |
| | B&C | 2411 | 1037 | | | |
| | C&D | 2875 | 1272 | | | |

TABLE 4 (cont.)

ARABIAN SEA

| STATION | LAYER | VELOCITY (m/sec) | LAYER THICKNESS (m) | WATER DEPTH (m) | LOCATION LAT. | LOCATION LONG. |
|---|---|---|---|---|---|---|
| 136 | | 1480 | 000 | 3280 | 23°42'N | 60°22'E |
| | A | 1914 | 550 | | | |
| | B | 2363 | 313 | | | |
| | C | 2618 | 353 | | | |
| | A&B | 2066 | 868 | | | |
| | B&C | 2495 | 667 | | | |
| 137 | | 1478 | 000 | 3317 | 23°31'N | 59°44'E |
| | A | 1852 | 352 | | | |
| | B | 2205 | 452 | | | |
| | A&B | 2043 | 807 | | | |
| 138 | Deleted | | | | | |
| 139 | | 1501 | 000 | 3353 | 23°02'N | 61°48'E |
| | A | 2014 | 634 | | | |
| 140 | Deleted | | | | | |

TABLE 4 (cont.)

ARABIAN SEA

| STATION | LAYER | VELOCITY (m/sec) | LAYER THICKNESS (m) | WATER DEPTH (m) | LOCATION LAT. | LOCATION LONG. |
|---|---|---|---|---|---|---|
| 141 | | 1492 | 000 | 3052 | 22°31'N | 62°01'E |
| | A | 1636 | 352 | | | |
| | B | 2390 | 368 | | | |
| | C | 3072 | 733 | | | |
| | A&B | 1986 | 733 | | | |
| | B&C | 2824 | 1109 | | | |
| 142 | | 1489 | 000 | 3249 | 22°29'N | 61°06'E |
| | A | 1716 | 412 | | | |
| | B | 2468 | 605 | | | |
| | A&B | 2129 | 1033 | | | |
| 143 | | 1470 | 000 | 2732 | 22°12'N | 60°30'E |
| | A | 2284 | 1142 | | | |
| | B | 3106 | 598 | | | |
| | A&B | 2540 | 1759 | | | |
| 144 | | 1484 | 000 | 3063 | 21°57'N | 61°01'E |
| | A | 1788 | 510 | | | |
| | B | 2488 | 504 | | | |
| | C | 2818 | 613 | | | |
| | A&B | 2107 | 1027 | | | |
| | B&C | 2664 | 1119 | | | |

TABLE 4 (cont.)

ARABIAN SEA

| STATION | LAYER | VELOCITY (m/sec) | LAYER THICKNESS (m) | WATER DEPTH (m) | LOCATION | |
|---|---|---|---|---|---|---|
| | | | | | LAT. | LONG. |
| 145 | | 1481 | 000 | 3158 | 21°56'N | 61°38'E |
| | A | 1771 | 399 | | | |
| | B | 2187 | 330 | | | |
| | C | 2632 | 450 | | | |
| | D | 3144 | 575 | | | |
| | A&B | 1949 | 733 | | | |
| | B&C | 2434 | 784 | | | |
| | C&D | 2908 | 1030 | | | |

TABLE 4 (cont.)

ARABIAN SEA

(OWENS Abyssal Plain, Stations 167, 168, 169, 170, 180, 181)

| STATION | LAYER | VELOCITY (m/sec) | LAYER THICKNESS (m) | WATER DEPTH (m) | LOCATION LAT. | LOCATION LONG. |
|---|---|---|---|---|---|---|
| 167 | | 1481 | 000 | 3258 | 21°29'N | 61°17'E |
| | A | 1690 | 181 | | | |
| | B | 1877 | 246 | | | |
| | C | 2288 | 332 | | | |
| | D | 2623 | 289 | | | |
| | E | 3363 | 2044 | | | |
| | A&B | 1795 | 427 | | | |
| | B&C | 2103 | 580 | | | |
| | C&D | 2438 | 622 | | | |
| | D&E | 3260 | 2341 | | | |
| 168 | | 1481 | 000 | 3289 | 21°12'N | 60°47'E |
| | A | 1602 | 235 | | | |
| | B | 2137 | 401 | | | |
| | C | 2318 | 287 | | | |
| | D | 2737 | 475 | | | |
| | E | 3467 | 1774 | | | |
| | A&B | 1921 | 641 | | | |
| | B&C | 2211 | 689 | | | |
| | C&D | 2570 | 765 | | | |
| | D&E | 3298 | 2259 | | | |

TABLE 4 (cont.)

ARABIAN SEA

| STATION | LAYER | VELOCITY (m/sec) | LAYER THICKNESS (m) | WATER DEPTH (m) | LOCATION LAT. | LOCATION LONG. |
|---|---|---|---|---|---|---|
| 169 | | 1483 | 000 | 3398 | 20°41'N | 60°29'E |
| | A | 1562 | 255 | | | |
| | B | 1995 | 315 | | | |
| | C | 2513 | 285 | | | |
| | D | 2737 | 374 | | | |
| | A&B | 1788 | 575 | | | |
| | B&C | 2227 | 605 | | | |
| | C&D | 2637 | 659 | | | |
| 170 | | 1480 | 000 | 3446 | 20°17'N | 60°30'E |
| | A | 1665 | 311 | | | |
| | B | 2108 | 318 | | | |
| | C | 2512 | 392 | | | |
| | A&B | 1876 | 634 | | | |
| | B&C | 2322 | 713 | | | |
| 180 | | 1486 | 000 | 3382 | 18°51'N | 59°25'E |
| | A | 1546 | 292 | | | |
| | B | 2095 | 392 | | | |
| | C | 2392 | 383 | | | |
| | D | 2891 | 580 | | | |
| | A&B | 1840 | 692 | | | |
| | B&C | 2266 | 786 | | | |
| | C&D | 2681 | 967 | | | |

TABLE 4 (cont.)

ARABIAN SEA

| STATION | LAYER | VELOCITY (m/sec) | LAYER THICKNESS (m) | WATER DEPTH (m) | LOCATION LAT. | LOCATION LONG. |
|---|---|---|---|---|---|---|
| 181 | | 1486 | 000 | 3326 | 19°26'N | 59°58'E |
| | A | 1786 | 412 | | | |
| | B | 2079 | 305 | | | |
| | C | 2271 | 311 | | | |
| | D | 2526 | 802 | | | |
| | A&B | 1905 | 718 | | | |
| | B&C | 2174 | 616 | | | |
| | C&D | 2452 | 1114 | | | |

TABLE 4 (cont.)

ARABIAN SEA

(Indus Cone, Stations 146-166, 171-176, 182-186, 300-312 and 344-346)

| STATION | LAYER | VELOCITY (m/sec) | LAYER THICKNESS (m) | WATER DEPTH (m) | LOCATION LAT. | LONG. |
|---|---|---|---|---|---|---|
| 146 | | 1459 | 000 | 2102 | 22°30'N | 65°58'E |
| | A | 1753 | 245 | | | |
| 147 | | 1452 | 000 | 1507 | 21°19'N | 67°43'E |
| | A | 1596 | 335 | | | |
| | B | 2143 | 1088 | | | |
| | A&B | 1998 | 1434 | | | |
| 148 | | 1456 | 000 | 2721 | 20°43'N | 68°18'E |
| | A | 1715 | 315 | | | |
| | B | 2260 | 1063 | | | |
| | A&B | 2121 | 1387 | | | |
| 149 | | 1460 | 000 | 3180 | 18°59'N | 69°07'E |
| | A | 2033 | 620 | | | |

TABLE 4 (cont.)

ARABIAN SEA

| STATION | LAYER | VELOCITY (m/sec) | LAYER THICKNESS (m) | WATER DEPTH (m) | LOCATION LAT. | LOCATION LONG. |
|---|---|---|---|---|---|---|
| 150 | | 1480 | 000 | 3142 | 19°36'N | 68°17'E |
| | A | 1784 | 383 | | | |
| | B | 2354 | 350 | | | |
| | C | 2583 | 637 | | | |
| | A&B | 2036 | 740 | | | |
| | B&C | 2499 | 987 | | | |
| 151 | | 1480 | 000 | 2982 | 20°19'N | 67°20'E |
| | A | 1637 | 190 | | | |
| | B | 1975 | 474 | | | |
| | A&B | 1871 | 666 | | | |
| 152 | | 1471 | 000 | 2771 | 21°19'N | 65°52'E |
| | A | 1882 | 463 | | | |
| | B | 2609 | 978 | | | |
| | A&B | 2348 | 1458 | | | |

TABLE 4 (cont.)

ARABIAN SEA

| STATION | LAYER | VELOCITY (m/sec) | LAYER THICKNESS (m) | WATER DEPTH (m) | LOCATION LAT. | LOCATION LONG. |
|---|---|---|---|---|---|---|
| 153 | | 1471 | 000 | 2796 | 21°52'N | 65°11'E |
| | A | 1993 | 804 | | | |
| | B | 3087 | 1230 | | | |
| | C | 3327 | 567 | | | |
| | D | 3472 | 608 | | | |
| | A&B | 2595 | 2081 | | | |
| | B&C | 3161 | 1799 | | | |
| | C&D | 3401 | 1175 | | | |
| 154 | | 1482 | 000 | 3300 | 21°24'N | 64°27'E |
| | A | 1635 | 229 | | | |
| | B | 2080 | 260 | | | |
| | C | 2820 | 903 | | | |
| | D | 3064 | 881 | | | |
| | A&B | 1858 | 492 | | | |
| | B&C | 2634 | 1172 | | | |
| | C&D | 2938 | 1785 | | | |
| 155 | | 1479 | 000 | 2893 | 20°43'N | 65°23'E |
| | A | 2022 | 743 | | | |
| | B | 2769 | 487 | | | |
| | A&B | 2291 | 1245 | | | |

TABLE 4 (cont.)

ARABIAN SEA

| STATION | LAYER | VELOCITY (m/sec) | LAYER THICKNESS (m) | WATER DEPTH (m) | LOCATION LAT. | LONG. |
|---|---|---|---|---|---|---|
| 156 | | 1476 | 000 | 2639 | 19°56'N | 66°29'E |
| | A | 1787 | 380 | | | |
| | B | 2392 | 493 | | | |
| | C | 2542 | 544 | | | |
| | D | 3151 | 1276 | | | |
| | A&B | 2107 | 882 | | | |
| | B&C | 2470 | 1037 | | | |
| | C&D | 2955 | 1829 | | | |
| 157 | | 1471 | 000 | 3003 | 19°34'N | 67°06'E |
| | A | 1660 | 168 | | | |
| | B | 2008 | 252 | | | |
| | C | 2451 | 611 | | | |
| | D | 3224 | 941 | | | |
| | A&B | 1861 | 421 | | | |
| | B&C | 2312 | 867 | | | |
| | C&D | 2905 | 1567 | | | |
| 158 | | 1470 | 000 | 3311 | 18°31'N | 68°29'E |
| | A | 1606 | 168 | | | |
| | B | 1957 | 281 | | | |
| | C | 2298 | 299 | | | |
| | A&B | 1818 | 451 | | | |
| | B&C | 2126 | 581 | | | |

TABLE 4 (cont.)

ARABIAN SEA

| STATION | LAYER | VELOCITY (m/sec) | LAYER THICKNESS (m) | WATER DEPTH (m) | LOCATION LAT. | LOCATION LONG. |
|---|---|---|---|---|---|---|
| 159 | | 1468 | 000 | 3347 | 17°44'N | 69°22'E |
| | A | 1469 | 207 | | | |
| | B | 1714 | 216 | | | |
| | C | 2199 | 227 | | | |
| | A&B | 1589 | 424 | | | |
| | B&C | 1947 | 446 | | | |
| 160 | | 1476 | 000 | 3622 | 16°19'N | 70°04'E |
| | A | 1577 | 244 | | | |
| | B | 1799 | 238 | | | |
| | C | 3148 | 1569 | | | |
| | A&B | 1683 | 484 | | | |
| | B&C | 2917 | 1841 | | | |
| 161 | | 1476 | 000 | 3605 | 16°37'N | 69°12'E |
| | A | 1590 | 209 | | | |
| | B | 1741 | 206 | | | |
| | C | 2402 | 312 | | | |
| | A&B | 1664 | 416 | | | |
| | C&B | 2113 | 525 | | | |

TABLE 4 (cont.)

ARABIAN SEA

| STATION | LAYER | VELOCITY (m/sec) | LAYER THICKNESS (m) | WATER DEPTH (m) | LOCATION LAT. | LOCATION LONG. |
|---|---|---|---|---|---|---|
| 162 | | 1475 | 000 | 3544 | 17°12'N | 68°15'E |
| | A | 1597 | 221 | | | |
| | B | 2074 | 288 | | | |
| | C | 2589 | 472 | | | |
| | A&B | 1851 | 514 | | | |
| | B&C | 2380 | 765 | | | |
| 163 | | 1475 | 000 | 3360 | 18°12'N | 66=47'E |
| | A | 1704 | 277 | | | |
| | B | 2145 | 354 | | | |
| | C | 2422 | 270 | | | |
| | D | 2808 | 653 | | | |
| | A&B | 1939 | 635 | | | |
| | B&C | 2261 | 625 | | | |
| | C&D | 2689 | 925 | | | |

TABLE 4 (cont.)

