AD-778 348

STATISTICAL ANALYSIS OF MARINE SEDIMENT PROPERTIES FROM THE SAN DIEGO TROUGH

Frank Simpson

Lockheed Missiles and Space Company
Incorporated

Prepared for:

Office of Naval Research

April 1974

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

AD 778 348

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER LMSC D359428	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Statistical Analysis of MARINE Sediment Properties from the San Diego Trough		5. TYPE OF REPORT & PERIOD COVERED Final
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Frank Simpson		8. CONTRACT OR GRANT NUMBER(s) N00014-73-C-0204
9. PERFORMING ORGANIZATION NAME AND ADDRESS Lockheed Missiles and Space Company Lockheed Ocean Laboratory, 3380 N. Harbor Drive, San Diego, California 92101		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS Office of Naval Research Code 485 Washington, D. C.		12. REPORT DATE April 1974
		13. NUMBER OF PAGES ~~157~~ 165
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Distribution of this document is unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

Reproduced by
NATIONAL TECHNICAL
INFORMATION SERVICE
U S Department of Commerce
Springfield VA 22151

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Seafloor soil properties, statistical analysis of sediment properties, sediment properties in-situ seafloor testing, submersible seafloor investigation, sampling planning, San Diego Trough, variability of sediment properties.

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Results of measurements of the properties of sediments in the San Diego Trough were statistically analyzed by computer. Data analyzed included results of 37 series of in-place vane shear strength measurements and laboratory tests on 67 sediment cores collected in a 40 km^2 area during 21 dives with the submersible DEEP QUEST. Sediment properties determined to a depth of 1.2 m included original and remolded vane shear strength, water content, saturated and dry unit weight, porosity, void ratio, and several grain size distribution

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

Unclassified

165

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

Block 20 Continued

parameters. A computer data mangement system was developed specifically to efficiently manipulate and interface the geotechnical data with major statistical programs. Statistical methods selected included analysis of variance, linear partial and multiple correlation, and simple and multiple regression. Over the entire sediment depth range examined, the major source of variability in most sediment properties is introduced by test depth differences ($\simeq 80\%$). Within discrete sediment depths, however, micro-areal effects and test method precision account for the largest percentage of the total variability. Macro-areal effects were shown to be of minor consequence in the variability measured. Laboratory methods were compared; in-place and laboratory vane shear test results were determined to be nearly identical. Predictory equations for sediment properties were developed by forward stepwise multiple regression procedures. Examples for the development of sediment sampling programs based on simple random sampling, stratified sampling, and multistage sampling techniques are presented.

LMSC/D359428

STATISTICAL ANALYSIS OF MARINE SEDIMENT PROPERTIES FROM THE SAN DIEGO TROUGH

April 1974

F. Simpson
Senior Scientist

Approved: Robert A. Tyrrell
R. A. Tyrrell, Manager
Lockheed Ocean Laboratory

Approved:
L. D. Coates, Manager
Ocean Sciences

Lockheed Missiles & Space Company, Inc.
Lockheed Ocean Laboratory
San Diego, California

The research reported herein was sponsored by the Office of Naval Research under Contract No. N-00014-73-C-0204. Reproduction in whole or in part is permitted for any purpose of the United States Government.

ib

TABLE OF CONTENTS

TABLE OF CONTENTS (cont)

FIGURES

TABLES

TABLES (cont)

ACKNOWLEDGEMENTS

The author wishes to express his appreciation to several persons for their assistance in this project.

Special thanks are given to D. P. Hamm for the development of the data management system which proved to be so essential to this study. His assistance in all phases of the computer analysis and processing of the data was invaluable. Also, his suggestions and review of the report, including his assistance on the preparation of the data management sections, are greatly appreciated.

The author is especially indebted to C. S. Wallin for his many helpful suggestions and criticisms during the final preparation of this report. His editorial assistance, critical review of the final paper, and his help in the makeup and compilation of this paper are immensely appreciated.

Thanks are given to B. N. Nelson for his valuable assistance in the planning and selection of the statistical analysis methods used in this study. His review of the statistical discussions in this paper and his helpful suggestions provided on the subject are appreciated.

Thanks are given to J. G. Wilder III for his aid in the preparation and proofing of all the data stored in the computer data bank generated and for his help in completing numerous computer runs on the Lockheed computer terminal.

The author is also grateful to A. L. James for his many efforts in the preparation of the numerous illustrations presented in this report.

The overall assistance provided by Dr. A. L. Inderbitzen (University of Delaware) in the development of a practical study approach and the program planning throughout the course of this study was appreciated in addition to his editorial assistance and review of this manuscript.

Appreciation is also extended to E. P. Wheaton, Vice President and General Manager of the Research and Development Division, Lockheed Missiles and Space Company, Inc., and J. G. Wenzel, Vice President--Ocean Systems, R&D Division,

Preceding page blank

Lockheed Missiles and Space Company, Inc., for their encouragement and continued support of seafloor research studies. Acquisition of all sediment data using DEEP QUEST, laboratory testing and data reduction were funded by Lockheed's Independent Research Programs during 1970-1973.

In conclusion, the Office of Naval Research has provided support to perform this research study for which we are most grateful.

SECTION 1. INTRODUCTION

Future expected engineering and exploration activities in the oceans require development of improved geotechnical information gathering techniques. The approach necessary involves establishing the accuracy of laboratory and in-place measurements of sediment properties and investigating the natural variability of mass physical and engineering properties within major depositional environments.

The importance of determining the accuracy and variability of marine sediments becomes more evident when one realizes the number of scientific and engineering projects that require an answer to such fundamental questions as:

- How representative are laboratory measurements of the true field conditions?
- How do these sediment properties vary over a particular seafloor area?
- How should sampling be done efficiently to obtain an accurate estimate of the properties over a particular seafloor area?

Purpose of Study

The object of this study was to perform a detailed analysis of the variability of geotechnical properties of marine sediments from a specific area in the San Diego Trough. The methods applied and the results obtained are useful for evaluating data from other sedimentary environments and for developing better geotechnical sampling and testing programs. Advanced statistical techniques were employed to examine the major sources of variability present in the following mass physical and engineering properties: vane shear strength, water content, saturated unit weight, unit weight of solids, void ratio, grain size distribution and Atterberg limits. Statistical methods were also used to determine the precision of laboratory and field tests, compare laboratory and in-place vane shear measurements, and establish principal interrelationships between geotechnical properties.

Specifically, the study was designed to answer the following questions pertaining to a particular relatively uniform, depositional seafloor area:

1. What is the areal and vertical variability of geotechnical properties?
2. What are the principal factors responsible for the variability observed in each property?
3. What is the precision of the measurements for each property?
4. How representative are laboratory vane shear measurements of the true field conditions?
5. What are the fundamental interrelationships between the geotechnical properties and other variables?
6. How should sampling and testing be conducted to efficiently and accurately estimate the properties within a particular seafloor area?

Ocean engineering and research projects using seafloor data require consideration of the above questions in view of the large economic and time factors associated with seafloor exploration. Examples of ocean engineering projects requiring information on the geotechnical properties of marine sediments include design and construction of offshore structures for petroleum production and transfer, seafloor mining systems, underwater habitats, and ASW instrumentation arrays. Other programs requiring information on seafloor sediments and their variability include environmental impact studies, dredging operations, and coastal baseline studies.

Data available for analysis were ideally suited for this type of investigation and are believed to represent the largest assemblage of core and in-place vane shear measurements reported to date for a single, relatively small seafloor area. All cores and in-place tests were obtained using Lockheed's submersible DEEP QUEST. This not only enabled visual observation of the seafloor area to be sampled and the environmental conditions present, but also facilitated precise selection of sampling stations, and accurate determination of their location relative to one another. Use of a submersible also permitted undertaking a sampling program appropriate for analysis by advanced statistical methods. For example, replicate cores, replicate in-place vane tests, and paired core and in-place tests were obtained.

Previous Studies

Despite the significant number of studies undertaken to investigate sediment properties, only a limited number of investigators have attempted to describe the variability of the data collected. The majority of studies in this field are presented in the literature survey by Garcia (1971) or referenced in the state-of-the-art reviews by Noorany and Gizienski (1970) and Noorany (1972).

Most recently, Hirst (1973) published findings on the vertical variability of in-place shear strength measurements taken in the same San Diego Trough seafloor area. Variability results of seven in-place bulk density measurements taken in the Gulf of Maine have been reported by Perlow and Richards (1973). Other studies which have investigated the variability of geotechnical properties include Keller and Bennett (1970); Bennett, et al., (1970); Hamilton (1969 a, b, c); Holmes and Goodall (1964); Hamilton (1963); and, Richards and Keller (1962).

Work done at the Lockheed Ocean Laboratory related to this study has been presented in Simpson and Inderbitzen (1971); Inderbitzen, et al., (1971); and, Inderbitzen and Simpson (1971; 1972). Also, a publication currently is in preparation by Lehigh University which will discuss the variability of other geotechnical data collected in the San Diego Trough during a four year cooperative Lehigh-Lockheed study for the Sea Grant Office (Carius and Richards, in preparation).

Test Area

The San Diego Trough is one of several open basins in the continental borderland off Southern California and was presumably formed by faulting. Sedimentation within this basin has been sufficient to fill the basin depressions and form a continuous slope southward to where the trough meets the deeper San Clemente Basin (Shepard and Einsele, 1962).

The geotechnical data used for this study were collected in the San Diego Trough within a 40 square kilometer area extending from Lat. 32° 31.0' N to 32° 36.0' N and Long. 117° 27.0'W to 117° 31.0'W, which is approximately 24 km southwest of San Diego, California (Figure 1). Although water depths in the area vary from 1100 to 1250 m, the majority of sampling stations are at water depths of about 1240 m.

The seafloor area sampled is nearly flat with bottom slopes of less than two degrees as measured from DEEP QUEST. Sediment within the upper 1.2 m investigated is classified as a clayey silt (nomenclature of Shepard, 1954), and grain size distributions for samples tested indicate particle size does not change significantly in either lateral or vertical directions. Clayey silt sediments are reported to predominate in the San Diego Trough and other nearby basins (Emery et al., 1952). The sediments within this part of the San Diego Trough are derived primarily from the nearby continental land mass rather than having a considerable admixture from the north, as would be the case if sediments were being brought down by turbidity currents entering the trough from the north (Shepard and Einsele, 1962).

The area represents a low energy environment. Bottom currents measured from DEEP QUEST were less than 10 cm/sec. Additional evidence of weak bottom currents are the numerous Holothuria present on the bottom and the detailed microtopography observed which included hummocks, craters and tracks created by benthic organisms.