ARABIAN SEA

| STATION | LAYER | VELOCITY (m/sec) | LAYER THICKNESS (m) | WATER DEPTH (m) | LOCATION LAT. | LOCATION LONG. |
|---|---|---|---|---|---|---|
| 164 | | 1478 | 000 | 3187 | 19°07'N | 65°44'E |
| | A | 1764 | 357 | | | |
| | B | 2456 | 606 | | | |
| | C | 3047 | 599 | | | |
| | D | 3264 | 653 | | | |
| | E | 3705 | 874 | | | |
| | A&B | 2172 | 975 | | | |
| | B&C | 2734 | 1211 | | | |
| | C&D | 3158 | 1252 | | | |
| | D&E | 3509 | 1530 | | | |
| 165 | | 1483 | 000 | 3235 | 20°07'N | 64°11'E |
| | A | 1746 | 268 | | | |
| | B | 2274 | 540 | | | |
| | C | 2735 | 449 | | | |
| | D | 3110 | 485 | | | |
| | E | 3899 | 2808 | | | |
| | A&B | 2083 | 814 | | | |
| | B&C | 2473 | 993 | | | |
| | C&D | 2924 | 936 | | | |
| | D&E | 3771 | 3303 | | | |

TABLE 4 (cont.)

ARABIAN SEA

| STATION | LAYER | VELOCITY (m/sec) | LAYER THICKNESS (m) | WATER DEPTH (m) | LOCATION LAT. | LOCATION LONG. |
|---|---|---|---|---|---|---|
| 166 | | 1470 | 000 | 3317 | 21°02'N | 63°10'E |
| | A | 1699 | 323 | | | |
| | B | 2269 | 374 | | | |
| | C | 2754 | 547 | | | |
| | A&B | 1985 | 705 | | | |
| | B&C | 2545 | 925 | | | |
| 171 | | 1486 | 000 | 3416 | 19°26'N | 63°03'E |
| | A | 1699 | 257 | | | |
| | B | 2323 | 588 | | | |
| | C | 2831 | 842 | | | |
| | D | 3066 | 667 | | | |
| | A&B | 2111 | 853 | | | |
| | B&C | 2610 | 1437 | | | |
| | C&D | 2932 | 1510 | | | |
| 172 | | 1486 | 000 | 3457 | 18°37'N | 64°16'E |
| | A | 1785 | 280 | | | |
| | B | 2163 | 359 | | | |
| | C | 2469 | 388 | | | |
| | D | 3011 | 780 | | | |
| | E | 3241 | 911 | | | |
| | A&B | 1988 | 642 | | | |
| | B&C | 2317 | 748 | | | |
| | C&D | 2818 | 1172 | | | |

## TABLE 4 (cont.)

### ARABIAN SEA

| STATION | LAYER | VELOCITY (m/sec) | LAYER THICKNESS (m) | WATER DEPTH (m) | LOCATION LAT. | LOCATION LONG. |
|---|---|---|---|---|---|---|
| 173 | | 1484 | 000 | 3388 | 17°40'N | 65°34'E |
| | A | 1707 | 239 | | | |
| | B | 2223 | 311 | | | |
| | C | 2262 | 662 | | | |
| | D | 3161 | 751 | | | |
| | A&B | 1982 | 555 | | | |
| | B&C | 2249 | 973 | | | |
| | C&D | 2702 | 1432 | | | |
| 174 | | 1480 | 000 | 3622 | 16°40'N | 66°54'E |
| | A | 1824 | 228 | | | |
| | B | 2191 | 362 | | | |
| | C | 2808 | 660 | | | |
| | A&B | 2041 | 592 | | | |
| | B&C | 2571 | 1029 | | | |
| 175 | | 1482 | 000 | 3930 | 15°09'N | 67°40'E |
| | A | 1584 | 162 | | | |
| | B | 2032 | 274 | | | |
| | C | 2084 | 263 | | | |
| | D | 2305 | 349 | | | |
| | A&B | 1852 | 440 | | | |
| | B&C | 2057 | 537 | | | |
| | C&D | 2207 | 613 | | | |

TABLE 4 (cont.)

ARABIAN SEA

| STATION | LAYER | VELOCITY (m/sec) | LAYER THICKNESS (m) | WATER DEPlH (m) | LOCATION LAT. | LOCATION LONG. |
|---|---|---|---|---|---|---|
| 176 | | 1485 | 000 | 3866 | 15°01'N | 66°09'E |
| | A | 1909 | 441 | | | |
| | B | 2250 | 402 | | | |
| | C | 2690 | 576 | | | |
| | A&B | 2064 | 845 | | | |
| | B&C | 2500 | 981 | | | |
| 182 | | 1473 | 000 | 3702 | 18°58'N | 61°13'E |
| | A | 1616 | 174 | | | |
| | B | 1870 | 107 | | | |
| | C | 2066 | 200 | | | |
| | D | 2413 | 322 | | | |
| | E | 2711 | 384 | | | |
| | A&B | 1708 | 282 | | | |
| | B&C | 1996 | 307 | | | |
| | C&D | 2273 | 524 | | | |
| | D&E | 2571 | 707 | | | |
| 183 | | 1482 | 000 | 3638 | 18°10'N | 62°08'E |
| | A | 1782 | 258 | | | |
| | B | 2049 | 328 | | | |
| | C | 2431 | 321 | | | |
| | D | 2537 | 445 | | | |
| | E | 3035 | 809 | | | |
| | A&B | 1927 | 588 | | | |
| | B&C | 2230 | 651 | | | |

## TABLE 4 (cont.)

### ARABIAN SEA

| STATION | LAYER | VELOCITY (m/sec) | LAYER THICKNESS (m) | WATER DEPTH (m) | LOCATION LAT. | LOCATION LONG. |
|---|---|---|---|---|---|---|
| 184 | | 1491 | 000 | 3733 | 17°26'N | 63°03'E |
| | A | 1645 | 269 | | | |
| | B | 2015 | 241 | | | |
| | C | 2571 | 798 | | | |
| | D | 3147 | 787 | | | |
| | A&B | 1810 | 512 | | | |
| | B&C | 2429 | 1045 | | | |
| | C&D | 2843 | 1593 | | | |
| 185 | | 1490 | 000 | 3638 | 16°43'N | 64°01'E |
| | A | 1603 | 299 | | | |
| | B | 2296 | 539 | | | |
| | C | 2509 | 759 | | | |
| | D | 3157 | 1184 | | | |
| | A&B | 2019 | 851 | | | |
| | B&C | 2418 | 1300 | | | |
| | C&D | 2886 | 1955 | | | |
| 186 | | 1486 | 000 | 3678 | 15°50'N | 65°08'E |
| | A | 1790 | 246 | | | |
| | B | 2153 | 475 | | | |
| | C | 2668 | 925 | | | |
| | D | 3302 | 918 | | | |
| | A&B | 2021 | 724 | | | |
| | B&C | 2481 | 1407 | | | |
| | C&D | 2967 | 1853 | | | |

TABLE 4 (cont.)

ARABIAN SEA

| STATION | LAYER | VELOCITY (m/sec) | LAYER THICKNESS (m) | WATER DEPTH (m) | LOCATION LAT. | LOCATION LONG. |
|---|---|---|---|---|---|---|
| 300 | | 1482 | 000 | 3884 | 16°44'N | 062°04'E |
| | A | 1926 | 428 | | | |
| | B | 2211 | 434 | | | |
| | A&B | 2065 | 864 | | | |
| 301 | | 1482 | 000 | 3936 | 16°06'N | 062°44'E |
| | A | 1941 | 270 | | | |
| | B | 2061 | 196 | | | |
| | C | 2323 | 296 | | | |
| | A&B | 1991 | 466 | | | |
| | B&C | 2215 | 493 | | | |
| 302 | | 1486 | 000 | 3753 | 15°09'N | 064°00'E |
| | A | 1890 | 319 | | | |
| | B | 1986 | 255 | | | |
| | A&B | 1932 | 575 | | | |
| 303 | | 1486 | 000 | 4287 | 11°33'N | 068°33'E |
| | A | 2025 | 447 | | | |
| | B | 2295 | 530 | | | |
| | C | 2895 | 1210 | | | |
| | A&B | 2167 | 979 | | | |
| | B&C | 2697 | 1750 | | | |

TABLE 4 (cont.)

ARABIAN SEA

| STATION | LAYER | VELOCITY (m/sec) | LAYER THICKNESS (m) | WATER DEPTH (m) | LOCATION LAT. | LOCATION LONG. |
|---|---|---|---|---|---|---|
| 304 | | 1488 | 000 | 4353 | 10°58'N | 066°59'E |
| | A | 1510 | 223 | | | |
| | B | 2278 | 722 | | | |
| | A&B | 2065 | 959 | | | |
| 305 | | 1495 | 000 | 4253 | 11°48'N | 066°01'E |
| | A | 1876 | 385 | | | |
| | B | 2661 | 997 | | | |
| | C | 3265 | 811 | | | |
| | A&B | 2412 | 1399 | | | |
| | B&C | 2917 | 1817 | | | |
| 306 | | 1486 | 000 | 4072 | 13°45'N | 063°22'E |
| | A | 1850 | 375 | | | |
| | B | 1944 | 237 | | | |
| | C | 2376 | 449 | | | |
| | D | 2495 | 306 | | | |
| | A&B | 1886 | 613 | | | |
| | B&C | 2217 | 689 | | | |
| | C&D | 2424 | 755 | | | |

TABLE 4 (cont.)

ARABIAN SEA

| STATION | LAYER | VELOCITY (m/sec) | LAYER THICKNESS (m) | WATER DEPTH (m) | LOCATION LAT. | LOCATION LONG. |
|---|---|---|---|---|---|---|
| 307 | | 1486 | 000 | 4109 | 14°24'N | 062°34'E |
| | A | 1848 | 389 | | | |
| | B | 2118 | 199 | | | |
| | C | 2355 | 298 | | | |
| | A&B | 1936 | 589 | | | |
| | B&C | 2257 | 498 | | | |
| 308 | | 1490 | 000 | 4332 | 11°58'N | 063°13'E |
| | A | 1692 | 219 | | | |
| | B | 2106 | 366 | | | |
| | C | 2694 | 750 | | | |
| | D | 3612 | 970 | | | |
| | A&B | 1940 | 589 | | | |
| | B&C | 2484 | 1124 | | | |
| | C&D | 3178 | 1738 | | | |
| 309 | | 1489 | 000 | 4372 | 10°55'N | 064°38'E |
| | A | 1748 | 266 | | | |
| | B | 2291 | 377 | | | |
| | C | 2385 | 427 | | | |
| | D | 3228 | 644 | | | |
| | A&B | 2048 | 648 | | | |
| | B&C | 2341 | 804 | | | |
| | C&D | 2861 | 1083 | | | |

TABLE 4 (cont.)

ARABIAN SEA

| STATION | LAYER | VELOCITY (m/sec) | LAYER THICKNESS (m) | WATER DEPTH (m) | LOCATION LAT. | LOCATION LONG. |
|---|---|---|---|---|---|---|
| 310 | | 1489 | 000 | 4514 | 09°16'N | 064°22'E |
| | A | 1887 | 471 | | | |
| | B | 2116 | 273 | | | |
| | A&B | 1968 | 745 | | | |
| 311 | | 1489 | 000 | 4455 | 10°18'N | 063°06'E |
| | A | 1902 | 530 | | | |
| | B | 2433 | 307 | | | |
| | A&B | 2082 | 842 | | | |
| 312 | | 1489 | 000 | 4518 | 10°00'N | 061°54'E |
| | A | 1651 | 236 | | | |

TABLE 4 (cont.)

ARABIAN SEA

| STATION | LAYER | VELOCITY (m/sec) | LAYER THICKNESS (m) | WATER DEPTH (m) | LOCATION LAT. | LOCATION LONG. |
|---|---|---|---|---|---|---|
| 344 | | 1486 | 000 | 3856 | 14°14'N | 065°08'E |
| | A | 1735 | 487 | | | |
| | B | 2265 | 587 | | | |
| | A&B | 2007 | 1083 | | | |
| 345 | | 1486 | 000 | 4052 | 13°21'N | 066°12'E |
| | A | 1817 | 514 | | | |
| | B | 2435 | 576 | | | |
| | A&B | 2121 | 1102 | | | |
| 346 | | 1486 | 000 | 4323 | 12°25'N | 067°22'E |
| | A | 1609 | 281 | | | |
| | B | 2344 | 517 | | | |
| | A&B | 2052 | 810 | | | |

# APPENDIX B

## CORE VELOCITY CORRECTION PROCEDURES

### FIELD DETERMINATION OF APPROXIMATE IN SITU SOUND VELOCITY

Information Supplied:

(1) Core Interval Depth (cm.)
(2) Laboratory Temperature (Reference/Sediment) (=C)
(3) Time Delay through the Reference Water Sample (Tw)
(4) Time Delay through the Sediment (Ts)

To calculate the laboratory sediment sound velocity (in meters per second), use the formula:

$$Cs = Cw \quad 1 / 1-Cw*(t/d)$$

Where,

- Cs is the sound velocity through the sediment;
- Cw is the sound velocity through the reference water sample. This value is extrapolated from Wilson's Tables for the speed of sound in distilled water;
- t is the difference in time arrival for the pulse through the sediment as compared to the reference water sample. [(Tw-Ts) 20x10-6];
- d is the inside diameter of the core liner USE:0.059m

To correct the laboratory sediment sound velocity to approximate in situ velocity, the following information is needed:

(1) The uncorrected laboratory sediment sound velocity value (in meters per second)
(2) The in situ environmental data, which includes:
    (a) Bottom depth
    (b) Bottom temperature ( C)
    (c) Bottom salinity (o/oo)
(3) Wilson's Sound Speed Tables: #12B, 12E, and 12F (From SP-68, Handbook of Oceanographic Tables)

Steps:

(1) Find the correction factor for changes in depth (Table 12B).
    (a) Obtain the sound velocity at the given depth (extrapolate).
    (b) Subtract the sound velocity 1449.1 m/sec from the sound velocity at the given depth.

(c) The result is the positive correction factor for changes in depth.

(2) Find the correction factor for changes in temperature (Table 12E).
   (a) Obtain the factor for laboratory temperature.
   (b) Subtract the factor for in situ temperature from the factor for laboratory temperature.
   (c) The result is the negative correction factor for temperature.

(3) Find the correction factor for simultaneous changes in salinity, temperature and pressure, VSTP (Table 12F) using the in situ temperature, salinity and depth.
   (a) The result of the above search is the negative correction factor for VSTP.

(4) Add algebraically the three correction factors which are:
   (a) The negative temperature correction factor.
   (b) The positive, depth correction factor.
   (c) The negative VSTP correction factor.

(5) The above result, when added or subtracted, whichever the case, to the laboratory sediment sound velocity will yield an approximate in situ sound velocity.

Example:
Required information
1. Depth = 4250 meters
2. Salinity = 34.75 o/oo
3. In situ Temp. = 1.39 C
4. Laboratory Temp. = 26.42 C
5. Measured Sound velocity = 1489.58 m/sec

Correction Factor (Depth)
4250 meters = 1522.2 m/sec
VO = 1449.1 m/sec
VP = + 73.1 m/sec
Correction Factor (Temperature)
Lab = 26.42= = 88.8
In situ = 1.39 = 6.3
-82.5 m/sec
Correction Factor VSTp = -.1

VT + VP + VSTP = Total Correction Factor
-82.5 + 73.1 + (-.1) = -9.5.m/sec

Measured Sound Velocity = 1489.58 + (-9.5) = 1480.08 in situ Sound Velocity

## LABORATORY DETERMINATION OF IN SITU SOUND VELOCITY

### COMPRESSIONAL WAVE VELOCITY

Descriptions which delineate sediment boundary layers are observed from X-radiographs of the core. Each core is analyzed for compressional wave velocity (sound velocity) at the sediment boundary layers.

An underwater sediment velocimeter measures the time required for a 400Hz signal to travel through the core liner thickness at the transiting crystal, travel through the sediment thickness, and travel through the core liner at the receiving crystal. Another time delay measurement (90o to the axis of the first time delay measurement) is taken so that sound velocity changes caused by grain orientation will be detected. Similar time delay measurements are noted for a distilled water reference standard.

The time delay difference between the reference standard and the sediment is calculated for each sub-sampling interval within the core. This difference is needed to calculate the sound velocity using Wilson's equations for computing the speed of sound in sea water.

In-situ salinity (in parts per thousand), in-situ temperature (in °C), and water column depth (in Meters) values are either directly measured by field surveys or obtained from historical database records. Salinity, temperature, and pressure correction factors are calculated using a modified version of Wilson's equations.

The SOUND VELOCITY OF THE BOTTOM WATER is calculated from the relationship:

CWB=1449.1+VP2+VS2+VT2+VSTP2)*3.28083

Equation terms are identical to those used by Wilson with the exception of CWB. This term combines Wilson's use of the letter "C" to denote sound velocity with the letter "W" to denote "water", and the letter "B" to denote "bottom".

Sediment sound velocity is calculated from an enhanced version of the Mandex Incorporated velocity calculation formula:

$$C_S = C_W * 1/1-C_W *(T/D)$$

Where:

Cs = Sound velocity through sediment (M/Sec.)
Cw = Sound velocity through distilled water (M/Sec.)
T = Difference in arrival time for the pulse through sediment as compared to the reference standard.
D = Inside diameter of the core tube (M.)

The enhanced version adjusts the sound velocity for temperature, pressure, and salinity conditions. Sediment interstitial salinity is assumed to be identical to the water in-situ salinity. The sediment core and distilled water reference standards are allowed to reach ambient temperature conditions (usually an eight hour equilibrium period) prior to time delay measurements. The pressure correction factor is reflected in Wilson's equations.

A graphical representation of the average sound velocity variations within the core is generated with a tabular listing which shows each plane's sediment sound velocity and the average of the two planes.

A discrete average and a weighted average tabular listing which also indicates the sediment/water velocity ratio is included when it is requested by the user community.

Where:

Cs = Sound velocity through sediment (M/Sec.)
Cw = Sound velocity through distilled water (M/Sec.)
T = Difference in arrival time for the pulse through sediment as compared to the reference standard.
D = Inside diameter of the core tube (M.)

The enhanced version adjusts the sound velocity for temperature, pressure, and salinity conditions. Sediment interstitial salin- ity is assumed to be identical to the water in-situ salinity. The sediment core and distilled water reference standards are allowed to reach ambient temperature conditions (usually an eight hour equilibrium period) prior to time delay measurements. The pressure correction factor is reflected in Wilson's equations.

A graphical representation of the average sound velocity variations within the core is generated with a tabular listing which shows each plane's sediment sound velocity and the average of the two planes.

A discrete average and a weighted average tabular listing which also indicates the sediment/water velocity ratio is included when it is requested by the user community.

APPENDIX C

INTERVAL VELOCITY COMPUTER PROGRAM WABR

```
      CHARACTER*6 SHIP,IAR*1(5),HORIZ*16
      CHARACTER*5 AREA1,AREA2,AREA3,AREA4,CHK
      DIMENSION A(30,30),S(30,30),B(15),COC(8),ISTAT(30)
      DATA IAR/'A','B','C','D','E'/
C     WABR MADE BY MICHAEL A. MCGLAUGHLIN, AUG. 79,
C     THIS PROGRAM MODIFIED BY STEVEN G. CARRUBBA O/A DEC 1983
C     CONVERTED TO DISSPLA9-0 6/12/84 MARTIN H. BOODA
C     IT WILL NOW ALLOW ONE TO OMIT CERTAIN HORIZONS AND
C     CALCULATE SO DESIGNATED SEDIMENT THICKNESSES
      CALL COMPRS
C     STATION CARD FORMAT:COL.1-3 STA.#,COL.4-23 OCEAN AREA,
C     COL.24-29 SHIP NAME, COL.30-35 CRUISE#, COL.36-38
C     JD, COL.39-40 YEAR, COL.41-46 LATITUDE (DD.MM)N OR S,
C     COL.47-53  LONGITUDE (DDD.MM)E OR W,COL.54-56 # OF
C     DATA CARDS, COL.57-58 LEG #, COL.59-63 SURFACE WATER
C     VELOCITY (X.XXX)KM/SEC.
  100 READ(5,1)ISTANM,AREA1,AREA2,AREA3,AREA4,SHIP,ICRUZ,JD,IYR,
      *  ALAT,MLAT,DLT,ALON,MLON,DLN,NCDS,LEG,SWV,ICOU  1
      FORMAT(I3,4A5,A6,I6,I3,I2,A2,1X,A2,A1,A3,1X,A2,A1,I3,I2,
      *F5.3,I1)
C     USE 999 FOR STA. # AT END OF DATA CARDS TO GET OUT OF LOOP
      IF(ISTANM.EQ.999) GO TO 101  NUM=0
C     THE NEXT TWO DO LOOPS FILL THE ARRAY 'A' WITH 30 VALUES IN
C     BOTH DIRECTIONS
      DO 77 L=1,30
      DO 77 M=1,30
      77 A(L,M)=0.
C     THESE ARE MATRICES TO STORE STA. ARRIVAL TIMES A(30,30)
C     INTERMEDIATE LEAST SQUARES QUOTIENT (B(15)) AND COEFFICIENT
C     DATA CARD FORMAT:COL.1-5 DIRECT WAVE TRAVEL TIME(X.XXX)KM/SEC.
C     COL.11-31 TWO WAY REFLECTION TIME TO EACH HORIZON IN LOGICAL
C     ORDER(X.XXX)KM/SEC.,NO SPACING.
      READ(5,3)(A(I,J),J=1,7)
    3 FORMAT(F6.3,4X,6F6.3)
    2 CONTINUE
     DO 88 I=1,30
     DO 88 J=1,30
   88 S(I,J)=A(I,J)
   85 READ(5,82)CHK
   82 FORMAT(A5)
     DO 83 K=1,NCDS
     DO 81 I=1,5
  81 ISTAT(I)=INDEX(CHK,IAR(I))
83 J=1,5
 IF (ISTAT(J).EQ.0)GO TO 84
     A(K,ISTAT(J)+2)=A(K,J+2)
84 IF(J.GT.ISTAT(J))A(K,J+2)=0.
```

```
83 CONTINUE
     NUM=NUM+1
C      AN APPROPRIATE SWV MUST BE INPUT ON THE STATION HEADER CARD.
       DO 4 I=1,NCDS
       DO 5 J=1,7
       A(I,7+J)=A(I,J)**2.
       A(I,15)=A(I,1)*SWV
       A(I,16)=A(I,15)**2.
     5 CONTINUE
     4 CONTINUE
C      CONSTRUCT TABLE
C      THIS SERIES OF STATEMENTS SIMPLY ESTABLISHES THE TABLE
C      FORMAT WHICH IS PRINTED BY THE COMPUTER AS PART OF THE OUTPUT.
       WRITE(6,14)ISTANM,AREA1,AREA2,AREA3,AREA4,SWV
    14 FORMAT(1H1,'SONOBUOY STATION NO.',I3,23X,' AREA ',4A5,10X,'
     *SURFACE WATER VELOCITY  ',F5.3//)
       WRITE(6,15)SHIP,ICRUZ,LEG,JD,IYR,ALAT,MLAT,DLT,ALON,MLON,DLN
    15 FORMAT(' SHIP ',A6,1X,I6,3X,'LEG',1X,I2,18X,'DATE ',I3,'/',I2,
     *6X,'LATITUDE ',A2,1X,A2,1X,A1,12X,'LONGITUDE ',A3,1X,A2,1X,A1//)
       WRITE(6,16)
    16 FORMAT(2X,' DIRECT WAVE',7X,'DISTANCE',22X,'2-WAY REFLECTION TIME
     *( SECONDS)')
       WRITE(6,17)
    17 FORMAT(2X,' TRAVEL TIME',7X,'SHIP TO')
       WRITE(6,18)
    18 FORMAT(2X,' (ONE WAY) IN',6X,'SONOBUOY',6X,'SEA FLOOR',6X,
     *'HORIZON A',6X,'HORIZON B',6X,'HORIZON C',6X,'HORIZON D',6X,
     *'HORIZON E')
       WRITE(6,19)
    19 FORMAT(2X,' SECONDS',11X,'IN KM.',12X,'1',14X,'2',14X,'3',14X,
     *'4',14X,'5',14X,'6')
       WRITE(6,20)
    20 FORMAT(5X,'T',4X,'T^2',8X,'X',5X,'X^2',6(6X,'T',5X,'T^2'))
       DO 5000 I=1,NCDS
       WRITE(6,21)A(I,1),A(I,8),A(I,15),A(I,16),A(I,2),A(I,9),A(I,3),
     *A(I,10),A(I,4),A(I,11),A(I,5),A(I,12),A(I,6),A(I,13),A(I,7),
     *A(I,14)
    21 FORMAT(1X,F6.3,1X,F7.3,1X,F7.3,1X,F8.3,1X,6(F6.3,1X,F7.3,1X))
  5000 CONTINUE
     THIS ROUTINE ESTABLISHES THE GRAPH ITSELF AND THE TITLE
C      AND LEGEND ETC.
       CALL NOBRDR
       CALL PAGE(16.,14.)
       CALL AREA2D(12.,12.)
       CALL HEIGHT(.21)
       CALL MX1ALF('STANDA','/')
       CALL MX2ALF('INSTRU','+')
       *X/)',57)
       CALL YNAME('REFL TIME SQUARED, SEC+E0.9H.5/2+EXHX/
     *(T+E0.9H.5/2+EXHX/)',58)
       CALL XREVTK
       CALL YREVTK
       CALL INTAXS  CALL GRAF(0.,10.,200.,0.,10.,200.)
```

```
      CALL INTNO(ISTANM,7.,2.)
      CALL INTNO(ICRUZ,9.,2.)
      ENCODE(2002,HORIZ)CHK
 2002 FORMAT('HORIZONS:  ',A5)
      CALL MESSAG(HORIZ,16,11.,2.)
C     LEAST SQUARES ROUTINE
C     THIS SERIES OF STATEMENTS DOES A LEAST SQUARES LINEAR FIT
C     TO THE PLOT OF THE SQUARES OF THE DATA POINTS. THE LEAST
C     SQUARES FIT IS DONE MATHEMATICALLY BY USING THE SUM OF THE
C     X'S AND Y'S AND XY ETC. LINES 81 THRU 100 CALCULATE ALL OF
C     THESE PRODUCTS. LINES 109 THRU 116 ACTUALLY DETERMINE THE
C     CONSTANTS A & B FOR THE BEST FIT LINE Y=A+BX. LINES 105 THRU
C     108 SCALE THE DIRECT AND CORRESPONDING HORIZON ARRIVALS TO
C     THE GRAPH SCALE AND PLOTS THEM ON THE GRAPH. LINES 117 THRU
C     120 ARE COMMENT CARDS FOR THIS PROCESS.
      DO 1000 J=1,7
      SQX=0.
      SQY=0
      YPX=0.
      XBAR=0.
      YBAR=0.
      DO1001 I=1,NCDS
      IF(A(I,J).EQ.0..AND.I.NE.1)GO TO 1003
      XBAR=XBAR+A(I,16)
      YBAR=YBAR+A(I,J+7)
      SQX=A(I,16)**2.+SQX
      SQY=A(I,J+7)**2.+SQY
      GO TO 1001
 1003 PXY=XBAR*YBAR/(I-1)
      XBAR=(XBAR**2.)/(I-1)
      XNCDS=(I-1)
      GO TO 1002
 1001 YPX=A(I,16)*A(I,J+7)+YPX
      PXY=XBAR*YBAR/NCDS
      XBAR=(XBAR**2.)/NCDS
      XNCDS=NCDS
 1002 SSXY=0.
      SSX=0.
      DO 1004 I=1,NCDS
      IF(A(I,J+7).EQ.0..AND.I.NE.1)GO TO 3000
C     PLOT SYMBOL ON GRAPH
      CALL MARKER(J)
      CALL HEIGHT(.1)
      CALL CURVE(A(I,16),A(I,J+7),1,-1)
      SSX=SQX-XBAR
      SSXY=YPX-PXY
 1004 CONTINUE
 3000 BETA=SSXY/SSX
      COC(J)=BETA*((SQRT(SQX/XNCDS-XBAR/XNCDS))/(SQRT(SQY/XNCDS-
     *((YBAR/XNCDS)**2.))))
      ALPHA=YBAR-BETA*XBAR
      B(J)=BETA
C     Y=12.*ALPHA/200.+1.
```

```
C      CALL PLOT(2.,Y,3)
C      Y=ALPHA+BETA*200.+1.
C      CALL PLOT(14.,Y,2)
 1000 CONTINUE
C      CALCULATE AND PRINT VEL. AND THK.
C      CALCULATES THK. AND VEL. FOR EACH LAYER AND PRINTS THEM
C      OUT UNDER THE TABLE OF ARRIVALS.
       DO 1005 I=2,7
       IF(A(1,I).LE.A(1,I-1))GO TO 6000
       AVEL=SQRT(((1/B(I))*A(1,I)-(1/B(I-1))*A(1,I-1))/(A(1,I)
      *-A(1,I-1)))
       THK=AVEL*(A(1,I)-A(1,I-1))/2.
       IB=I-2
       IT=IB+1
       WRITE(6,22)IB,IT,AVEL,COC(I)
   22 FORMAT(' VELOCITY (',I1,' TO ',I1,' )',20X,F5.3,' KM./SEC.',7X,
      *' COC = ',3X,F6.4)
       WRITE(6,23)IB,IT,THK
   23 FORMAT(' THICKNESS (',I1,' TO ',I1,')',19X,F5.3,' KM.')
 1005 CONTINUE
 6000 WRITE(6,87)CHK
   87 FORMAT(1H0,'COMPUTED HORIZONS:',2X,A5)
       IF (NUM.NE.ICOU)GO TO 92
       CALL ENDPL(0)
       GO TO 100
   92 DO 91 I=1,30
       DO 91 J=1,30
   91 A (I,J)=S(I,J)
       CALL ENDPL(0)
       GO TO 85
  101 CALL DONEPL
       END
EOF:193
```