For these reasons, although this seafloor area is located relatively

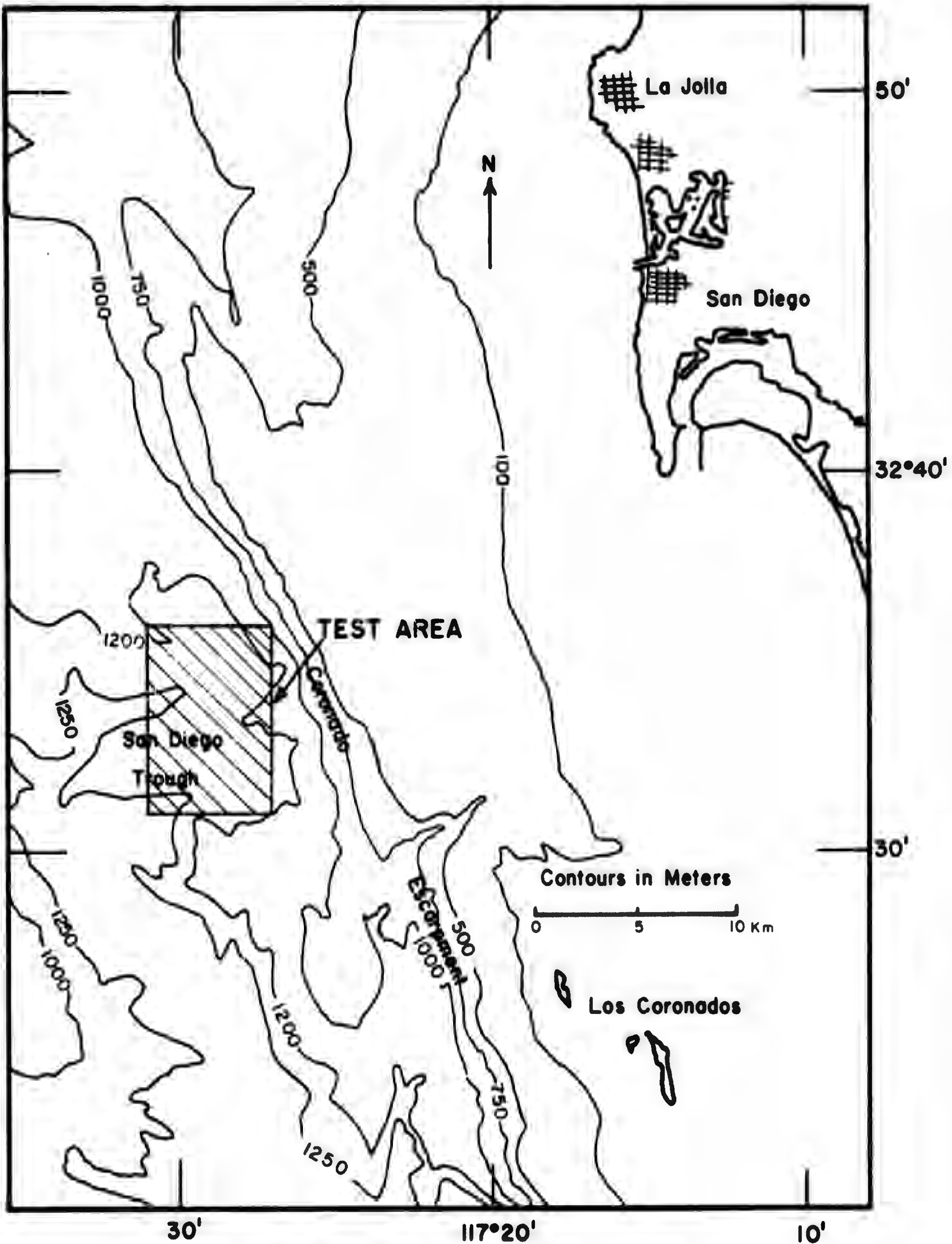


Figure 1. San Diego Trough Geotechnical Test Area

close to the coastline in a unique morphological zone, it is believed to be representative of depositional conditions found at abyssal depths in many areas of the world ocean.

Field Program

Figure 2 illustrates the sampling stations occupied in the study area. Geographical coordinates and water depth for each station are listed in Table A-1, Appendix A. A total of 47 stations were occupied on 21 DEEP QUEST dives; 67 cores were tested, and 37 series of in-place vane shear measurements were made.

Positions of sampling stations were determined by one of two techniques. One approach employed acoustic pingers emplanted by DEEP QUEST at Sites 1 and 2 (Figure 2) as seafloor reference points. The positions of stations close to these known locations were determined by dead reckoning between locations of acoustically reflective targets encountered between stations. The DEEP QUEST Straza Model 500 CTFM sonar system is capable of determining the range and bearing of these frequently occurring targets (metal cans and other reflective debris) to a maximum distance of 1400 meters. Targets were usually chosen about 500 meters apart to reduce sonar ranging errors.

The second method used to establish the position of sampling stations, relative to the surface, involved taking fixes of DEEP QUEST from the surface support vessel TRANSQUEST while the submersible was stationary on the bottom. Position fixes of DEEP QUEST were obtained with a Helle Location System and a Helle Acoustic Transmission Range System which provide bearing and range information, respectively. Accuracy of fixes with this system relative to the surface vessel is about ± 180 m. The latter method was used predominantly during the 1972 and 1973 dives as it was impractical to start all dives at Sites 1 or 2, and navigation by bottom targets in other sections of the test area was not always possible.

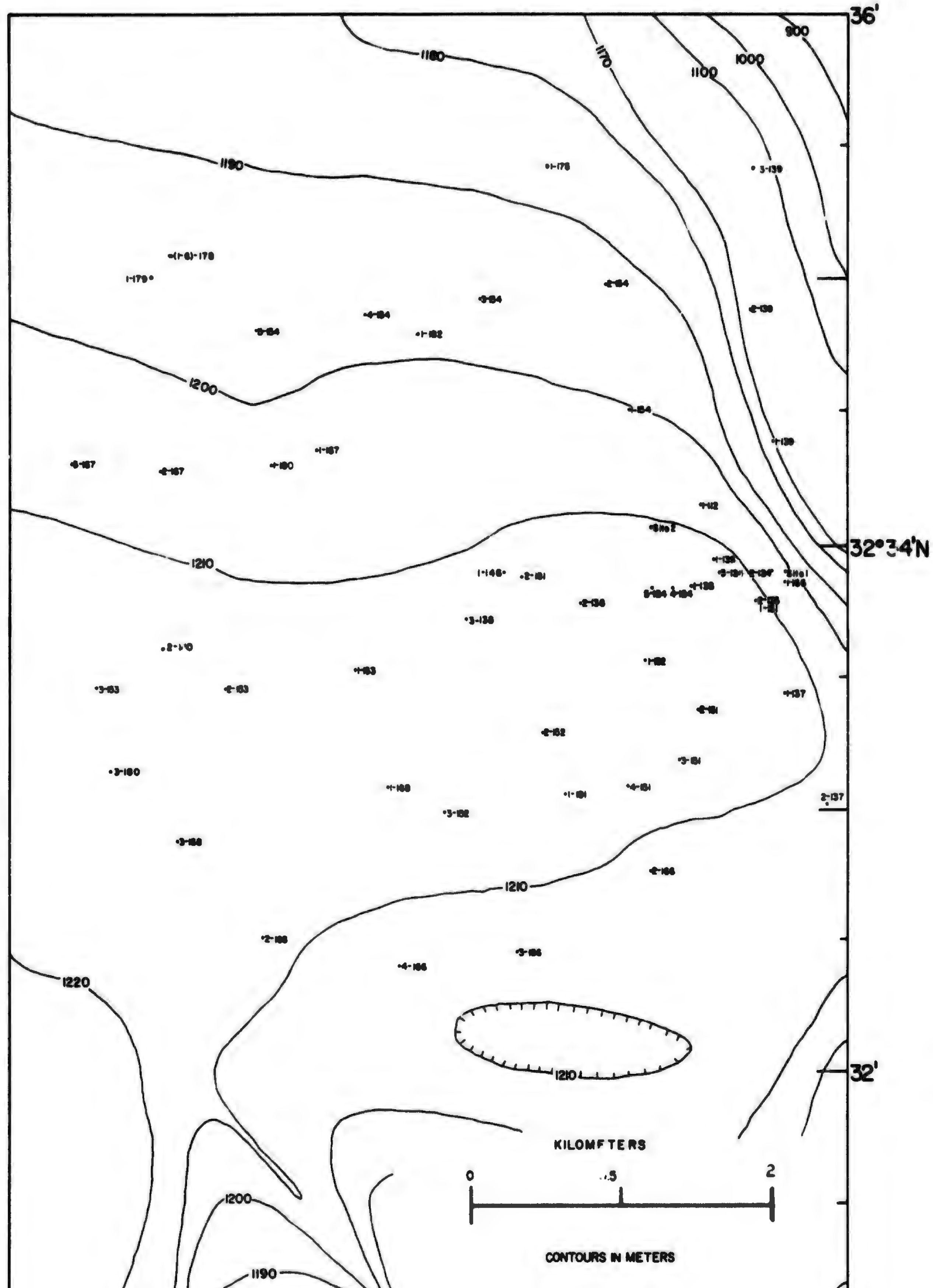


Figure 2. Location of DEEP QUEST Sampling and Test Stations

In-Place Vane Shear Measurements

In-place vane shear strength measurements were made at the test locations indicated in Table A-1, Appendix A. A single series of in-place tests consists of inserting the vane shear device at one location and performing several shear tests, each at a different depth in the sediment. The Sediment Shear Measurement Device was designed for installation on DEEP QUEST and has been described in detail elsewhere (Inderbitzen, et al., 1971). The vane shaft has a maximum penetration depth of 132 cm below the sediment surface; the rate of vane rotation is 12 degrees/minute. The vane is 7.0 cm high and 5.1 cm wide. Resistance to shearing produces a strain gauge voltage which is chart recorded inside the submersible. Because the strain gauges are mounted directly above the vane blades, friction on the vane shaft has no effect on gauge output.

Coring Procedures

Sediment cores were taken with DEEP QUEST's six-barrel hydraulic coring device. A full description of the coring device is available in Inderbitzen and Simpson (1972). The 1.52 m long core barrels are cellulose-acetate-butyrate with an inner diameter of 6.7 cm and an outer diameter of 7.3 cm. Cores up to 130 cm in length were recovered by slowly pushing the coring tubes past a stationary piston and into the sediment. Cores were capped and sealed upon surfacing of DEEP QUEST, and returned to Lockheed Ocean Laboratory in San Diego for analyses. All cores collected after 1970 were refrigerated at 6° C immediately after returning from an at-sea operation.

Laboratory Testing

Sediment properties measured at the Laboratory on core samples collected included vane shear strength, water content, saturated unit weight, void ratio, porosity, unit weight of solids, grain size distribution, and Atterberg limits. A brief description of the laboratory test techniques used is included in Appendix B. In general, test procedures used are in agreement with standard accepted techniques.

SECTION 2. STUDY APPROACH

The approach taken for this program involved the following four major phases:

1. Preliminary Data Review
2. Development of Computer Data Management Systems
3. Selection of Statistical Methods
4. Results of Statistical Analysis

Figure 3 illustrates the logical progression of the tasks of the project and their interrelationships. The first three phases are discussed within this section of the report.

Part 1. Preliminary Data Review

At the onset of this study, the geotechnical data available for statistical analysis consisted of 21 cores and 14 series of in-place vane shear measurements collected during the 1970-1971 DEEP QUEST dives. Since additional dives were anticipated in the same seafloor area as part of other Lockheed funded studies, the first task was to examine the available data and determine how complete it was for the statistical analysis planned. Review of the data indicated that information most lacking concerned (1) replicate vane shear measurements, both in the field and in the laboratory; (2) replicate cores within a station; and, (3) paired core and in-place tests.

Based on this information, sampling and laboratory testing programs undertaken as part of Lockheed's 1972-1973 Independent Research programs were modified to fill in the existing data gaps. Data obtained during the last two years more than tripled the size of the original data bank. Due to the continuous acquisition of core and in-place information, organization and synthesis of the data progressed up through the July/August 1973 dives.

Other parts of the this study phase are described below.