APPENDIX D

INSTANTANEOUS VELOCITY PROGRAM FOR INDIVIDUAL STATIONS

PROGRAM TIMVEL WITH SUBPROGRAMS LEAST,PARA AND EXPO

```
C     PROGRAM TIMVEL4 SETS UP A TIME/VELOCITY PLOT FOR A LAYER AND
C LAYERS.  (STANDARD NAVOCEANO WABR DATA)  AN OPTION "1" IN COLUMN
C 64 SETS UP A PLOT FOR CDP VALUES, I.E., ONE WAY TRAVEL TIME FROM
C THE SEDIMENT SURFACE TO A DEPTH AT WHICH A VELOCITY APPLIES.
C (USE PROGRAM TIMVEL6 IF USING LAMONT DATA.)
C SETS UP MATRICES FOR THE STORAGE OF THICKNESS,VELOCITY, AND TIME
C DATA.
      IMPLICIT DOUBLE PRECISION (S)
     DIMENSION THICK(100),
     *          VELOC(100),
     *          TIME(100)
      CHARACTER XTITLE*36,ICRUZ*6
      CALL COMPRS
C INDICATES THAT UP TO 70 INDIVIDUAL STATIONS CAN BE PROCESSED
C IN ONE RUN.
      DO 5000 II=1,70
C READS IN STATIONS DATA SUCH AS NUMBER AREA, LOCATION, SHIP
C CRUISE DATA AND NUMBER OF DATA CARDS IE ONE FOR EACH LAYER
C NOTE:   THE FIRST DATA CARD IS THE SEDIMENT SURFACE VELOCITY
C AND THEREFORE HAS A THICKNESS OF ZERO.
        READ(5,50)ISTANM,AREA1,AREA2,AREA3,AREA4,SHIP,ICRUZ,JD,IYR,
   *ALAT,DLT,ALON,DLN,NCDS,LEG,ITHTIM
 50     FORMAT(I3,4A5,A6,A6,I3,I2,F5.2,A1,F6.2,A1,I3,A2,6X,I1)

C INDICATES THE USE OF A 999 CARD TO GET OUT OF THE LOOP AND
C END THE RUN.
        IF (ISTANM.EQ.999) GO TO 9999
        IF(ITHTIM.LT.1)GO TO 51
    DO 52 JJ=1,NCDS
   52 READ(5,60)TIME(JJ),VELOC(JJ)
      GO TO 2500
C READ IN SEDIMENT SURFACE DATA
C READS IN THE SEDIMENT SURFACE VELOCITY AND THICKNESS.
   51 READ(5,55) THICK(1),VELOC(1)
 55   FORMAT(F5.3,1X,F5.3)
      TIME(1)=0.0
C ESTABLISHES THE NUMBER OF INDIVIDUAL LAYERS TO BE USED NCDS
C INCLUDES THOSE DATA CARDS FOR COMBINATION LAYERS THUS NCRS/2
C + 1 WILL ALWAYS GIVE ONLY THE NUMBER OF INDIVIDUAL LAYERS
C INCLUDING THE SEDIMENT SURFACE LAYER.
        LAYER=NCDS/2+1
        CTIME=0.0
C SINGLE SEDIMENT LAYER DATA IS STORED IN ARRAYS
C TIME, VELOC, AND THICK FROM SUBSCRIPT (2) TO
C SUBSCRIPT (LAYER)
```

```
C READS IN THE INDIVIDUAL LAYER THICKNESS AND VELOCITIES ON EACH
C DATA CARD IN TURN (NOT INCLUDING SEDIMENT SURFACE) UP TO THE NUMBER
C SPECIFIED BY LAYER (SEE LINE 35).  IT THEN CALCULATES THE ONE
C WAY TRAVEL TIME FROM THE SEDIMENT SURFACE  TO THE MIDPOINT
C OF THE LAYER AND THIS TIME IS STORED IN A MATRIX.
        DO 1000 JJ=2,LAYER
          READ(5,60) THICK(JJ),VELOC(JJ)
 60       FORMAT(F5.3,1X,F5.3)
          TIME(JJ)=CTIME+((THICK(JJ)*0.5)/VELOC(JJ))
          CTIME=CTIME+(THICK(JJ)/VELOC(JJ))
 1000     CONTINUE
C CALCULATES THE ONE WAY TRAVEL TIME TO THE MIDPOINT OF THE
C LAYER FOR EACH OF THE COMBINATIONS OF LAYERS AND STORES THESE
C TIMES.  LINE 60 TAKES IT OUT OF THE LOOP IF THESE ARE TWO
C LAYERS OR LESS (IE. SURFACE LAYERS AND ONE LAYER) SINCE
C A COMBINATION CANNOT BE MADE OF THESE.
C CALCULATE ONE WAY TRAVEL TIME FOR COMBINED LAYERS
C SKIP THIS LOOP IF THERE IS ONLY SURFACE SEDIMENT DATA OR
C IF THERE IS ONLY SURFACE SEDIMENT DATA AND ONE LAYER
 IN THAT STATION
        IF(NCDS.LE.2) GO TO 2500
        CTIME=0.0
        ITALLY=2
C COMBINED LAYER DATA IS STORED IN ARRAYS FROM
C SUBSCRIPT (ICOMB) TO SUBSCRIPT (NCDS)
        ICOMB=LAYER+1
        DO 2000 KK=ICOMB,NCDS
          READ(5,70) THICK(KK),VELOC(KK)
 70       FORMAT(F5.3,1X,F5.3)
          TIME(KK)=CTIME+((THICK(KK)*0.5)/VELOC(KK))

          CTIME=CTIME+(THICK(ITALLY)/VELOC(ITALLY))
          ITALLY=ITALLY+1
 2000     CONTINUE
C ESTABLISHES THE TITLE AND FORMAT FOR PRINTING OUT
C THE INDIVIDUAL STATION THICKNESS, VELOCITIES AND ONE  WAY
C TRAVEL TIMES.
 2500   ENCODE(80,XTITLE) ICRUZ,LEG,ISTANM
 80     FORMAT(' CRUISE ',A6,2X,'LEG ',A2,2X,
     *         'STATION ',I3,'$')
      WRITE(6,72) ISTANM
 72   FORMAT(' DATA FOR STATION ',I3)
      DO 3000 LL=1,NCDS
        IF(ITHTIM.LT.1)WRITE(6,75) LL,THICK(LL),VELOC(LL),TIME(LL)
 75     FORMAT(' POINT NUMBER ',I2,3X,'THICKNESS= '
     *   F5.3,3X,'VELOCITY= ',F5.3,3X,'TIME= ',F5.3)
       IF(ITHTIM.GE.1)WRITE(6,76) LL,VELOC(LL),TIME(LL)
   76 FORMAT(' POINT NUMBER ',I2,3X,'VELOCITY= ',F5.3,3X,'TIME= '
     *,F5.3)
 3000 CONTINUE
      CALL TITLE(' ',1,0,0,'ONE WAY TRAVEL TIME IN SECS.$',
     *100,6.0,8.0)
      CALL XTICKS(1)
```

```
      CALL YTICKS(2)
      CALL GRAF(1.4,0.2,5.0,4.0,-0.5,0.0)
      CALL XGRAXS(1.4,0.2,5.0,6.0,'VELOCITY-KM/SEC$',
     *-100,0.,8.)
      CALL MARKER(8)
      CALL CURVE(VELOC,TIME,NCDS,-1)
C SETS UP THE GRAPH OF THE INDIVIDUAL STATION VELOCITIES
C VERSUS ONE WAY TRAVEL TIME, ESTABLISHES THE GRAPH SCALE ?,
C AXES AND AXES TITLES.
      CALL MESSAG(XTITLE,100,0.5,9.0)
      CALL LEAST(VELOC,TIME,NCDS,XTITLE)
      CALL PARA(VELOC,TIME,NCDS,XTITLE)
      CALL EXPO(VELOC,TIME,NCDS,XTITLE)
 5000 CONTINUE
 9999 CALL DONEPL
      STOP
      END
EOF:111
0:END ED. NO CORRECTIONS APPLIED
```

```
C SUBPROGRAM FOR LINEAR FIT OF VEL/TIME DATA
C SUMX=SUM OF THE XS (VELOC)
C SUMY=SUM OF THE YS (TIME)
C SUMW=SUM OF THE WS
C SUMXW=SUM OF THE X * W
C SUMYW=SUM OF THE Y * W
C SUMXYW=SUM OF THE X*Y*W'S
C SUMYSW=SUM OF Y SQ * W
C YAVE=AVERAGE OF THE YS
      SUBROUTINE LEAST(VELOC,TIME,NCDS,XTITLE)
C THIS ESTABLISHES MATRICES FOR STORING VARIOUS QUANTITIES
C TO BE MANIPULATED IN THE PROGRAM.
      DIMENSION VELOC(12),
     *          XEST(12),
     *          TIME(12)
      CHARACTER XTITLE*36,YTITLE*37,ZTITLE*31
       DIMENSION X(80),
     *          Y(80),
     *          W(12)
C THIS SEQUENCE SETS ALL OF THE QUANTITIES TO BE CALCULATED
C TO INTIAL ZERO VALUE.
      SUMW=0
      SUMX=0
      SUMXW=0
      SUMY=0
      SUMYW=0
      SUMXYW=0
      SUMYSW=0
      SUMYS=0
C WEIGHT FIRST POINT BY GIVING W(1) A HIGH VALUE
C IN ORDER TO GIVE MORE WEIGHT TO THE SEDIMENT SURFACE VELOCITY
C AND FORCE THE CURVE THROUGH THIS POINT, A WEIGHTING FACTOR IS
C USED IN THE CALCULATIONS AND THE SEDIMENT SURFACE VELOCITY IS
C GIVEN A WEIGHT OF 5 AND ALL OTHER VELOCITY POINTS A WEIGHT OF ONE.
      W(1)=5
      DO 500 LL=2,NCDS
 500  W(LL)=1.
C READ THROUGH VELOC AND TIME TO OBTAIN
C VARIABLES FOR LEAST SQUARES EQUATION
C THIS SERIES OF STATEMENTS CALCULATES THE VARIOUS QUANTITIES (SUMS)
C NEEDED TO PERFORM A MATHEMATICAL LEAST SQUARES FIT TO THE DATA.
C THE DATA ARE PULLED FROM THE MAIN PROGRAM AND NEED NOT BE READ
C IN AGAIN.
      DO 1000 JJ=1,NCDS
        SUMX=SUMX+VELOC(JJ)
        SUMY=SUMY+TIME(JJ)
        SUMW=SUMW+W(JJ)
        SUMXW=SUMXW+(VELOC(JJ)*W(JJ))
        SUMYW=SUMYW+(TIME(JJ)*W(JJ))
        SUMXYW=SUMXYW+(VELOC(JJ)*TIME(JJ)*W(JJ))
        SUMYS=SUMYS+TIME(JJ)**2
 1000   SUMYSW=SUMYSW+(TIME(JJ)**2*W(JJ))
        XAVE=SUMX/NCDS
```

```
C CREATE A0 VARIABLE FOR LEAST SQ EQUATION
C CALCULATES THE CONSTANTS A IN THE LINE Y=A+BX
        B0=((SUMXW*SUMYSW)-(SUMYW*SUMXYW))/
     *     ((SUMW*SUMYSW)-SUMYW**2)
C CREATE A1 VARIABLE FOR LEAST SQ EQUATION
C CALCULATES THE CONSTANT B IN THE LINE Y=A+BX
        B1=((SUMW*SUMXYW)-(SUMXW*SUMYW))/
     *     ((SUMW*SUMYSW)-SUMYW**2)
C THIS SERIES OF STATEMENTS USES THE EQUATION DETERMINED ABOVE
C Y=A+BX OR ACTUALLY X=A+BY TO DERIVE THE LINE WHICH BEST FITS
C THE DATA.  INCREMENTAL VALUES OF Y ARE USED ALONG WITH THE
C DETERMINED CONSTANTS A AND B. DERIVE X AND Y POINTS FOR LINE BY
C USING EQUATION FOR EVERY TICK MARK ON THE X AXIS
        YORIG=0.0
      DO 2000 II=1,50
        Y(II)=YORIG
        YORIG=YORIG+0.05
        X(II)=B0+B1*Y(II)
 2000   CONTINUE
C DETERMINES THE COEFFICIENT OF CORRELATION FOR THE LEAST SQUARES
C  FIT LINE AND PRINTS IT OUT.
C FIND ESTIMATED YS BY USING FORMULA ON EACH
C ACTUAL X VALUE
      SSR=0
      SST=0
      DO 1500 LL=1,NCDS
      XEST(LL)=B0+(B1*TIME(LL))
      SSR=SSR+(VELOC(LL)-XEST(LL))**2
      SST=SST+(VELOC(LL)-XAVE)**2
 1500   CONTINUE
      COC=SQRT(1-(SSR/SST))
        ENCODE(70,ZTITLE) COC
 70     FORMAT(' CORRELATION COEFFICIENT= ',F5.3)
C POINTS OUT THE COEFFICIENTS A AND B.
        ENCODE(80,YTITLE) B1,B0
  80    FORMAT(' B1=',F6.3,2X,'B0=',F6.3,5X,'X=B0 + B1*Y')
C THESE PLOT THE DATA AND THE BEST FIT LINE WITH HEADINGS AND
C AXIS NOTATION.
        CALL CURVE(X,Y,50,0)
        CALL MESSAG(YTITLE,37,0.5,-0.5)
        CALL MESSAG(ZTITLE,31,0.5,0.0)
      RETURN
     END
```

```