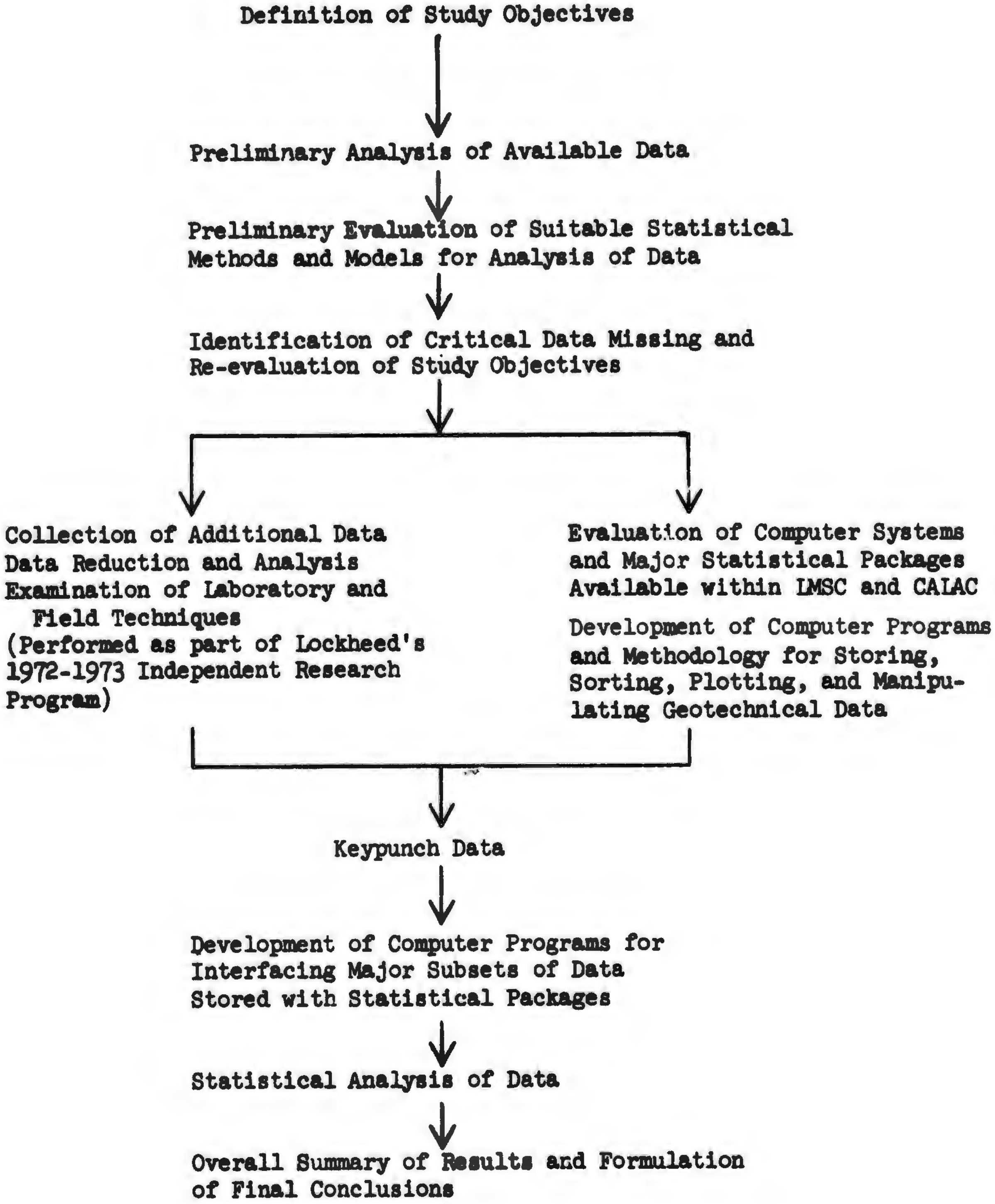


Figure 3. Flow Diagram of Study Approach

Bathymetry of Test Area

This task entailed constructing a bathymetric chart for the seafloor area sampled and determining the most accurate locations for the sampling and testing stations.

Bathymetry for the test area was determined by two separate methods. The first method involved using only the depth information collected by DEEP QUEST to contour the area. Since DEEP QUEST occupied several of the same stations on separate dives, multiple depth readings were often available. Also, DEEP QUEST is equipped with three separate systems for depth determinations (up-looking fathometer, depth pressure sensor, and the TIPE*); thus, data from these three sources could be compared.

The second bathymetric chart for the seafloor area (Figure 2) was prepared as part of a joint Lehigh University-Lockheed research effort for NOAA's Sea Grant Office. Bathymetric contours are based on information collected on a surface survey conducted by Lehigh University in 1971 and data from the latest U. S. Coast and Geodetic survey boat sheet number H-8980. Since the latter chart covers the entire area and is based on a larger number of data points, it has been adopted as the reference chart for the area.

Relative Position of Tests Within Each Station

In most cases, more than one core or one series of in-place measurements were obtained at each station (see Table A-1). To properly catalogue this information and facilitate its use in the statistical analysis, it was necessary to establish the relative positions of all in-place tests and cores obtained at each station. A separate chart was made for each station and the positions of each series of in-place tests and cores were plotted. Figure 4 illustrates the relative positions of all cores and tests obtained

---

*TIPE: Transponder Interrogator Pinger and Echo Sounder

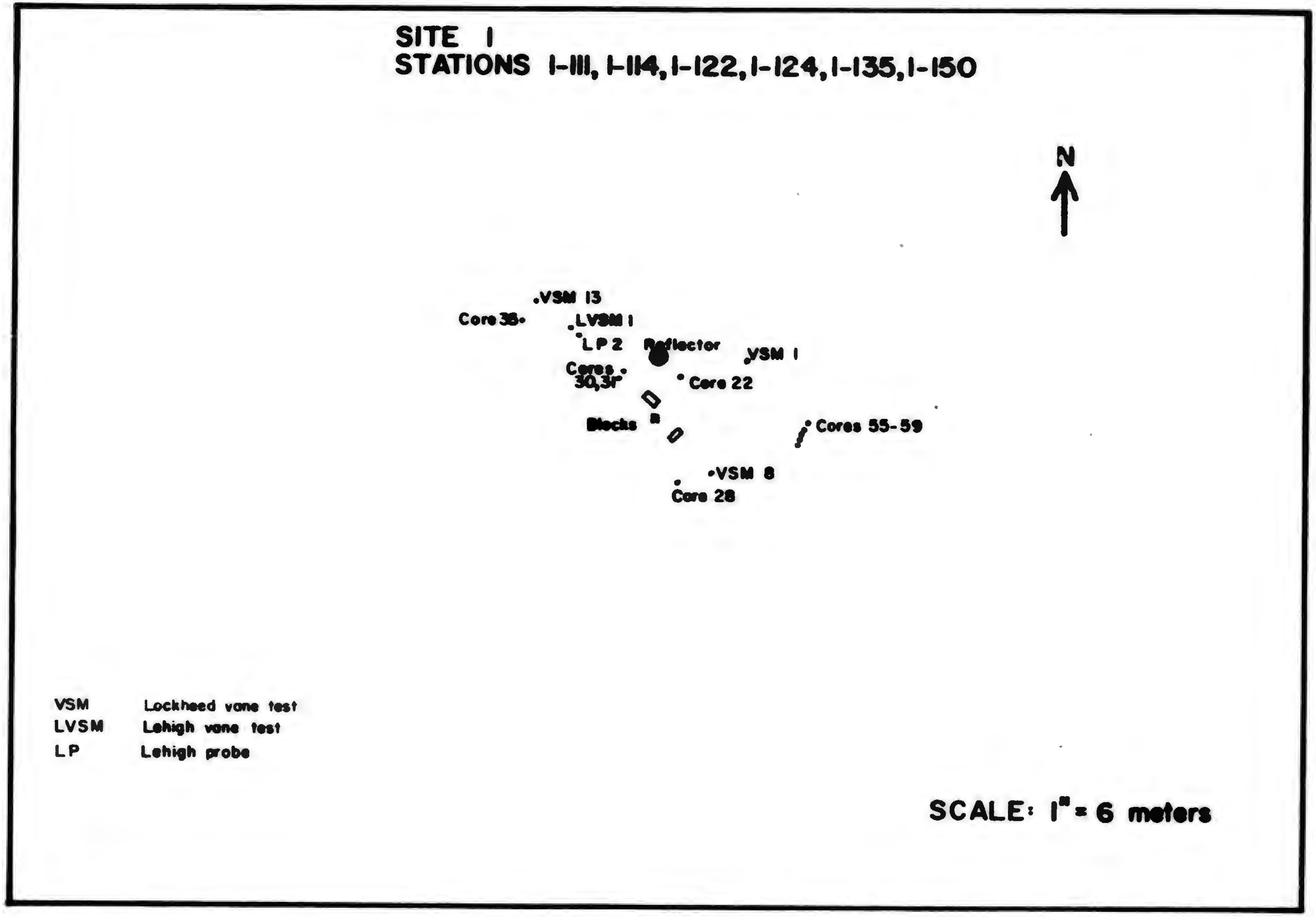


Figure 4. Sampling Locations at Site 1

at Site 1. Several cores and in-place tests were taken at this station, as many of the early dives were made at this location in conjunction with another project (Simpson et al., 1974).

Retesting of Sediment Properties

During the laboratory testing program important refinements in laboratory methods resulted from comparing the test results obtained by use of alternative techniques and equipments. Specific test modifications made to standard methods are presented in the "Laboratory Core Analysis Remarks Key" in Appendix C. Also, a computer printout identifying the specific test techniques used in each core is provided in Appendix D.

One significant improvement involved washing the salt from samples prior to grain size determination by diffusion of the salt into heated wash water. Another improvement resulted from the use of a gas-comparison pycnometer for grain density determinations. Acquisition of this instrument greatly increased the accuracy of density measurements and also reduced the length of time necessary for testing. In order to maintain consistency of results, all previously tested samples were rerun with the improved technique in both cases.

Part 2. Development of Computer Data Management Systems

Because of the large volume of data available for this study, it became necessary to develop a set of computer routines to store the data in a suitable format and manipulate the data for input into the statistical analysis programs. Although the ultimate product of this study is the conclusions obtained through the statistical analysis of the data, an important segment of the project was the preparation of the geotechnical data for generalized analysis by computer. Some of the methods and data files developed should have wide application in the processing, storage, and handling of geotechnical data.

To accomplish computer processing of the data it was necessary to:

1. Design data formats;
2. develop software for computer file generation;
3. interface these files to statistical packages for high level analysis; and,
4. provide for computer listing, plotting and retrieval of special subset groups from the data files.

All existing routines within the Lockheed computer centers for data storage, manipulation and statistical analysis were examined for possible application to these data. Computer systems within the Lockheed computer centers were compared on the basis of memory size requirements, input/output capability, accessibility, turn-around time, plotting capability, available statistical packages, cost per hour to operate, and anticipated problems in adapting to our data. Based upon this evaluation, it was determined that existing programs for statistical analysis could be utilized, but new programs would have to be written for data storage and manipulation prior to use of the more sophisticated statistical analysis routines.

A workable format with which geotechnical data can be entered and stored by high speed digital computers was designed, developed and put into practice. Efforts for efficient use of computer storage and execution time were successful. Growth of the record format for additional variables can be accomplished easily without disturbing the present file structure. A series of data manipulation and plot routines which interface to these formats was written. Routines were developed which prepared specified subsets of the data for entry into existing statistical packages.

The computer system used for the majority of the data processing was the IBM 360 Mod 91. Statistical analyses were also performed on selected data sets using the IBM 360-50 and the TYMSHARE system which is linked to LMSC's UNIVAC 1108 computers.

Computer Programs Developed

The new programs, specifically developed for the data used in this study, perform the following functions:

1. Reading, writing and storing data from core samples;
2. reading, writing, and storing data from in-place tests;
3. sorting and retrieving data based upon any property identification index or coded supplementary item;
4. forming data matrices appropriate for use in the statistical analyses; and,
5. plotting data.

Examples of the computer output sheets for data from core samples and in-place tests are presented in Appendix D. Also included is an example of the computer plots which can be generated to display graphically the sediment properties measured in each core as a function of depth below the seafloor surface.

The data entry and storage formats and the lists of measurements are described in Appendix C.

Data Processing and Analysis Procedure

Figure 5 shows an overall picture of the total data processing and analysis procedure. The system was developed to provide maximum flexibility for data presentation, retrieval, grouping, and calculation of various statistical parameters. Two important segments of the total system are (1) the storage of the raw data onto computer accessible magnetic tape, and (2) interfacing of the subset grouped data sets to widely used statistical packages, such as the UCLA Biomedical (BIOMED) routines; (Reference Anon) by means of computer oriented mass storage devices. Direct interfacing to the BIOMED routines was considered advisable because these programs are well documented, are convenient to use, and encompass a wide range of statistical techniques.

As indicated at the top of Figure 5, raw data tabulations as compiled from the at-sea in-place shear strength measurements and the laboratory

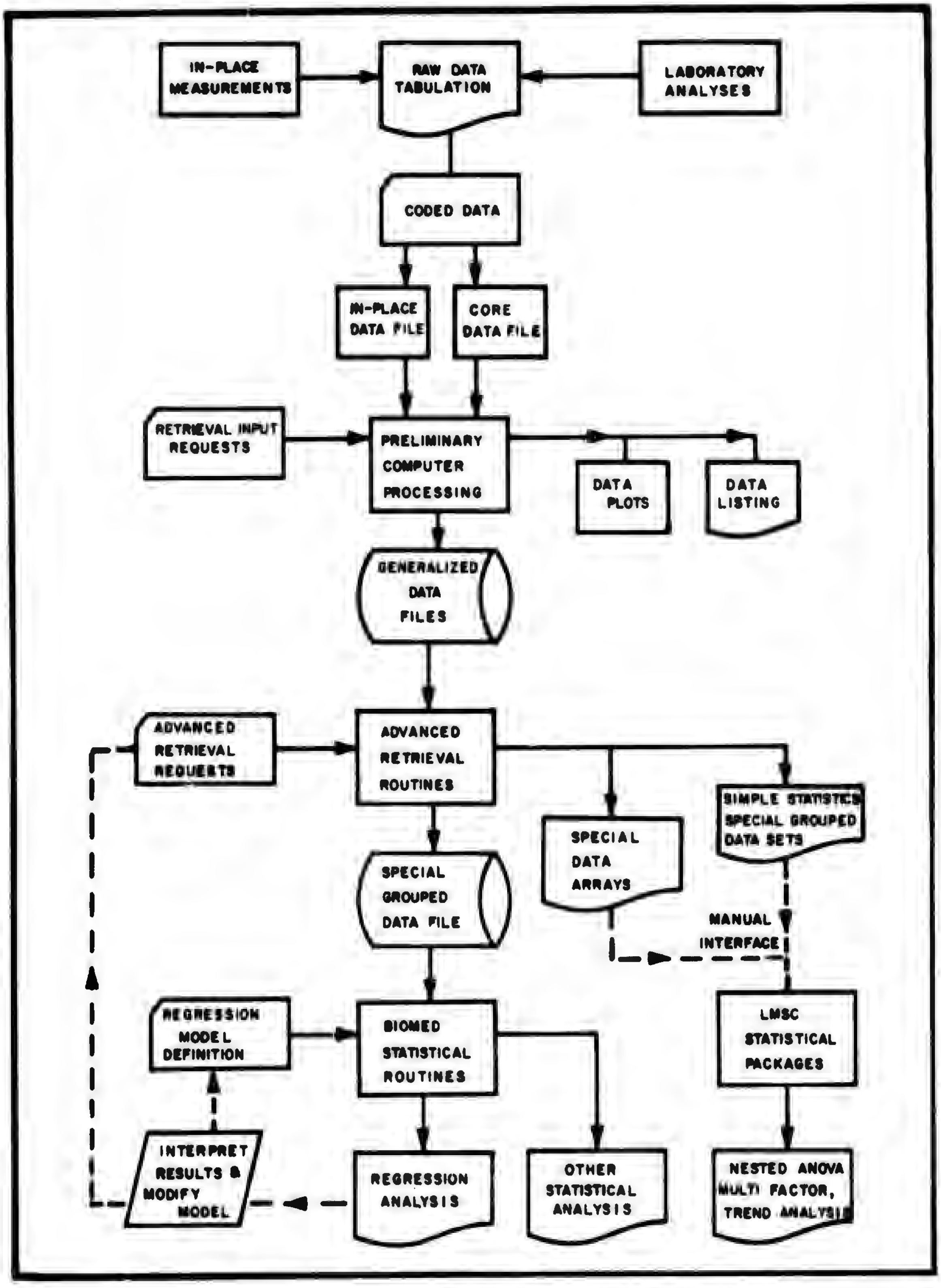


Figure 5. Data Processing and Analysis Procedure

analysis of the collected core samples were entered onto Hollerith cards. This was done according to the formats presented in Appendix C. It is believed that these formats are sufficiently general to have a wide application as standard formats for the storage of geotechnical data by computer.

The preliminary computer processing segment includes routines which generate magnetic tape files containing all raw data and routines which generate raw data plots and listings. These routines are for cursory looks, data editing, and other general inspection of data for trends, accuracy, and completeness.

The advanced retrieval routines facilitate forming of data subsets from the general data files. Definition of complex subsets is possible through the input of advanced retrieval request cards to these routines. Two classes of the advanced retrieval routines were developed. The first of these generates special data arrays and calculates tallies of the data, frequency distributions, averages, cross product and correlation arrays and other simple statistical parameters. Listings of the raw data of the retrieved subsets are printed for manual entry into other computer systems such as a time sharing terminal.

The second general class of retrieval routines generates data files of special formats which can be read by the routines of the BIOMED statistical package written at UCLA. For convenience when using the Lockheed computers, the special grouped data file is a temporary file on a fast access mass storage device. The file exists in the computer's memory only until the statistical analysis is complete so that no great number of data files with similar data are accumulated over a period of time. This also provides for great efficiency since no manual handling of the data between the routines is necessary. Consequently, a large number of statistical analyses may be done with great ease, minimum turn-around time and maximum efficiency.

By use of these programs and methods of data coding, it has been possible to develop a sophisticated cross-reference system. Data can be sorted and retrieved by core or in-place test number, dive or station number, project title, date collected, geographical coordinates, water depth, any of the properties or parameters measured, and any of the coded supplementary items presented in the "Code and In-Place Remark Keys" (Appendix C).

Part 3. Selection of Statistical Methods

Although a detailed presentation of the statistical methods used throughout the study is outside the scope of this report, a brief description of the major methods used is presented below and principal references used have been included.

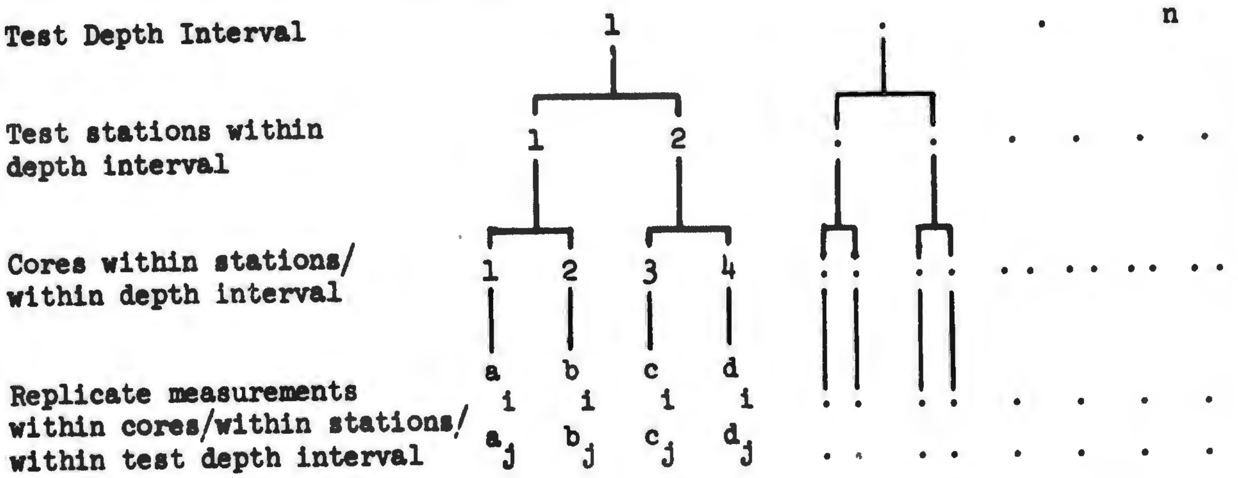
Where problems were encountered in applying statistical methods to certain data sets, a more comprehensive description of the assumptions and limitations of the statistical methods has been included.

Analysis of Variance (ANOVA) Methods

One of the most powerful statistical techniques used for examining the geotechnical data is the analysis of variance. Numerous ANOVA models were applied to the data sets depending on whether the source of variation was attributed entirely to random effects, to a specific treatment or test procedure, or to a combination of both. Also, the models solved two distinct types of problems; (1) those related to identifying the magnitude of variation and/or experimental error at different stages of a test procedure (nested or hierarchial ANOVA); and, (2) those related to determining if the differences between means of two or more groups of data are real or due to chance alone (one-way and multi-way ANOVA). A detailed description of these models and their uses in geological studies is available in Krumbein and Graybill (1965) pages 191-216, and Miller and Kahn (1965) pages 134-183.

A particular advantage of using the nested ANOVA for examining geotechnical data is that it can provide simultaneous answers to several questions. For example, a three level nested ANOVA having the structure shown in Table 1 can be used to partition the total variability into four components: test depth effects, station location effects, core location effects, and replicate measurement effects.

Table 1. Structure of Three Level Nested ANOVA



In interpreting the analysis of variance tables presented in the various sections of this report, "source of variation" refers to the class of differences being tested (e.g., differences between measurements from different test depth intervals; different test stations; different cores). The "degrees of freedom" relate to the number of measurements involved and the "mean squares" is the sum of squares divided by the degrees of freedom. In particular, the error mean square represents the smallest source of variability present for each ANOVA performed.

In the single and multi-factor ANOVA models, the variance F ratio is computed by dividing the mean squares between classes by the error mean square and is used as the criterion for testing the null hypothesis that the population means are the same in all classes. The F ratio is determined to be significant if it is greater than the values from the F distribution table.

In the case of the nested ANOVA model, the F ratio is also used except that it is obtained by dividing the mean square for the "source of variation" in question by the mean square of the next level in the ANOVA table. Excellent texts discussing the details of the calculations for the various ANOVA models are Snedecor and Cochran (1967), Krumbein and Graybill (1965), Sokal and Rohlf (1969), and Miller and Kahn (1965).

Tests on Assumptions of ANOVA and Multiple Comparison Procedures

In conjunction with the application of analysis of variance methods, several other statistical techniques were required to (1) evaluate the basic assumptions of ANOVA; (2) extend the results of the ANOVA to determine components of variance; and, (3) perform multiple comparisons.

Tests were conducted to establish normality of data when in question, as well as to test the homogeneity of the variances (Bartlett's test). These standard tests are presented in Snedecor and Cochran (1967). A detailed discussion of the assumptions of ANOVA is presented in Sokal and Rohlf (1969) Chapter 13.

In addition, since the analysis of variance establishes only if the variability differences are significant and estimates the magnitude of the variability present, multiple comparison techniques are required to identify which of the means compared (when more than two are tested) are not from the same population. In this study, Newman Keul's Procedure was used for this purpose. This procedure and other multiple comparison methods available are also discussed in Snedecor and Cochran (1967).