C SUBROUTINE FOR PARABOLIC CURVE ON VELOCITY/TIME DATA
      SUBROUTINE PARA(VELOC,TIME,NCDS,XTITLE)
C SUMX=SUM OF THE XS (VELOC)
C SUMY=SUM OF THE YS (TIME)
C SUMXSQ=SUM OF THE X SQUAREDS
C SUMXCU=SUM OF THE X CUBEDS
C SUMXFO=SUM OF THE X TO THE FOURTHS
C SUMXY=SUM OF THE X*YS
C SUMXSY=SUM OF THE X SQ. * YS
C YAVE= AVERAGE OF YS (WITHOUT WEIGHTED PTS.)
C THESE ESTABLISH MATRICES FOR STORING DATA TO BE MANIPULATED.
      DIMENSION VELOC(60),
     *          TIME(60)
      DIMENSION X(80),
     *          Y(80)
      CHARACTER XTITLE*36,YTITLE*32,ZTITLE*36
      DIMENSION A(3,3),
     *          B(3),
     *          XEST(12)
C THESE INITIALLY SET ALL QUANTITIES TO BE CALCULATED AT ZERO.
      SUMX=0
      SUMY=0
      SUMYSQ=0
      SUMYCU=0
      SUMYFO=0
      SUMXY=0
      SUMYSX=0
      ZERO=1.0E-06
C WEIGHTING FOR SEDIMENT SURFACE VALUES
C IWT IS THE WEIGHTING FACTOR FOR THE POINT
C THE VALUES FOR THAT POINT ARE ADDED ONTO
C THE EXISTING DATA ARRAYS
C NUM=FINAL NUMBER OF POINTS USED
C NOTE: AN IWT VALUE OF 1 MEANS THE VALUE IS WEIGHTED BY
C 2 SINCE THE VALUE HAS ALREADY BEEN READ INTO
C THE VELOC AND TIME ARRAYS IN THE INITIAL READ
C GIVES THE SURFACE SEDIMENT VELOCITY A WEIGHTING OF 5.
      IWT=4
      ITALLY=NCDS+1
      NUM=NCDS+IWT
      DO 500 MM=ITALLY,NUM
        VELOC(MM)=VELOC(1)
        TIME(MM)=TIME(1)
 500  CONTINUE
C READ THROUGH VELOC AND TIME TO OBTAIN SUMS
C CALCULATES THE QUANTITIES NEEDED TO DETERMINE THE COEFFICIENTS
C OF THE BEST FIT CURVE  X=A+BY+CY**2.
      DO 1000 JJ=1,NUM
        SUMX=SUMX+VELOC(JJ)
        SUMY=SUMY+TIME(JJ)
        SUMYSQ=SUMYSQ+(TIME(JJ)**2)
        SUMYCU=SUMYCU+(TIME(JJ)**3)
        SUMYFO=SUMYFO+(TIME(JJ)**4)
```

```
        SUMXY=SUMXY+(VELOC(JJ)*TIME(JJ))
        SUMYSX=SUMYSX+((TIME(JJ)**2)*VELOC(JJ))
 1000 CONTINUE
C PRINTS THE CALCULATED VALUES DETERMINED ABOVE.
          PRINT 90,SUMX,SUMY,SUMYSQ,SUMYCU,SUMYFO,SUMXY,SUMYSX
C SUM THE YS WITHOUT THE WEIGHTED VALUES
C FOR USE IN THE COC EQUATION
C DETERMINES THE SUM OF THE VELOCITIES AND THE AVERAGES OF THE
C VELOCITIES FOR DETERMINING THE COEFFICIENT OR CORRELATION .
C THIS IS THEN PRINTED OUT.
        XSUM=0
      DO 1200 KK=1,NCDS
 1200   XSUM=XSUM+VELOC(KK)
        XAVE=XSUM/NCDS
          PRINT 90,XAVE
C THIS DETERMINES THE COEFFICIENT A,B,AND C BY THE MATRIX METHOD OF
C SOLVING 3 EQUATIONS SIMULTANEOUSLY AND PRINTS OUT THE COEFFICIENTS.
C SOLVE SIMULTANEOUS EQUATIONS TO GET
C COEFFICIENTS FOR EQUATION
      A(1,1)=NUM
        A(1,2)=SUMY
        A(1,3)=SUMYSQ
        A(2,1)=SUMY
        A(2,2)=SUMYSQ
        A(2,3)=SUMYCU
        A(3,1)=SUMYSQ
        A(3,2)=SUMYCU
        A(3,3)=SUMYFO
        B(1)=SUMX
        B(2)=SUMXY
        B(3)=SUMYSX
      DO 100 I=1,3
        DIV=A(I,I)
        IF(ABS(DIV)-ZERO) 99,99,1
 1      DO 101 J=1,3
        A(I,J)=A(I,J)/DIV
 101    CONTINUE
      B(I)=B(I)/DIV
      DO 102 J=1,3
        IF(I-J) 2,102,2
 2      RATIO=A(J,I)
        DO 103 K=1,3
        A(J,K)=A(J,K)-RATIO*A(I,K)
 103    CONTINUE
      B(J)=B(J)-RATIO*B(I)
 102  CONTINUE
 100  CONTINUE
          PRINT 90,B(1),B(2),B(3)
C USES THE COEFFICIENTS DETERMINED , IN THE EQUATION X=A+BY+CY2 TO
C DERIVE THE BEST FIT PARABOLIC CURVE TO THE DATA.
 99     YORIG=0.0
C DERIVE X AND Y POINTS FOR LINE BY USING
C EQUATION FOR EVERY TICK MARK ON THE X AXIS
```

```
      DO 2000 II=1,50
        Y(II)=YORIG
        YORIG=YORIG+0.05
        X(II)=B(1)+(B(2)*Y(II))+(B(3)*Y(II)**2)
 2000   CONTINUE
C CALCULATES THE COEFFICIENT OF CORRELATION FOR THE BEST FIT CURVE
C AND PRINTS THIS VALUE.
C FIND ESTIMATED XS BY USING FORMULA
C ON EACH Y VALUE
      SSR=0.
      SST=0.
      DO 1500 LL=1,NCDS
        XEST(LL)=B(1)+(B(2)*TIME(LL))+(B(3)*TIME(LL)**2)
        SSR=SSR+(VELOC(LL)-XEST(LL))**2
        SST=SST+(VELOC(LL)-XAVE)**2
 1500   CONTINUE
      COC=SQRT(1-(SSR/SST))
          PRINT 90,COC
      ENCODE(70,ZTITLE) COC
 70   FORMAT(' CORRELATION COEFFICIENT PARA= ',F5.3)
C PRINTS OUT THE DETERMINED COEFFFICIENTS.
        ENCODE(80,YTITLE) B(1),B(2),B(3)
  80    FORMAT(' A0=',F6.3,2X,'A1=',F6.3,2X,'A2=',F6.3)
C PRODUCES THE GRAPH OF THE DATA POINTS AND THE CURVE AND ALL LEGEND
C INFORMATION.
        CALL CURVE(X,Y,50,0)
        CALL MESSAG(YTITLE,32,0.5,1.0)
      CALL MESSAG(ZTITLE,36,0.5,1.5)
      CALL MESSAG('  X= A0 + A1*Y + A2*Y**2',24,0.5,0.5)
  90    FORMAT( )
      RETURN
      END
```

```
C SUBPROGRAM FOR EXPONENTIAL CURVE
C (IF PROBLEMS OCCUR WITH NEGATIVE NUMBERS USE PROGRAM EXPO5.
C IT SOLVES EQUATION WITH ABSOLUTE VALUES.)
C SUMX=SUM OF THE XS (VELOC)
C SUMY=SUM OF THE YS (TIME)
C SUMW=SUM OF THE WS
C SUMXW=SUM OF THE X * W
C SUMYW=SUM OF THE Y * W
C SUMXYW=SUM OF THE X*Y*W'S
C SUMXSW=SUM OF X SQ * W
C YAVE=AVERAGE OF THE YS
      SUBROUTINE EXPO(VELOC,TIME,NCDS,XTITLE)
C PROVIDES MATRICES FOR THE STORAGE OF QUANTITIES TO BE
C MANIPULATED.
      DIMENSION VELOC(12),
     *          LOGVEL(12),
     *          TIME(12)
      CHARACTER*36 XTITLE,YTITLE,ZTITLE
      DIMENSION X(80),
     *          Y(80),
     *          W(12),
     *          XEST(12)
      REAL LOGVEL
C INITIALIZE ALL OF THE QUANTITIES AT ZERO.
      SUMY=0
      SUMW=0
      SUMX=0
      SUMXW=0
      SUMYW=0
      SUMXYW=0
      SUMYSW=0
C TAKES THE NATURAL LOG OF THE VELOCITIES FROM THE MAIN PROGRAM
C AND STORES THESE VALUES FOR FURTHER USE.  ALSO PRINTS OUT
C THESE QUANTITIES.
C LOG X AND Y VALUES
      DO 300 KK=1,NCDS
        LOGVEL(KK)=ALOG(VELOC(KK))
          PRINT 90,VELOC(KK),TIME(KK),LOGVEL(KK)
 300    CONTINUE
C WEIGHTS THE SEDIMENT SURFACE VELOCITY WITH A WEIGHT OF 5 TO
C FORCE THE BEST FIT CURVE  THROUGH THIS POINT.
C WEIGHT FIRST POINT BY GIVING W(1) A HIGH VALUE
      W(1)=5
      DO 500 LL=2,NCDS
 500  W(LL)=1.
C CALCULATES THE VARIOUS SUMS NEEDED TO MAKE A LEAST SQUARE FIT
C AND PRINTS OUT THE SUMS.
C READ THROUGH VELOC AND LOGTIM TO OBTAIN
C VARIABLES FOR LEAST SQUARES EQUATION
      DO 1000 JJ=1,NCDS
        SUMX=SUMX+VELOC(JJ)
        SUMY=SUMY+TIME(JJ)
        SUMW=SUMW+W(JJ)
```

```
          SUMXW=SUMXW+(LOGVEL(JJ)*W(JJ))
          SUMYW=SUMYW+(TIME(JJ)*W(JJ))
          SUMXYW=SUMXYW+(LOGVEL(JJ)*TIME(JJ)*W(JJ))
 1000     SUMYSW=SUMYSW+(TIME(JJ)**2*W(JJ))
            PRINT 90,SUMX,SUMY,SUMW,SUMXW,SUMYW,SUMXYW,SUMYSW
        XAVE=SUMX/NCDS
C THE EXPONENTIAL EQUATION X=AB**Y HAS BEEN PUT IN THE FORM
C LOGX=LOGA+YLOGB (STRAIGHT LINE FORM).  THIS SEQUENCE
C DETERMINES THE CONSTANT B0 = LOGA.
C CREATE A1 VARIABLE FOR LEAST SQ EQUATION
        B1=((SUMW*SUMXYW)-(SUMXW*SUMYW))/
     *    ((SUMW*SUMYSW)-SUMYW**2)
C THIS SEQUENCE DETERMINES THE CONSTANT B1=LOG B.
C CREATE A0 VARIABLE FOR LEAST SQ EQUATION
        B0=((SUMXW*SUMYSW)-(SUMYW*SUMXYW))/
     *    ((SUMW*SUMYSW)-SUMYW**2)
C TAKES THE ANTILOG OF B0 AND B1 AND PRINTS THESE VALUES.
        A0=EXP(B0)
        A1=EXP(B1)
            PRINT 90,A0,A1
C PRODUCES THE BEST FIT CURVE BY CALCULATING VALUES OF X FOR
C INCREMENTAL VALUES OF Y USING THE CONSTANTS DETERMINED ABOVE.
C DERIVE X AND Y POINTS FOR LINE BY USING
C EQUATION FOR EVERY TICK MARK ON THE X AXIS
          YORIG=0.0
        DO 2000 II=1,50
          Y(II)=YORIG
          YORIG=YORIG+0.05
          X(II)=A0*(A1**Y(II))
 2000     CONTINUE
C CALCULATES THE CORRELATION COEFFICIENT FOR THE BEST FIT CURVE
C TO THE DATA
C POINTS AND PRINTS THIS VALUE.
C CORRELATION COEFFICIENT
C FIND ESTIMATED YS BY USING FORMULA ON EACH
C ACTUAL X VALUE
        SSR=0.
        SST=0.
        DO 1500 LL=1,NCDS
        XEST(LL)=A0*(A1**TIME(LL))
        SSR=SSR+(VELOC(LL)-XEST(LL))**2
        SST=SST+(VELOC(LL)-XAVE)**2
 1500     CONTINUE
        COC=SQRT(1-(SSR/SST))
          PRINT 90,COC
C PLOTS THE DATA POINTS ON A GRAPH, DRAWS THE BEST FIT CURVE,
C LABELS THE AXIS AND PRINTS THE STATION NUMBERS, CURVE EQUATION
C AND CONSTANTS,
          ENCODE(70,ZTITLE) COC
 70       FORMAT(' CORRELATION COEFFICIENT EXPO= ',F5.3)
          ENCODE(80,YTITLE) A1,A0
  80      FORMAT(' A1=',F6.3,2X,'A0=',F6.3,5X,'X=A0*A1**Y')
          CALL CURVE(X,Y,50,0)
```

```
      CALL MESSAG(YTITLE,36,0.5,2.0)
      CALL MESSAG(ZTITLE,36,0.5,2.5)
90    FORMAT( )
    CALL ENDPL(1)
    RETURN
    END
```