Linear Partial and Multiple Correlation

Correlation methods were used to determine the degree of association between two or more independent variables. The correlation coefficients calculated were compared to values in statistical tables to find the probability of obtaining a value as large or larger than the calculated coefficient. By this procedure, associations between variables were determined to be either significant or not. Although correlation coefficients are valuable for examining linear relationships between variables, they do not necessarily imply a cause and effect relationship. The interpretation of the correlation coefficient has to be evaluated in terms of the actual physical interaction between the variables considered. A detailed discussion of the topic of correlation is presented in Snedecor and Cochran (1967) Chapters 7 and 13, and in Sokal and Rohlf (1969) Chapter 15.

Simple and Multiple Regression

Stepwise regression analysis methods were used extensively (1) to investigate the degree of dependence between the independent and dependent variables; (2) to rank independent variables in order of their importance; (3) to determine the best predictory equations for the most interesting geotechnical parameters; and (4) to examine the nature of the residuals after the effects of the independent variables had been taken out. Readers are referred to Draper and Smith (1966) for one of the best presentations on stepwise regression analysis.

Although use of curvilinear regression techniques was originally considered as possibly necessary in the analysis, examination of the data showed that linear regression was adequate in most cases. In those instances where the geotechnical parameter exhibited a non-linear trend, such as in the water content versus depth, logarithmic transformation was used to correct the non-linearity.

One important aspect of the regression analysis performed for this study is that for each successive regression equation obtained, appropriate statistical tests were conducted to verify its significance, establish the confidence limits of the equation and the various regression coefficients, and determine if the regression model used was adequate.

For the simple regression analysis, computer programs developed by LMSC were used. For the multiple regression analysis the forward stepwise regression program (BMD02R) from the UCLA Biomedical Statistical Library was modified for use with our data. The Biomedical regression program has capabilities important for examining a large number of independent variables, performing transformations of original variables, generating new variables, and examining the residuals. Another valuable capability of the BIOMED regression program is the plotting of residual values; these are essential for interpreting the suitability of the regression model and detecting gross errors in the data.

Other Methods

Several other multivariate statistical methods, such as cluster and factor analysis, and trend analysis, were considered for application. These, however, were not used since the techniques described above were found to be adequate for the quantity and type of data available.

Two possible techniques which might be valuable in further investigations of these data are Analysis of Covariance and Analysis of Principal Components. Due to limited time, these methods were deferred for future studies.

SECTION 3. RESULTS OF STATISTICAL ANALYSIS

In order to simplify the discussion of statistical methods and results, major problem areas and study objectives have been categorized under the following six topics:

1. Descriptive Sample Statistics
2. Test Method Variability
3. Comparison of Different Test Methods
4. Areal and Vertical Variability of Sediment Properties
5. Multiple Relationships of Geotechnical Properties and Predictory Equations
6. Development of Sampling Criteria

In discussing each topic, consideration is given to the following items: (a) identification of specific questions to be answered; (b) data sets available for answering questions; (c) statistical methods and models used to analyze the data; and, (d) discussion of results derived from statistical analysis.

Part 1. Descriptive Sample Statistics

The purposes of this study part were to (1) summarize the sample statistics for each sediment property and thus provide an overview of the general characteristics of the data; (2) briefly describe the manner in which the sample statistics have been presented and the advantages of having the data available in this form; and, (3) illustrate some uses of these results.

Analysis of the data involved the following: (a) computing for each property, sample means, standard deviations, coefficient of variation and correlation coefficients; (b) identifying possible trends between the computed sample mean and variance for each sediment property and test depth; and, (c) comparing the relative variability (coefficients of variation) obtained for the sediment properties considered.

Statistical Parameters of Sediment Properties

Sample means, standard deviations, and ranges calculated for all laboratory and in-place measurements made in the upper 130 cm sediment depth and throughout the test area are presented in Table 2. In addition, means, standard deviations, and coefficients of variation for all properties analyzed are compiled in Tables E-1 through E-6, Appendix E, for test depth intervals of 10 cm, 20 cm, 50 cm, and the entire test depth range. These tables can be used to compare sediment property statistics and identify changes of means and variances with test depth.

Figures E-1 through E-15, Appendix E, contain mean values for sediment properties plotted at the various depth intervals. These graphs help to identify significant linear and nonlinear trends present and indicate how the size of the test depth intervals relates to trends in the results.

To complement trend information presented in the above figures and tables, the correlation coefficients (r) and coefficients of determination (r^2) were calculated for each sediment property as a function of test depth and are presented in Table 3. The correlation results are useful for confirming linear relationships between any of the examined sediment properties and test depth.

The sample mean represents the best estimate of the population mean for the particular sediment property considered, and the standard deviation is the best estimate of the population variance or average spread of the individuals in the population. The ability of the sample means to characterize the population mean values is determined by whether the population variance is small or large.

One accepted method for evaluating whether the variability is small or large is to compute the coefficient of variation which is the ratio of the standard deviation to the sample means. Tables E-3 and E-6 list the coefficients of variation for the entire sediment depth range, as well as for the 10 cm, 20 cm, and 50 cm intervals. Note the significant difference between coefficients of variation for the smaller test depth intervals versus the interval for the entire test depth range.

The standard deviations computed for the entire test area and sediment depths investigated estimate the total variability present for each sediment property measured. This total variability includes (a) test depth effects; (b) lateral or areal effects; (c) test methods effects; and, (d) natural or inherent variability of each sediment property. A full discussion of these sources of variability is presented in sections to follow. Assuming that the component of variability contributed by each of the above sources is small, then the standard deviation also can be expected to be relatively small. This is illustrated by the standard deviation of saturated unit weight, unit weight of solids, and porosity measurements shown in Table 2. If, on the other hand, the variability contributed by one or more of the above factors is significant, then the standard deviations will reflect this. As an example, note the larger standard deviations for the water content and in-place and laboratory vane shear measurements given in Table 2.

To obtain better estimates of the sample means and variances, sample statistics were computed for measurements grouped into smaller test depth intervals. This approach has some definite advantages. By presenting the sample statistics as a function of the size of the test depth interval, it enables the user to compare sample means and variances and establish those sediment depths where the mean and standard deviations change significantly. Also, confidence limits for the sample means and variances can be computed for any depth interval. As an example, the 95 percent confidence limits of the mean in-place vane shear strength for the 0-130 sediment depth are presented below.

$$\bar{X} - t_{.05(n-1)} \frac{s}{\sqrt{n}} \leq \mu \leq \bar{X} + t_{.05(n-1)} \frac{s}{\sqrt{n}} \tag{1}$$

Where:

μ = Population mean for the in-place vane shear strength

$\bar{X}$ = Average in-place vane strength which is equal to 54.4 g/cm^2

s = Standard deviation for measurements within the 0-130 cm test depth interval, which is equal to 27.7 g/cm^2

n = Number of measurements, within 0-130 cm test depth interval, which is equal to 250

$t_{.05}$ = t value at the 95% confidence level obtained from Student's t-distribution for (n-1) degrees of freedom. $t_{.05(249)} = 1.96$

Therefore, 95% confidence limits of sample mean are

$$54.4 \pm (1.96) \left(\frac{27.7}{250} \right) = 54.4 \pm 3.43 \ g/cm^2$$

Table 2. Summary of Sediment Properties Analyzed

Soil Property	Symbol	Mean	Standard Deviation	Range Min.	Range Max.	No. of Tests	Depth Interval (cm)
In-place vane shear (g/cm^2)	S_u(nat)	54.4	27.7	4.3	142.0	250	0-130
Lab. vane shear-orig. (g/cm^2)	S_u(nat)	41.5	23.1	1.0	96.4	478	0-110
Lab. vane shear-rem. (g/cm^2)	S_u(rem)	19.3	11.9	0.0	48.2	478	0-110
Water content (% of dry weight)	w	153.0	39.1	105.0	315.0	581	0-120
Median grain size (mm)	M_d	.0037	.0010	.0015	.0069	142	0-120
25th percent diameter (mm)	Q_1	.012	.008	.0045	.0950	142	0-120
75th percent diameter (mm)	Q_3	.0008	.0005	.0001	.0027	142	0-120
Sorting $(\frac{Q_1-Q_3}{2}$ (mm)	QD_a	.006	.004	.002	.047	142	0-120
% Sand >(62 μm)	Sd	2.0	1.0	0.0	6.0	142	0-120
% Silt(2-62 μm)	St.	60.0	6.0	51.0	76.0	142	0-120
% Clay (< 2 μm)	Cl	38.0	6.0	23.0	56.0	142	0-120
Saturated unit weight (g/cm^3)	γ_{sat}	1.40	0.037	1.30	1.47	174	20-100
Unit weight of solids (g/cm^3)	γ	2.53	0.044	2.24	2.76	170	20-100
Porosity (%)	n	78.4	1.22	65.0	82.8	174	20-100
Void ratio	e	3.7	0.49	2.1	4.8	174	20-100
Plastic limit (%)	W_P	50.0	9.0	35.0	66.0	27	30-100
Liquid limit (%)	W_L	109.0	13.5	75.0	129.0	27	30-100
Plasticity Index (%)	I_P	58.0	12.3	30.0	82.0	27	30-100

Table 3. Correlations Between Measured Properties and Sediment Depth (Depth Interval 0-130 cm)

Soil Property	Coefficient of Correlation (r)	Coefficient of Determination (r^2)(%)	No. of Values
In-place vane shear strength	.908	82.4	250
Lab vane shear strength-original	.895	80.1	375
$\log_e$ (lab vane shear strength-orig)	.825	68.1	375
Lab vane shear strength-remolded	.824	67.9	375
$\log_e$ (lab vane shear strength-rem.)	.734	53.9	375
Water content	- .816	66.6	375
$\log_e$ (water content)	- .871	75.9	375
Saturated unit weight	.736	54.2	176
Porosity	.683	46.6	176
Void ratio	- .756	57.2	176
Unit weight of solids	.296	8.8	176
Median grain size	NS	----	118
Q_1-25th percentile	NS	----	118
Q_3-75th percentile	NS	----	118
Sorting (Q_1-$Q_3/2$)	NS	----	118
% sand	NS	----	118
% silt	NS	----	118
% clay	NS	----	118
Plastic limit	NS	----	25
Liquid limit	NS	----	25
Plasticity index	NS	----	25

Note: Correlation coefficients listed are significant at the 95% confidence levels.

NS - Correlation coefficient is not significant.

Second, by decreasing the size of the test depth interval over which measurements are grouped, the variability contributed by test depth effects is essentially removed. Thus, assuming that the variability contributed by other sources is approximately the same for all test depths, by comparing standard deviations obtained for a 10 cm interval versus the total 130 cm test depth range, one can obtain a preliminary idea of the variability contributed by test depth effects. For example, standard deviations of in-place vane shear measurements within the 0-10 cm sediment depth and the 0-130 cm test depth range are 6.3 g/cm^2, and 27.7 g/cm^2, respectively (see Tables E-2 and E-4). Therefore, the variability contributed by lateral effects, test method precision and natural variability only represents approximately 25 percent of the total variability calculated for the 0-130 cm sediment depth range. The other 75 percent apparently is contributed by test depth effects. The validity of the assumption made above also can be examined by ascertaining if the standard deviations for the in-place vane shear measurements listed in Table E-2 change significantly between one sediment depth interval and the next.

A third important aspect of examining the sample statistics as a function of test depth interval size is that as the interval size is increased it has the effect of filtering noise from the data and in certain instances more clearly illustrating existing trends. An example of this is presented in Figures E-1 and E-3 for the vane shear values. Average values plotted for the 10 cm interval size indicate a step-function trend between shear strength and sediment depth. This step-like behavior though present in the graph for the 5 cm interval size is not easily detected. Also, in the 20 cm interval size plot, the trend is lost by averaging over too large an interval. Thus, the interval size over which sediment property values are averaged is of important consideration when attempting to establish trends in the data.

Trends Between Sample Means and Test Depth

Trends for those sediment properties exhibiting significant correlation coefficients with test depth are briefly summarized below. Results are based on the 5 cm depth interval profiles shown in Figures E-1 through E-15.

(a) In-place vane shear strength - Increases linearly with sediment depth. Change in slope occurs at approximately 20 cm depth.

(b) Lab. vane shear strength (original) - Increases linearly with sediment depth. Change in slope occurs at approximately 20 cm depth.

(c) Lab. vane shear strength (Remolded) - Increases linearly with sediment depth. Change in slope occurs at approximately 50 cm depth.

(d) Water content - Decreases nonlinearly in the first 60 cm of sediment depth, thereafter decreases linearly with depth.

(e) Saturated unit weight - Increases nonlinearly in the first 60 cm of sediment depth, thereafter remains essentially constant.

(f) Porosity - Decreases linearly with sediment depth.

(g) Void ratio - Decreases nonlinearly in the first 60 cm of sediment depth, thereafter remains essentially constant.

(h) Unit weight of solids - Minor linear decrease in the first 40 cm of sediment, thereafter remains essentially constant.

Trends Between Sample Variances and Test Depth

Investigation of the variances or standard deviations computed for each sediment property at 10, 20, and 50 cm test depth intervals (Tables E-2 and E-5) demonstrated that the magnitude of the variance for in-place and laboratory vane shear measurements and water content determinations changed noticeably with sediment depth. For the vane shear parameter the variability of the measurements increases with test depth, and for the water content the variability of the measurements decreases with test depth. The variability of the measurements for the other sediment properties examined do not change significantly with test depth.

The larger standard deviations obtained for the water content measurements in the upper 20 cm of sediment depths were expected as the water content values change significantly with slight changes in sediment depth in this depth range.

The increase in the variability of shear strength measurements with test depth is believed to be directly related to the increase in the mean shear strength values. In other words, the absolute magnitude of the standard deviation is increasing with test depth since the range of shear strength values is also increasing. However, if one examines the relative variability (i.e., coefficient of variation) for the vane shear measurements (Table E-3 and E-6) one notices that in fact the ratio of the standard deviation to the mean is decreasing with sediment depth. This is illustrated in Table 4 for the laboratory vane shear measurements (original test).

Table 4. Comparison of Absolute and Relative Variability for Laboratory Vane Shear Measurements (original test).

Depth Interval (cm)	Absolute Variability (Standard Deviation) (g/cm^2)	Relative Variability (Coefficient of Variation) (%)
0-20	6.9	61.7
20-40	9.8	30.6
40-60	11.1	23.2
60-80	9.8	16.5
80-100	11.9	17.7
100-120	12.7	17.4

Relative changes in the variance with test depth for all sediment properties investigated were examined through the coefficient of variation values. These results are presented in Tables E-3 and E-6.

The importance of recognizing or identifying these variance trends is that they provide insight for the development of more meaningful regression models for predicting these properties (Draper and Smith, 1966, pp. 86-91).

Also, knowledge of the variability of each property at particular sediment depth intervals enables determining the number of samples or tests required to estimate the population mean for any confidence level desired. A more thorough development of the subject on design of sampling and laboratory test programs for geotechnical properties is presented in Part 6.

Comparison of Variability Differences for Sediment Properties

Coefficients of variation for each sediment property presented in Tables E-3 and E-6 are graphically summarized for the 20 cm, 50 cm, and entire sediment depth investigated in Figures 6 and 7. From these figures one can easily identify those sediment properties with high or low standard deviation to mean ratios. These figures also enable establishing the trend of the

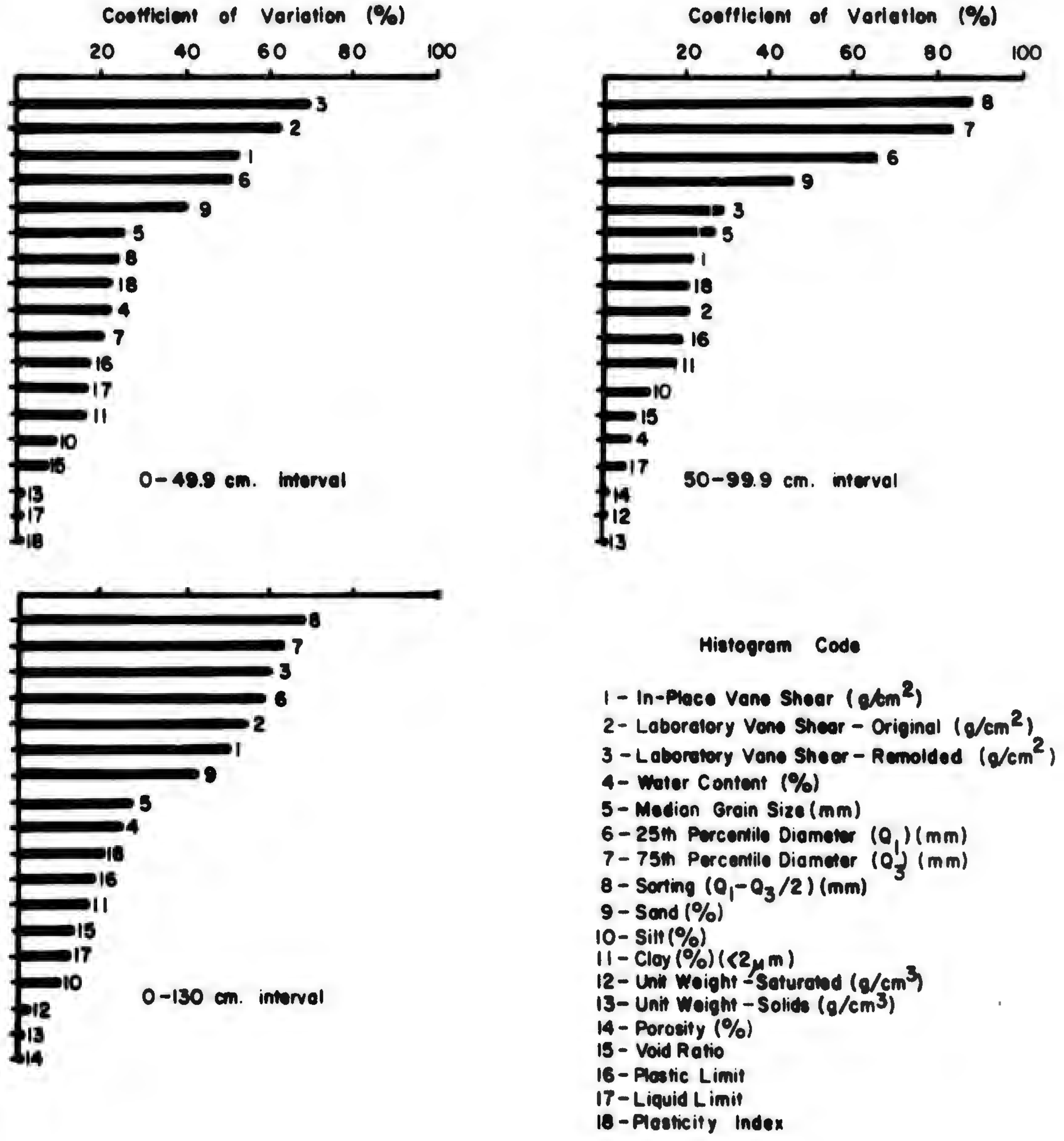


Figure 6. Coefficients of Variation for Sediment Properties

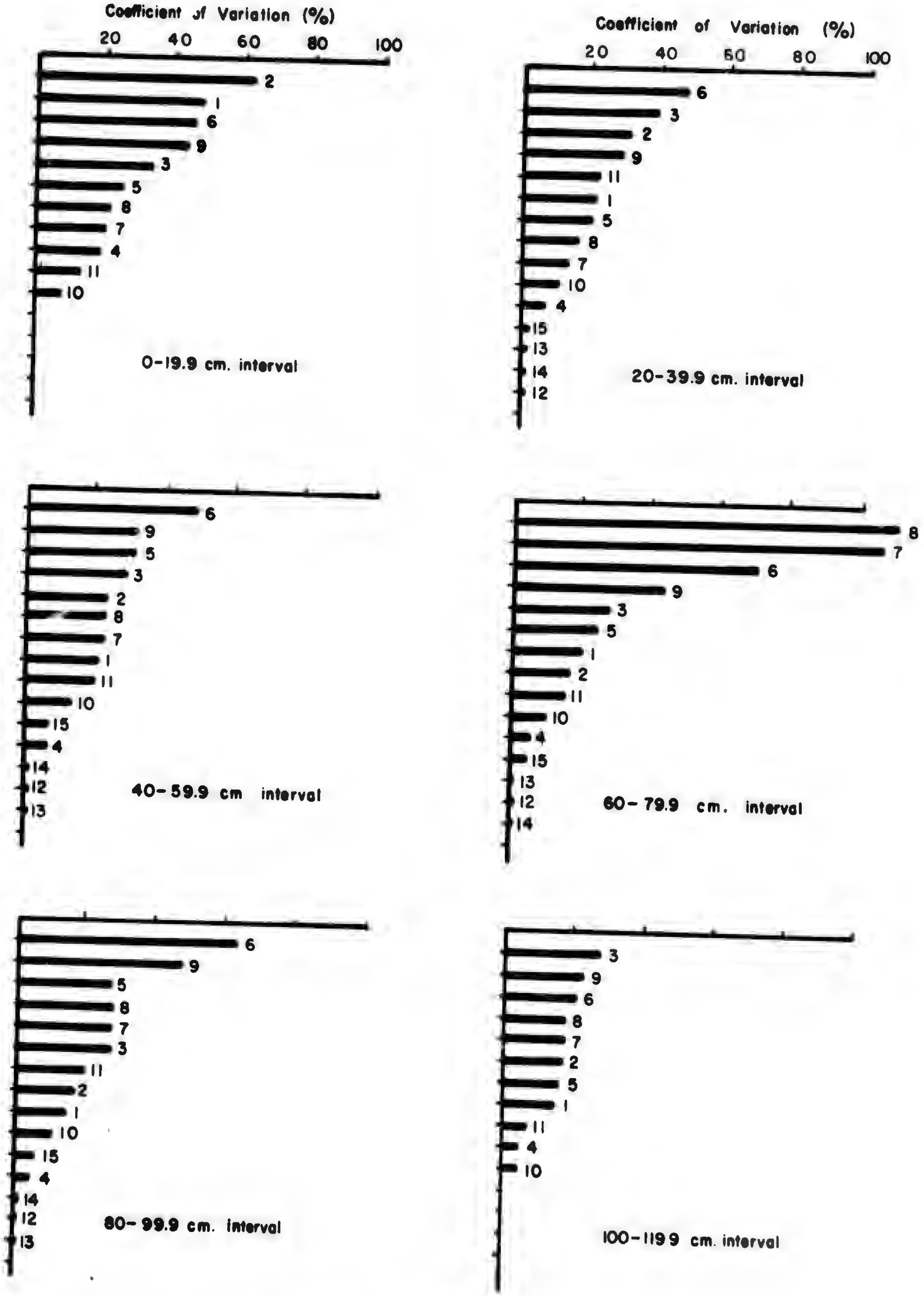


Figure 7. Coefficients of Variation for Sediment Properties

coefficient of variation as size of test depth interval increases.