# APPENDIX E

## INSTANTANEOUS VELOCITY PROGRAM FOR GROUPS OF STATIONS

```
                              PROGRAM VLEG
C PROGRAM FOR VEL/ONE WAY TRAVEL TIME PLOT BY LEG AND
C  SUBROUTINES LEGLST, LEGPAR AND LEGEXPO

 IMPLICIT DOUBLE PRECISION (S)

C THIS CREATES STORAGE FOR QUANTITIES SUCH AS THICKNESS,VELOCITY,
  TIME TO BE MANIPULATED LATER.
      DIMENSION THICK(100),
     *          VELOC(100),
     *          THIN(500),
     *          TIME(100)
      DIMENSION VLEG(500),
     *          TLEG(500)
      CHARACTER*6 SHIP,ACRUZ,ICRUZ,XTITLE*23,LEG*2,ILEG*2,AREA*20,
     *DLT*1,DLN*1
      CALL COMPRS
C THIS READS A CARD WHICH INDICATES HOW MANY TIMES THE PROGRAM  WILL
C BE RUN IE HOW MANY LEGS OF DATA TO BE PROCESSED.
      READ(5,40)NUM
40    FORMAT(I2)
      DO 4000 MM=1,NUM
C SETS COUNTERS AT ZERO THESE ARE USED TO KEEP TRACK OF NUMBER OF
C LAYERS AND NUMBER OF STATIONS.
        ITOTAL=1
        ICOUNT=0
C SETS THE LIMITS FOR THE NUMBER OF STATIONS TO BE PROCESSED
C IN ONE LEG.
      DO 5000 II=1,50
C ON STATION NUMBER, AREA, SHIP, CRUISE,DAY AND YEAR,POSITION, LEG
C ON WHICH STATION TAKEN AND NUMBER OF DATA CARDS IN THIS STATION.
      READ(5,50)ISTANM,AREA,SHIP,ICRUZ,JD,IYR,ALAT,
     *DLT,ALON,DLN,NCDS,LEG,ITHTIM
C GIVES THE FORMAT FOR PUTTING THE ABOVE DATA ON CARDS.
 50    FORMAT(I3,A20,A6,A6,I3,I2,F5.2,A1,F6.2,A1,I3,A2,6X,I1)
C SAVE THE LEG AND CRUISE NUMBERS FOR LABELS
C THIS SAVES THE CRUISE NUMBER AND LEG NUMBER FROM THE FIRST
C HEADER  CARD  FOR USE IN LABELING THE PLOTS.
      IF(II.NE.1) GO TO 500
        ILEG=LEG
        ACRUZ=ICRUZ
 500    IF (ISTANM.EQ.999) GO TO 2550
C INDICATES THAT A 999 CARD IS NEEDED AFTER THE LAST STATION
C DATA CARD IN EACH LEG.
C READ IN SEDIMENT SURFACE DATA
      IF(ITHTIM.LT.1)GO TO 51
C THIS READS IN THE SEDIMENT SURFACE VELOCITY AND TIME
```

```
      DO 52 JJ=1,NCDS
   52 READ(5,60)TIME(JJ),VELOC(JJ)
      GO TO 2001
C THIS READS IN THE SEDIMENT SURFACE VELOCITY AND THICKNESS
C THIS IS THE FIRST DATA CARD FOR EACH STATION AND THE THICKNESS
C WILL ALWAYS BE ZERO SINCE THIS IS SEDIMENT SURFACE.
   51 READ(5,55) THICK(1),VELOC(1)
 55   FORMAT(F5.3,1X,F5.3)
C INITIALIZES TIME AT ZERO.
      TIME(1)=0.0
C READ IN SINGLE LAYER DATA AND CONVERT TO ONE
C WAY TRAVEL TIME.  SINGLE LAYER DATA ARE STORED IN
C THE ARRAYS THICK, VELOC, AND TIME FROM SUBSCRIPT
C (2) TO SUBSCRIPT (LAYER)
C THIS DETERMINES HOW MANY INDIVIDUAL LAYERS ARE TO BE CALCULATED
C FOR A STATION.
       LAYER=NCDS/2+1
C THIS TAKES CARE OF THE CASE OF ONLY A SEDIMENT SURFACE VELOCITY.
      IF (LAYER.LE.1) GO TO 2001
C INITIALIZE CTIME
        CTIME=0.0
C THIS LOOP TAKES THE DATA READ IN ON INDIVIDUAL LAYERS AND CALCULATES
C THE MIDPOINT TO THE LAYER IN TERMS OF ONE WAY TRAVEL TIME FROM THE
C SEDIMENT SURFACE THESE ARE STORED IN ARRAYS FOR FURTHER USE.
        DO 1000 JJ=2,LAYER
          READ(5,60) THICK(JJ),VELOC(JJ)
 60       FORMAT(F5.3,1X,F5.3)
          TIME(JJ)=CTIME+((THICK(JJ)*0.5)/VELOC(JJ))
          CTIME=CTIME+(THICK(JJ)/VELOC(JJ))
 1000     CONTINUE
C READ IN AND PROCESS COMBINED LAYER DATA.
C COMBINED LAYER VALUES ARE STORED IN ARRAYS FROM
C SUBSCRIPT (ICOMB) TO SUBSCRIPT (NCDS)
C SKIP THIS LOOP IF ONLY SEDIMENT SURFACE DATA IS
C AVAILABLE OR ONLY SURFACE AND ONE SEDIMENT LAYER
C DATA IS USED.
       IF(NCDS.LE.2) GO TO 2001
        CTIME=0.0
        ITALLY=2
        ICOMB=LAYER+1
        DO 2000 KK=ICOMB,NCDS
          READ(5,70) THICK(KK),VELOC(KK)
 70       FORMAT(F5.3,1X,F5.3)
          TIME(KK)=CTIME+((THICK(KK)*0.5)/VELOC(KK))
          CTIME=CTIME+(THICK(ITALLY)/VELOC(ITALLY))
          ITALLY=ITALLY+1
C THIS SEQUENCE STORES THE CALCULATED TRAVEL TIMES, THE THICKNESS
C  AND VELOCITIES  FROM INDIVIDUAL STATIONS INTO LARGE ARRAYS FOR
C THE ENTIRE  LEG.
              2000     CONTINUE
  2001 ICOUNT=ICOUNT+NCDS
      ITALLY=1
      DO 3000 NN=ITOTAL,ICOUNT
```

```
        VLEG(NN)=VELOC(ITALLY)
        TLEG(NN)=TIME(ITALLY)
        THIN(NN)=THICK(ITALLY)
        ITALLY=ITALLY+1
 3000   CONTINUE
      ITOTAL=ITOTAL+NCDS
 5000 CONTINUE
C ESTABLISHES THE PLOT TITLE
 2550 WRITE(6,72) ILEG
 72   FORMAT(' DATA FOR LEG ',A2)
C PRINTS OUT THICKNESS, TRAVEL TIME, AND VELOCITY BY STATION.
      DO 350 LL=1,ICOUNT
        IF(ITHTIM.LT.1)WRITE(6,75) LL,THIN(LL),VLEG(LL),TLEG(LL)
 75     FORMAT(' POINT NUMBER ',I3,3X,'THICKNESS ',
     *   F5.3,3X,'VELOCITY= ',F5.3,3X,'TIME= ',F5.3)
      IF(ITHTIM.GE.1)WRITE(6,76)LL,VLEG(LL),TLEG(LL)
   76 FORMAT(' POINT NUMBER ',I3,3X,'VELOCITY= ',F5.3,3X,'TIME= '
     *,F5.3)
 350  CONTINUE
C ESTABLISHES CRUISE AND LEG TITLE FOR PLOTS
 2500   ENCODE(80,XTITLE) ACRUZ,ILEG
 80     FORMAT(' CRUISE ',A6,2X,'LEG ',A2,'$')
C CALLS THE LEAST SQUARE FIT SUBPROGRAMS.
      CALL LEGLST(VLEG,TLEG,ICOUNT,XTITLE)
      CALL LEGPAR(VLEG,TLEG,ICOUNT,XTITLE)
      CALL LEGEXP(VLEG,TLEG,ICOUNT,XTITLE)
 4000 CONTINUE
      CALL DONEPL
      STOP
      END
EOF:124
0:END ED. NO CORRECTIONS APPLIED
```

```
C SUBPROGRAM FOR LEAST SQUARE LINE OF VEL/TIME DATA BY LEG
C SUMX=SUM OF THE XS (VLEG)
C SUMY=SUM OF THE YS (TLEG)
C SUMW=SUM OF THE WS (A WEIGHTING FACTOR)
C SUMXW=SUM OF THE X * WS
C SUMYW=SUM OF THE Y * WS
C SUMXYW=SUM OF THE X * Y * WS
C SUMYSW=SUM OF THE Y SQ. * WS
      SUBROUTINE LEGLST(VLEG,TLEG,ICOUNT,XTITLE)
C SETS AND CREATES STORAGE FOR DATA TO BE MANIPULATED.
      DIMENSION VLEG(500),
     *          XEST(500),
     *          TLEG(500)
      DIMENSION X(80),
     *          Y(80),
     *          W(1000)
      CHARACTER XTITLE*23,
     *          YTITLE*36,
     *          ZTITLE*32
C INITIALIZED THESE QUANTITIES AT ZERO.
      SUMW=0.
      SUMX=0.
      SUMXW=0.
      SUMY=0.
      SUMYW=0.
      SUMXYW=0.
      SUMYSW=0.
C GIVES WEIGHTING TO FIRST DATA POINT THIS POINT SHOULD BE THE
C SEDIMENT SURFACE VELOCITY VALUE DESIRED FOR THE DATA GROUP AND
C THE SURFACE POINT THROUGH WHICH THE CURVE FIT IS TO BE FORCED.
C WEIGHT FIRST POINT BY GIVING W(1) A HIGH VALUE
      W(1)=5
      DO 500 LL=2,ICOUNT
 500  W(LL)=1.
C TAKING THE VALUES CALCULATED AND STORED IN THE MAIN PROGRAM,
C THE VARIOUS SUMS ARE CALCULATED FROM THE VALUES. READ THROUGH
C VELOC AND TIME TO OBTAIN VARIABLES FOR LEAST SQUARES EQUATION
      DO 1000 JJ=1,ICOUNT
        SUMX=SUMX+VLEG(JJ)
        SUMY=SUMY+TLEG(JJ)
        SUMW=SUMW+W(JJ)
        SUMXW=SUMXW+(VLEG(JJ)*W(JJ))
        SUMYW=SUMYW+(TLEG(JJ)*W(JJ))
        SUMXYW=SUMXYW+(VLEG(JJ)*TLEG(JJ)*W(JJ))
 1000   SUMYSW=SUMYSW+(TLEG(JJ)**2.*W(JJ))
        XAVE=SUMX/ICOUNT
C USE THE CALCULATED SUMS TO OBTAIN CONSTANT 'A' FOR EQUATION
C OF BEST LEAST SQUARE FIT LINE X=A+BY
C CREATE A0 VARIABLE FOR LEAST SQ EQUATION
      A0=((SUMXW*SUMYSW)-(SUMYW*SUMXYW))/
     *   ((SUMW*SUMYSW)-SUMYW**2)
C USE CALCULATED SUMS TO OBTAIN CONSTANT 'B'.
C CREATE A1 VARIABLE FOR LEAST SQ EQUATION
```

```
      A1=((SUMW*SUMXYW)-(SUMXW*SUMYW))/
     *    ((SUMW*SUMYSW)-SUMYW**2)
C PRINT CONSTANTS A AND B.
        PRINT 90,A0,A1
C DERIVE POINTS FOR BEST FIT LINE USING DETERMINED CONSTANTS AND
C ITERATED VALUES OF Y.
C DERIVE X AND Y POINTS FOR LINE BY USING
C EQUATION FOR EVERY TICK MARK ON THE Y AXIS
        YORIG=0.0
      DO 2000 II=1,80
        Y(II)=YORIG
        YORIG=YORIG+0.05
        X(II)=A0+A1*Y(II)
 2000   CONTINUE
C DETERMINE CORRELATION COEFFICIENT FOR THE BEST FIT LINE USING
C DETERMINED COEFFICIENTS AND OTHER PREVIOUSLY CALCULATED SUMS.
C CORRELATION COEFFICIENT
C FIND ESTIMATED YS BY USING FORMULA
C ON EACH X VALUE
        SSR=0
        SST=0
      DO 1500 LL=1,ICOUNT
        XEST(LL)=A0+(A1*TLEG(LL))
        SSR=SSR+(VLEG(LL)-XEST(LL))**2
        SST=SST+(VLEG(LL)-XAVE)**2
 1500   CONTINUE
      COC=SQRT(ABS(1-(SSR/SST)))
C PRINT THE DETERMINED CORRELATION COEFFICIENT.
        PRINT 90,COC
C CALCULATES VARIANCE FOR BEST FIT LINE.
        SUMV=0.0
      DO 750 NN=1,ICOUNT
        SUMV=SUMV+((VLEG(NN)-XEST(NN))**2)
 750  CONTINUE
        VAR=SUMV/ICOUNT
C PRINTS VARIANCE VALUES.
        PRINT 90,VAR
C CALLS COMMANDS FOR DRAWING GRAPH, PLOTTING POINTS AND CURVE AND
C LABELING PLOT AND AXES.
      ENCODE(70,ZTITLE) COC
 70   FORMAT(' CORRELATION COEFFICIENT= ',F5.3,'$')
        ENCODE(80,YTITLE) A1,A0
  80    FORMAT(' A1=',F5.3,2X,'A0=',F5.3,5X,'X=A0 + A1*Y$')
        CALL TITLE(' ',1,0,0,'ONE WAY TRAVEL TIME IN SECS.$',
     *    100,6.0,8.0)
        CALL XTICKS(1)
        CALL YTICKS(2)
        CALL GRAF(1.4,0.2,5.0,4.0,-0.5,0.0)
        CALL XGRAXS(1.4,0.2,5.0,6.0,'VELOCITY-KM/SEC$',
     *        -100,0.,8.)
        CALL MARKER(8)
        CALL CURVE(VLEG,TLEG,ICOUNT,-1)
        CALL CURVE(X,Y,19,0)
```

```
        CALL MESSAG(YTITLE,100,0.5,-0.5)
        CALL MESSAG(XTITLE,100,0.5,9.0)
      CALL MESSAG(ZTITLE,100,0.5,0.0)
90    FORMAT( )
      RETURN
      END
```

```
C SUBPROGRAM FOR PARABOLIC CURVE ON VEL/TIME DATA BY LEG
      SUBROUTINE LEGPAR(VLEG,TLEG,ICOUNT,XTITLE)
C SUMX=SUM OF THE XS (VELOC)
C SUMY=SUM OF THE YS (TIME)
C SUMYSQ=SUM OF THE Y SQUAREDS
C SUMYCU=SUM OF THE Y CUBEDS
C SUMYFO=SUM OF THE Y TO THE FOURTHS