Over the entire test depth range investigated, sediment properties exhibiting the highest relative variability are grain size quartiles, vane shear strength and percent sand. Medium range variability was exhibited by median grain size, water content, Atterberg limits, void ratio and percentages of silt and clay. The lowest variability was observed in saturated unit weight, unit weight of solids, and porosity.

Part 2. Test Method Variability

The principal objectives of this part of the study were to:

(a) establish the test method variability for each of the geotechnical properties measured,

(b) determine if the test method variability exhibited any trends with test depth,

(c) compare the relative magnitude of test method variability for the geotechnical properties measured.

The test method variability is the smallest variability that can be determined for each sediment property analyzed. Since multiple measurements of a single sediment property are not always possible on the same sediment sample, this variability is obtained by testing replicate samples or samples sufficiently close to each other to represent the same population. Therefore, the test method variability consists of two components: (1) inherent or natural variability of the sediment property being measured; and, (2) precision of the test method used; i. e., its ability to produce the same results assuming the same sample could be tested repeatedly.

Estimates of the test method variability for in-place and laboratory vane shear measurements were obtained by statistically analyzing results of replicate vane shear tests. The variability of the in-place vane shear test method was also evaluated using results of vane tests taken reasonably close to each other, which represent another form of replication.

For grain size, saturated unit weight, and water content properties, no replicate measurements were made. Thus, the statistical analysis is based entirely on tests conducted in cores taken adjacent to each other. Table A-1 lists all cores and in-place tests obtained within each station.

In-Place Vane Shear Tests

Two separate approaches were employed to determine the variability of the in-place vane test method over the entire sediment depth investigated. In the first approach, a single classification analysis of variance (ANOVA) was used to examine the two series of replicate vane tests conducted at test stations 2-166 and 1-167. Seven replicate tests were obtained at each test station in sediment depths varying from 7 to 123 cm. Since replicate tests conducted at each station were less than 1 meter apart, test results are assumed to represent the same population.

Structure of the analysis is shown in Table 5. Results of the analysis of variance are given in Table 6. Terms used in the analysis of variance table were explained earlier.

Table 5. Structure of Analysis

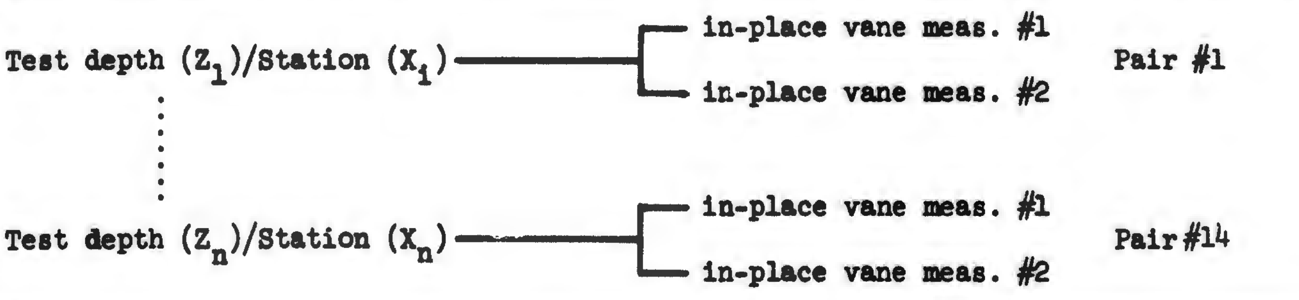


Table 6. Analysis of Variance (1)

Source of Variation	Degrees of Freedom (df)	Mean Square (MS)	F ratio
Between replicate pairs	13	1637.9	30.61**
Within replicate pairs (error)	14	53.5	
Total	27		

**F ratio is significant at 99% confidence level (i.e., probability of obtaining as high a ratio by chance alone is less than 1%). Table value for $F_{.01(14,14)} = 3.70$

Discussion: The mean square value (MS) for the "within replicate pairs" is the smallest variability measureable in the in-place vane shear data, based on the differences observed within each replicate pair of measurements. Therefore, the test method variability is directly obtained from the MS value for the "within replicate pairs". Results indicate that the variance (s^2) for a single in-place vane test is equal to 53.5 gm^2/cm^4 and the standard deviation (s) is equal to 7.3 g/cm^2. Knowing this information, the precision of a single in-place vane test, over the test depth range examined, can be estimated for any desired confidence level. This is illustrated later in this section.

Another conclusion obtained from the analysis of variance results is that the variability "between replicate pairs" is significantly greater than the variability within each pair of replicate tests. This implies that at least one of the replicate pairs differs significantly from the rest. The high F ratio obtained also indicates that some other major source of variation is present in the "between replicate pairs" class that has not been accounted for. In this design, a high F ratio was expected because the MS for the "between replicate pairs" includes effects due to the difference in the locations of station 2-166 and 1-167, and more importantly, effects due to differences in test depths.

The second approach used for estimating the in-place test method variability consisted of examining all vane shear measurements within each station made at approximately the same test depth. Lateral distances between vane tests at a station varied from about 1 meter for test pairs termed replicates, to as much as 30 meters for those termed adjacent. Both replicate and adjacent tests were used in this analysis. The purpose of this investigation was to determine how closely the variability of the test method could be estimated using vane test results from more widely spaced locations.

A two-level nested ANOVA with unequal sample sizes was used to examine the data. A description of this special design is presented in chapter 10 of Sokal and Rohlf (1969). For purposes of brevity, the structure of the analysis and the analysis of variance table have been omitted.

Discussion: The variance or MS value for the in-place tests within stations was determined to be 114.8 based on 65 degrees of freedom. The standard deviation of an in-place vane test calculated from this is equal to 10.7 g/cm^2, which agrees closely with the 7.3 g/cm^2 value obtained when only the replicate vane shear measurements were considered. The F ratio computed using the error mean squares of the two ANOVA indicated that the variances were not significantly different at the 95 percent confidence level ($F_{ratio} = 114.8/_{53.5}$ or 2.15). It is therefore concluded that for the seafloor area investigated, a good estimate of the in-place vane test method variability could have been derived from measurements taken at locations more widely spaced within each station.

Precision of a Single In-Place Vane Test

One of the major benefits of having established the variability of the test method is that the precision of a single test can be estimated for any confidence level desired. From the results shown in Table 6, the absolute and relative precision of a single in-place test were determined using the following expressions:

$$\text{Absolute Precision} = \pm\, t_{(df)} \sqrt{MS_{(error)}} \qquad (2)$$

where

The t value is obtained from Student's t distribution for the degrees of freedom indicated and the confidence level desired.

$$\text{Relative Precision} = \left(\frac{\text{Absolute Precision}}{\begin{array}{l}\text{Average in-place vane}\\ \text{strength for sediment}\\ \text{depth of interest}\end{array}} \right) \times 100 \qquad (3)$$

Discussion: Absolute precision of a single in-place vane test at the 95% confidence level was determined to be 15.7 g/cm^2. Using the average in-place vane strength of 54.4 g/cm^2 given in Table E-4 for the 0-130 cm sediment depth range, the relative precision of a single test was calculated to be 29%.

Changes in the Test Method Variability with Test Depth

Although an estimate of the test method variability for a single in-place test over the entire sediment depth interval was presented in Table 6, an additional number of single classification ANOVA were performed on the in-place vane results to investigate if the test method variability changed with sediment depth. In-place data were grouped into seven discrete sediment depth intervals, and data within each interval were examined using a structure similar to that described in Table 7. Since the replicate vane tests available were too few for these purposes, the analysis is based on all measurements within each station made at approximately the same depth.

Table 7. Structure of Analysis

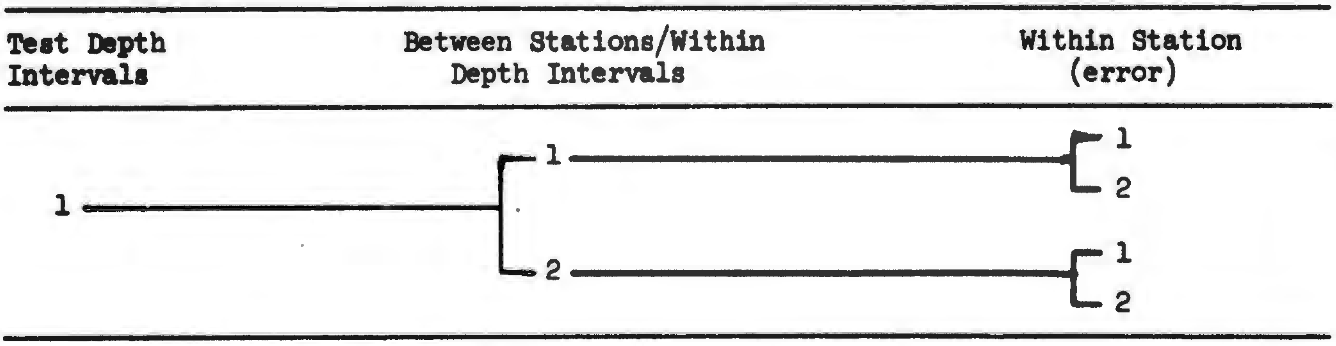


Table 8. Analysis of Variance (2) through (8)

ANOVA #	Depth Interval (cm)	Between Stations df	Between Stations MS	Within Stations df	Within Stations MS	F ratio
2	5-15	2	17.7	7	26.6	0.7 NS
3	25-35	3	18.1	10	46.9	0.4 NS
4	45-55	5	163.5	12	37.5	4.3 *
5	65-75	3	65.8	9	84.9	0.8 NS
6	85-95	3	48.6	10	20.6	2.3 NS
7	105-115	3	581.2	8	118.1	4.9 *
8	120-130	3	241.3	9	327.3	0.9 NS

NS means F ratio not significant.
* F ratio is significant at the 95% level, but not at the 99% level.

Discussion: Results indicate that the test method variability (i.e., the "within stations" MS value) fluctuates with test depth and the greatest variability occurs in the 105-115 cm and 102-130 cm depth intervals. This implies that at greater test depths, the standard deviation for replicate in-place vane shear measurements is larger. This is to be expected since the mean shear strength values increase with sediment depth.

Absolute and relative precision estimates were obtained for each of the above intervals using the "within stations" MS values.

Precision estimates derived are presented in Table 9. Since these results also are based on a limited number of measurements, they are not conclusive and should be used with caution.

Results suggest that to obtain a better estimate of the absolute precision of a single in-place test, within a selected depth interval, an ANOVA of similar structure as shown in Table 7 should be performed using only replicate test results.

Another conclusion drawn from the results presented in Table 8 is that the "between stations" variability is significant (at the 95% confidence level) for the sediment depth intervals 45-55 cm and 105-115 cm. This indicates that at least one of the test stations within each of these sediment depth ranges is different from the others.

Table 9. Absolute and Relative Precision of a Single In-Place Vane Test for Various Sediment Depths at 95% Confidence Level

Sediment Depth (cm)	Absolute Precision [1]	Relative Precision (%) [2]
5-15	12.2	90.3
25-35	15.2	47.4
45-55	13.3	28.6
65-75	20.8	37.3
85-95	10.1	15.1
105-115	25.1	31.2
120-130	40.9	43.5

Note: (1) Same units as in-place vane shear strength.

(2) Relative precision estimates were obtained using the average in-place vane shear strength within each of these depth intervals.