C SUMXY=SUM OF THE X*YS
C SUMYSX=SUM OF THE Y SQ. * XS
C XAVE= AVERAGE OF XS (WITHOUT WEIGHTED PTS.)
C ESTABLISHES LIMIT AND STORAGE FOR DATA TO BE MANIPULATED.
      DIMENSION VLEG(500),
     *          TLEG(500)
      DIMENSION X(80),
     *          Y(80),
     *          A(3,3),
     *          B(3),
     *          WTVEL(5),
     *          WTTIM(5),
     *          XEST(500)
      CHARACTER XTITLE*23,
     *          YTITLE*30,
     *          ZTITLE*32
C INITIALIZES SUMS TO ZERO.
      SUMX=0.
      SUMY=0.
      SUMYSQ=0.
      SUMYCU=0.
      SUMYFO=0.
      SUMXY=0.
      SUMYSX=0.
      ZERO=1.0E-06
C THIS WEIGHTS THE INITIAL DATA POINT (SEDIMENT SURFACE VELOCITY)
  WITH A WEIGHT AS SPECIFIED IN LINE 276 WHILE ALL OTHER DATA
  POINTS HAVE A VALUE OF ONE.
C WEIGHTING FOR SPECIFIC POINTS
C VALUES TO BE WEIGHTED ARE ADDED ONTO THE END OF
C EXISTING DATA ARRAYS AND PROCESSED AS ACTUAL POINTS
C ISED=NUMBER OF POINTS BEING WEIGHTED
C WTVEL AND WTTIM ARE ARRAYS THAT HOLD THE VALUES
C THAT ARE TO BE WEIGHTED
C IWT IS AN ARRAY WHICH HOLDS THE WEIGHT FACTOR
C FOR THE WTVEL AND WTTIM VALUES OF THE CORRESPONDING
C SUBSCRIPT.
C NOTE: AN IWT VALUE OF 1 MEANS THAT A VALUE IS BEING
C WEIGHTED BY 2 SINCE THE VALUE HAS ALREADY BEEN READ
C INTO VLEG AND TLEG ARRAYS ON THE INITIAL READ
C NUM= FINAL NUMBER OF POINTS AFTER WEIGHTING
      WTTIM(1)=0.000
      WTVEL(1)=VLEG(1)
      IWT=5
      ITALLY=ICOUNT+1
      NUM=ICOUNT+IWT
```

```
      DO 500 NN=ITALLY,NUM
        VLEG(NN)=WTVEL(1)
        TLEG(NN)=WTTIM(1)
 500  CONTINUE
C THIS CALCULATES THE SUM OF THE VARIOUS SUMS NEEDED FOR MAKING
C THE LEAST SQUARE PARABOLIC FIT TO THE DATA.  DATA IS PULLED
C FROM THE MAIN PROGRAM.
C READ THROUH VELOC AND TIME TO OBTAIN SUMS
      DO 1000 JJ=1,NUM
        SUMX=SUMX+VLEG(JJ)
        SUMY=SUMY+TLEG(JJ)
        SUMYSQ=SUMYSQ+(TLEG(JJ)**2)
        SUMYCU=SUMYCU+(TLEG(JJ)**3)
        SUMYFO=SUMYFO+(TLEG(JJ)**4)
        SUMXY=SUMXY+(VLEG(JJ)*TLEG(JJ))
        SUMYSX=SUMYSX+((TLEG(JJ)**2)*VLEG(JJ))
 1000 CONTINUE
C CALCULATES THE SUM OF THE VELOCITIES FOR USE LATER IN THE
C COEFFICIENT OF CORRELATION COMPUTATION.
C SUM THE XS WITHOUT THE WEIGHTED VALUES TO
C FIND A TRUE AVERAGE FOR THE COC EQUATION
        XSUM=0.
      DO 1200 KK=1,ICOUNT
 1200   XSUM=XSUM+VLEG(KK)
        XAVE=XSUM/ICOUNT
C DETERMINE COEFFICIENT OF LEAST SQUARE BEST FIT PARABOLA  CURVE
C X=A+BY+CY2 USING METHOD OF SIMULTANEOUS SOLUTION  OF THREE
C EQUATIONS BY MATRIX METHOD .  PRINT THE THREE COEFFICIENTS.
C SOLVE SIMULTANEOUS EQUATIONS FOR
C COEFFICIENTS OF PARABOLIC EQUATION
        A(1,1)=NUM
        A(1,2)=SUMY
        A(1,3)=SUMYSQ
        A(2,1)=SUMY
        A(2,2)=SUMYSQ
        A(2,3)=SUMYCU
        A(3,1)=SUMYSQ
        A(3,2)=SUMYCU
        A(3,3)=SUMYFO
        B(1)=SUMX
        B(2)=SUMXY
        B(3)=SUMYSX
      DO 100 I=1,3
        DIV=A(I,I)
        IF(ABS(DIV)-ZERO) 99,99,1
 1      DO 101 J=1,3
        A(I,J)=A(I,J)/DIV
 101    CONTINUE
      B(I)=B(I)/DIV
      DO 102 J=1,3
        IF(I-J) 2,102,2
 2      RATIO=A(J,I)
        DO 103 K=1,3
```

```
        A(J,K)=A(J,K)-RATIO*A(I,K)
 103    CONTINUE
      B(J)=B(J)-RATIO*B(I)
 102  CONTINUE
 100  CONTINUE
        PRINT 90,B(1),B(2),B(3)
C USING THE THREE COEFFICIENTS JUST DETERMINED DERIVE POINTS FOR
C THE CURVE  BY USING ITERATED VALUES OF Y AND CALCULATING THE
C CORRESPONDING X VALUES.
 99     YORIG=0.0
C DERIVE X AND Y POINTS FOR LINE BY USING
C EQUATION FOR EVERY TICK MARK ON THE Y AXIS
      DO 2000 II=1,80
        Y(II)=YORIG
        YORIG=YORIG+0.05
        X(II)=B(1)+(B(2)*Y(II))+(B(3)*Y(II)**2)
 2000   CONTINUE
C CALCULATES THE CORRELATION COEFFICIENT FOR THE BEST FIT LEAST
C SQUARE PARABOLA TO THE DATA USING PREVIOUSLY CALCULATED
C QUANTITIES.
C CORRELATION COEFFICIENT
C FIND ESTIMATED XS BY USING FORMULA
C ON EACH Y VALUE
        SSR=0
        SST=0
      DO 1500 LL=1,ICOUNT
        XEST(LL)=B(1)+(B(2)*TLEG(LL))+(B(3)*TLEG(LL)**2)
        SSR=SSR+(VLEG(LL)-XEST(LL))**2
        SST=SST+(VLEG(LL)-XAVE)**2
 1500   CONTINUE
      COC=SQRT(ABS(1-(SSR/SST)))
C PRINT THE CORRELATION COEFFICIENT.
        PRINT 90,COC
C USING PREVIOUSLY CALCULATED QUANTITIES CALCULATE AND PRINT
C OUT THE VARIANCE FOR THE LEAST SQUARE  FIT CURVE.
        SUMV=0.0
      DO 750 NN=1,ICOUNT
        SUMV=SUMV+((VLEG(NN)-XEST(NN))**2)
 750  CONTINUE
        VAR=SUMV/ICOUNT
        PRINT 90,VAR
C ESTABLISH GRAPH PLOT HEADINGS AND CALL  PLOT ROUTINES
C FOR THE GRAPH.
      ENCODE(70,ZTITLE) COC
 70   FORMAT(' CORRELATION COEFFICIENT= ',F5.3,'$')
        ENCODE(80,YTITLE) B(1),B(2),B(3)
  80    FORMAT(' B0=',F5.3,2X,'B1=',F5.3,2X,'B2=',F5.3,'$')
        CALL CURVE(X,Y,19,0)
        CALL MESSAG(YTITLE,100,0.5,1.0)
        CALL MESSAG(XTITLE,100,0.5,9.0)
        CALL MESSAG(ZTITLE,100,0.5,1.5)
      CALL MESSAG('  X= B0 + B1*Y + B2*Y**2$',100,0.5,0.5)
 90   FORMAT( )
```

```
C SUBPROGRAM FOR EXPONENTIAL CURVE FIT OF VELOCITY/TIME DATA BY
C LEG THE METHOD IS THE SAME AS THAT FOR THE FIT TO DATA BY
C STATION
C THE XS,YS,XYS AND YSQUARES ARE SUMMED AND A W WEIGHTING FACTOR
C IS USED
      SUBROUTINE LEGEXP(VLEG,TLEG,ICOUNT,XTITLE)
C ESTABLISHES STORAGE AND LIMITS FOR QUANTITIES TO BE CALCULATED
C FOR LATER MANIPULATION.
      DIMENSION VLEG(500),
     *          TLEG(500),
     *          XEST(500)
      DIMENSION X(80),
     *          Y(80),
     *          W(500),
     *          LOGVEL(500)
      CHARACTER XTITLE*23,
     *          YTITLE*35,
     *          ZTITLE*37
      REAL LOGVEL
C INITIALIZES THE QUANTITIES TO BE CALCULATED AT ZERO.
      SUMX=0.
      SUMY=0.
      SUMW=0.
      SUMXW=0.
      SUMYW=0.
      SUMXYW=0.
      SUMYSW=0.
C TAKES THE LOG OF THE VELOCITY VALUES (VLEG) IN THE MAIN PROGRAM
C AND PRINTS THE LOG VALUES AND THE BASIC VALUES.
C LOG X VALUES(VLEG)
      DO 300 KK=1,ICOUNT
        LOGVEL(KK)=ALOG(VLEG(KK))
          PRINT 90,VLEG(KK),TLEG(KK),LOGVEL(KK)
 300  CONTINUE
C GIVES THE SEDIMENT SURFACE VELOCITY AND THICKNESS A WEIGHTING.
C THIS IS THE FIRST DATA POINT READ IN THE MAIN PROGRAM.
C WEIGHT FIRST POINT BY GIVING W(1) A HIGH VALUE
      W(1)=5
      DO 500 LL=2,ICOUNT
 500  W(LL)=1.
C USING DATA QUANTITIES FROM MAIN PROGRAM AND CALCULATED LOG
C VALUES ABOVE , CALCULATES THE VARIOUS  SUMS NEEDED FOR THE
C LEAST SQUARES FIT TO THE DATA  AND PRINTS OUT THE SUMS.
C READ THROUGH LOGVEL AND TLEG TO OBTAIN VARIABLES
C FOR LEAST SQUARES EQUATION
      DO 1000 JJ=1,ICOUNT
        SUMX=SUMX+VLEG(JJ)
        SUMY=SUMY+TLEG(JJ)
        SUMW=SUMW+W(JJ)
        SUMXW=SUMXW+(LOGVEL(JJ)*W(JJ))
        SUMYW=SUMYW+(TLEG(JJ)*W(JJ))
        SUMXYW=SUMXYW+(LOGVEL(JJ)*TLEG(JJ)*W(JJ))
 1000   SUMYSW=SUMYSW+(TLEG(JJ)**2*W(JJ))
```

```
        PRINT 90,SUMX,SUMY,SUMW,SUMXW,SUMYW,SUMXYW,SUMYSW
C CALCULATES A SUM NEEDED IN DETERMINING THE CORRELATION
C COEFFICIENT.
      XAVE=SUMX/ICOUNT
C DETERMINES THE COEFFICIENT B0 IN THE LEAST SQUARE FIT EQUATION
C LOGX=LOGA+LOGBY WHERE B0=LOGA.
C CREATE B0 VARIABLE FOR LEAST SQUARES EQUATION
      B0=((SUMXW*SUMYSW)-(SUMYW*SUMXYW))/
     *    ((SUMW*SUMYSW)-SUMYW**2)
C DETERMINES THE COEFFICIENT B1 WHERE B1=LOGB
C CREATE B1 VARIABLE FOR LEAST SQUARES EQUATION
      B1=((SUMW*SUMXYW)-(SUMXW*SUMYW))/
     *    ((SUMW*SUMYSW)-SUMYW**2)
C TAKE THE ANTILOG OF B0 AND B1 TO OBTAIN COEFFICIENTS A0 AND A1
C OF THE EQUATION X=AB**Y     PRINT THE COEFFICIENTS.
      A0=EXP(B0)
      A1=EXP(B1)
         PRINT 90,A0,A1
C DERIVE THE POINTS FOR THE BEST FIT CURVE X=AB**Y USING THE
C COEFFICIENTS JUST DETERMINED AND ITERATED VALUES OF Y TO
C CALCULATE CORRESPONDING VALUES OF X.
C DERIVE X AND Y POINTS FOR CURVE BY USING
C EQUATION FOR EVERY 0.05 VALUE OF THE Y AXIS
        YORIG=0.0
      DO 2000 II=1,50
        Y(II)=YORIG
        YORIG=YORIG+0.05
        X(II)=A0*(A1**Y(II))
 2000   CONTINUE
C CALCULATES CORRELATION COEFFICIENT USING DERIVED EQUATION
C COEFFICIENTS AND PREVIOUSLY CALCULATED QUANTITIES
C PRINT COEFFICIENT.
C CORRELATION COEFFICIENT
C FIND ESTIMATED XS BY USING FORMULA
C ON EACH ACTUAL Y VALUE
      SSR=0
      SST=0
      DO 1500 LL=1,ICOUNT
        XEST(LL)=A0*(A1**TLEG(LL))
        SSR=SSR+(VLEG(LL)-XEST(LL))**2
        SST=SST+(VLEG(LL)-XAVE)**2
 1500 CONTINUE
      COC=SQRT(ABS(1-(SSR/SST)))
        PRINT 90,COC
C CALCULATES VARIANCE USING PREVIOUSLY DERIVED EQUATION
C COEFFICIENTS AND PRINTS VARIANCE.
        SUMV=0.0
      DO 750 NN=1,ICOUNT
        SUMV=SUMV+((VLEG(NN)-XEST(NN))**2)
 750  CONTINUE
        VAR=SUMV/ICOUNT
        PRINT 90,VAR
C CALL VARIOUS CURVE PLOTTING AND TITLE PLOTTING ROUTINES,
```

```
C PLOT GRAPH AND BEST FIT CURVE WITH AXES TITLES AND GRAPH TITLES.
        ENCODE(70,ZTITLE) COC
 70     FORMAT(' CORRELATION COEFFICIENT EXPO= ',F5.3,'$')
        ENCODE(80,YTITLE) A1,A0
 80     FORMAT(' A1=',F5.3,2X,'A0=',F5.3,5X,'X=A0*A1**Y$')
        CALL CURVE(X,Y,50,0)
        CALL MESSAG(YTITLE,100,0.5,2.0)
        CALL MESSAG(ZTITLE,100,0.5,2.5)
 90     FORMAT( )
      CALL ENDPL(1)
      RETURN
      END
```

APPENDIX F

PROGRAM FOR VELOCITY/DEPTH PLOT FOR GROUPS OF STATIONS

```
      IMPLICIT DOUBLE PRECISION(S)
C  ESTABLISHES STORAGE FOR THE VELOCITY, TIME, DEPTH, AND TITLE
   QUANTITIES
C TO BE USED LATER IN PLOTTING AND CURVE FITTING.
       DIMENSION VINST(50),
    * DEPTH(50),
    * TIM(50),
    * XTITLE(7)
    CALL COMPRS
C READS IN COEFFICIENTS FOR THE VELOCITY FUNCTION OBTAINED IN
C 9UVLEG.
C AN 'END' CARD STOPS THE PROGRAM.
 5     READ(5,10,END=4000)A,B,IGROUP
 10    FORMAT(F7.4,1X,F7.4,1X,I2)
C THE FOLLOWING FORTRAN STATEMENTS ARE COMMENTED OUT BUT WHEN
C THE CUBED  TERM IS NOT DESIRED THEY SHOULD BE CONVERTED INTO
C LEGITIMATE STATEMENTS AND THE PRECEEDING FORTRAN STATEMENTS
C SHOULD BE COMMENTED OUT.
C ****************************************************************
C5     READ(5,10,END=4000)A,B,C,IGROUP
C10    FORMAT(F7.4,1X,F7.4,1X,F7.4,1X,I2)
C *****************************************************************
C ESTABLISHES THE GRAPH PLOT TITLE   INSERT GROUP NUMBER DESIRED.
       ENCODE(15,XTITLE),IGROUP
 15    FORMAT(' DATA GROUP ',I2,'$')
C INITIALIZES TIME AT ZERO.
       TIME=0.0
C ESTABLISHES THE NUMBER OF DATA POINTS TO BE GENERATED.
       ICOUNT=9
C GENERATES THE DATA POINTS FOR THE VELOCITY VERSUS DEPTH PLOT.
       DO 300 MM=1,ICOUNT
       TIM(MM)=TIME
       VINST(MM)=A+(B*TIM(MM))
       DEPTH(MM)=A*TIM(MM)+((B*TIM(MM)**2)/2)
C THE FOLLOWING FORTRAN STATEMENTS ARE COMMENTED OUT ALSO; BUT
C WHEN THE CUBED TERM IS NOT DESIRED THEY, TOO, SHOULD BE
C CONVERTED INTO LEGITIMATE STATEMENTS AND THE TWO PRECEEDING
C STATEMENTS SHOULD BE COMMENTED OUT.
C *****************************************************************
C VINST(MM)=A+(B*TIM(MM))+(C*(TIM(MM))**2)
C DEPTH(MM)=A*TIM(MM)+((B*(TIM(MM))**2)/2)+((C*(TIM(MM))**3)/3)
C ******************************************************************
         TIME=TIME+0.05
 300     CONTINUE
C PRINTS OUT THE HEADING FOR THE TABULATION OF PLOT VALUES.
       WRITE(6,72)IGROUP
 72    FORMAT(' DATA FOR GROUP ',I2)
```

```
C PRINTS OUT THE PLOT VALUES.
      DO 350 LL=1,ICOUNT
        WRITE(6,75)LL,DEPTH(LL),VINST(LL),TIM(LL)
 75     FORMAT(' POINT NUMBER ',I3,3X,' DEPTH ',
     *   F6.4,3X,' VELOCITY= ',F5.3,3X,' TIME= ',F4.2)
 350    CONTINUE
C CALLS THE PARABOLIC LEAST SQUARES CURVE FITTING SUB PROGRAM.
      CALL LEGPAX(VINST,DEPTH,ICOUNT,XTITLE)
C     CALL LSTPAX(VINST,DEPTH,ICOUNT,XTITLE)
C CALLS THE PLOTTING ROUTINE.
      CALL ENDPL(1)
C RETURNS TO THE START OF THE PROGRAM TO PROCESS ANOTHER SET OF
C DATA.
      GO TO 5
 4000 CONTINUE
C ENDS THE PROGRAM.
      CALL DONEPL
      STOP
      END
```

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