Laboratory Vane Shear Tests

Investigation of the original and remolded vane shear strength results, as well as the computed sensitivity parameter (i.e., original shear strength ÷ remolded shear strength) was undertaken using a single classification nested ANOVA. Estimate of the test method variability and the precision of a single vane shear test were obtained for the entire sediment depth range tested from analysis of 75 pairs of replicate original and remolded strength measurements made at various depths in 29 cores. The general structure used to analyze the above three shear strength variables is similar to that illustrated in Table 5.

Original Vane Shear Strength Measurements

Results of the analysis of variance performed on the replicate pairs of vane measurements are presented in Table 10.

Table 10. Analysis of Variance (9)

Source of Variation	df	MS	F ratio
Between replicate pairs	74	941.1	43.1 **
Within replicate pairs (error)	75	21.8	
Total	149		

** F ratio is significant at 99% confidence level.

Table value for $F_{.01(75,80)} = 1.85$.

Discussion: The high F ratio indiates that significant differences exist between replicate pairs. This result was anticipated since by partitioning the total variability into two classes (a) between replicate pairs, and (b) within replicate pairs, the between replicate pairs variability component includes effects due to different stations and different test depths.

Results in the ANOVA table also indicate that the MS value for the "within replicate pairs" is very small. The standard deviation for a single vane measurement, based on the replicate tests, was computed to be 4.7 g/cm^2.

A comparison of the "error" MS value for replicate laboratory and in-place vane measurements demonstrates that the variability of the laboratory test method is in fact less than the variability of the in-place test method. The reader is reminded, however, that replicate laboratory vane tests were conducted 2 - 3 cm apart, whereas the in-place replicate tests were taken approximately 1 meter apart.

Absolute and relative precision estimates for a single laboratory vane test were determined by equations (2) and (3). The absolute precision was computed to be 9.3 g/cm^2 at the 95 percent confidence level. Thus, if a single laboratory test is made within the test area anywhere in the upper 0-120 cm sediment depth interval, the 95 percent confidence limits of the measured value are $\pm$ 9.3 g/cm^2. The relative precision computed for the same confidence level was 22.5%. This value was determined by using the average shear strength value of 41.3 g/cm^2 computed for the 0-120 cm depth interval.

Remolded Vane Shear Strength Measurements

Results of statistical analysis performed on 75 pairs of replicate remolded vane shear measurements are presented in Table 11.

Table 11. Analysis of Variance (10)

Source of Variation	df	MS	F ratio
Between replicate pairs	74	244.0	42.2**
Within replicate pairs (error)	75	5.8	
Total	149		

**F ratio is significant at the 99% confidence level. Table value for $F_{.01(50,70)}$ which is more conservative (i.e., larger F value) due to less degrees of freedom, equals 1.82.

Discussion: Results from the analysis of variance indicate that significant differences exist between the various replicate pairs. The explanation for this is due to the inclusion of tests from different stations and test depths, as explained in the original vane shear strength section.

The standard deviation for replicate remolded vane shear measurements is 2.4 g/cm^2, and was obtained by taking the square root of the error MS in Table 11. Absolute and relative precision of a single remolded vane test at the 95 percent confidence level were determined to be 4.8 g/cm^2 and 24.9%, respectively. The relative precision estimate was calculated using 19.3 g/cm^2 as the average remolded shear strength for the entire 0-120 cm sediment depth range.

Sensitivity Parameter

Statistical analysis of the 75 pairs of calculated sensitivity values was also performed to establish the precision of a single sensitivity determination and examine if the sensitivity parameter changed within the test area or sediment depth investigated. Results are given in Table 12.

Table 12. Analysis of Variance (11)

Source of Variation	df	MS	F ratio
Between replicate pairs	74	.210	5.33**
Within replicate measurements	75	.039	
Total	149		

**F ratio is significant at 99% confidence level. Table value for $F_{.01(50,70)} = 1.82$.

Discussion: Interpretation of the above results indicates that the variability within replicate sensitivity determinations (i.e., standard deviation) is equal to 0.2. This small value demonstrates how consistent the ratio of original to remolded vane strength remains within the seafloor area investigated. This result is also supported by the smaller F ratio obtained. In spite of this, however, the analysis of variance results suggest that at least one replicate pair differs significantly from the rest based on the F ratio test.

Absolute precision of a single sensitivity determination was calculated to be 0.4 at a 95 percent confidence level. The relative precision, at the same confidence level, was determined to be 18.1% using a value of 2.2 for the average sensitivity value for the 0-120 cm sediment depth range.

Changes in Test Method Variability with Test Depth

Replicate laboratory shear strength values, original and remolded, were also used to establish if the variability of the test method changed with test depth. A single classification nested ANOVA was performed for the shear strength data at three different depth intervals (20-30 cm, 40-50 cm, and 80-90 cm). These depth intervals were representative of the overall sediment depths investigated and contain the largest number of replicate tests. Results of the nested ANOVA for the original and remolded shear strength values are presented in Tables 13 and 14, respectively. The structure of the analysis has a form similar to that described for the in-place results in Table 7.

Table 13. Analysis of Variance (12) through (14)

Original Laboratory Vane Shear Strength

ANOVA #	Depth Interval (cm)	Between Replicate Pairs		Within Replicates (error)		
		MS	df	MS	df	F ratio
12	20-30	219.4	17	11.5	18	19.1**
13	40-50	250.3	11	7.8	12	32.1**
14	80-90	146.8	14	19.2	15	7.6**

**F ratio is significant at 99% confidence level; $F_{.01(16,18)} = 3.19$, $F_{.01(11,12)} = 4.22$, $F_{.01(14,15)} = 3.56$.

Table 14. Analysis of Variance (15) through (17)

Remolded Laboratory Vane Shear Strength

ANOVA #	Depth Interval (cm)	Between Replicate Pairs		Within Replicates (error)		
		MS	df	MS	df	F ratio
15	20-30	60.0	17	2.8	18	21.4**
16	40-50	81.7	11	3.0	12	27.4**
17	80-90	29.8	15	8.0	16	3.7**

**F ratio is significant at 99% confidence level; $F_{.01(16,18)} = 3.19$, $F_{.01(11,12)} = 4.22$, $F_{.01(14,16)} = 3.45$.

Discussion: Results indicate that the variability of the vane test method for original shear strength measurements does not vary significantly in these depths. This conclusion is based on the F ratio value obtained by dividing the error MS for ANOVA 14 by that for ANOVA 13. This represents the largest difference for the intervals considered. Results also demonstrate that a better estimate of the precision of a single vane test can be obtained by examining the replicate vane results within the interval of interest. Note that the error MS values in Table 13 are less than that presented in Table 10.

F ratios computed for each of the "MS between replicate pairs" divided by the "MS within replicate" shown in Table 13 were found to be significant at the 99 percent confidence level. This means that significant differences exist between pairs of replicate measurements. These results were expected since the variability of the "between replicate pairs" includes location and test depth effects.

Results for the remolded shear strength values indicate that the mean squares for the "within replicates" increase significantly between ANOVA 15 and ANOVA 17 (i.e., 2.8 versus 8.0). The implications are that remolded strengths are less consistent at deeper sediment depths and, correspondingly, the confidence limits for a single remolded test at the 80-90 cm test depth are wider. These conclusions are also corroborated by the standard deviations computed for all remolded shear strength values (see Table E-2).

A comparison of the mean square values for the "between replicate pairs" shown in Tables 13 and 14 indicate no significant changes with test depth intervals. Absolute and relative precision estimates for each test method as a function of test depth can be obtained by use of equations (2) and (3) presented earlier.

Analysis of Test Methods for Other Sediment Properties Measured

Analysis of tests conducted on adjacent core samples provided an excellent opportunity to examine the precision of the laboratory test method over the entire test depth range for median grain size, saturated unit weight, unit weight of solids, porosity, and water content properties. Although the best precision estimate of a test method is generally obtained from "true" replicate tests, use of test results from adjacent core samples were shown by the results of vane shear tests to be more than adequate for a first order estimate. Replicate tests within a single core sample for these properties is often impossible due to the destructuve nature of the tests.

The statistical analysis was performed with the aid of a single classification nested ANOVA. The structure of the analysis used is illustrated in Table 15. All core measurements within each station at approximately the same test depth were grouped, and the variability within each group compared with the variability between groups.

Table 15. Structure of Analysis

Test depth interval (#)/Station (#) —— (Test results of Cores within Station) — Group (1)

.
.
.

Test depth interval (#)/Station(#) —— (Test results of Cores within Station) — Group (n)

Statistical results for each sediment property are summarized below:

Table 16. Analysis of Variance (18) through (22)

ANOVA 18 (Median Grain Size-mm)

Source of Variation	df	MS	F ratio
Between groups	21	5.176×10^{-7}	0.877 NS
Within groups (error)	22	5.90×10^{-7}	
Total	43		

NS - not significant (i.e., F ratio value < table value for $F_{.05(21,22)}$).

ANOVA 19 (% Water Content)

Source of Variation	df	MS	F ratio
Between groups	121	1745.7	21.8**
Within groups (error)	122	80.1	
Total	243		

**F ratio is significant at 99% confidence level.
Table value for $F_{.01(100,100)} = 1.59$.

ANOVA 20 (% Porosity)

Source of Variation	df	MS	F ratio
Between groups	44	9.23	14.70**
Within groups (error)	45	.63	
Total	89		

**F ratio is significant at 99% confidence level.
Table value for $F_{.01(40,40)} = 2.11$.

Table 16 Continued.

ANOVA 21 (Saturated Unit Weight-g/cm^3)

Source of Variation	df	MS	F ratio
Between groups	118	18.953×10^{-4}	11.66**
Within groups	55	1.626×10^{-4}	
Total	173		

**F ratio is significant at 99% confidence level.
Table value for $F_{.01(100,55)} = 1.78$.

ANOVA 22 (Unit Weight of Solids-g/cm^3)

Source of Variation	df	MS	F ratio
Between groups	41	.0022	2.17**
Within groups (error)	42	.0010	
Total	83		

**F ratio is significant at 99% confidence level.
Table value for $F_{.01(40,40)} = 2.11$.

Discussion: Results of the analysis of variance for the median grain size parameter indicate that the F ratio obtained by dividing the "between groups" MS value by the "within groups" MS value is not significant at the 99 percent confidence level. Therefore, one can conclude that median grain size does not differ significantly throughout the test area or sediment depths investigated. These results were anticipated on the basis of preliminary grain size determinations made on samples collected early in 1970 and 1971.

Analysis of variance results for water content, porosity, saturated unit weight and unit weight of solids demonstrated that for these properties the variability "between groups" was significantly greater than the variability for the "within groups". This was anticipated because the variability for the "between groups" contains test depth and geographical location effect, and the first three sediment properties listed above are known to change significantly with test depth. A discussion of the areal and vertical variability observed in these properties is presented in Part 4.

Estimates of the test method variability for each sediment property were obtained using the error mean square value in each ANOVA and equations (2) and (3) given earlier. These results are presented in Table 17.

Table 17. Absolute and Relative Precision of Test Methods at 95% Confidence Level.

Sediment Property	Absolute Precision[1]	Relative Precision (%)[2]
Median grain size (mm)	.00153	41.4
Water content (%)	17.7	11.6
Porosity (%)	1.60	2.0
Saturated unit weight (g/cm^3)	0.025	1.8
Unit weight of solids (g/cm^3)	0.064	2.5

Note: (1) Same units as shown for the sediment property.
(2) Based on average value determined for each sediment property for the entire seafloor area sampled. (See Table E-4, Appendix E).

As stated earlier, since some sediment properties change significantly with test depth, absolute precision estimates will vary depending on the test depth interval considered (i.e., entire test depth, 50 cm, or 10 cm intervals). Thus, if a particular depth interval is of more interest than another, the appropriate absolute precision should be calculated based on replicate measurements within this interval.

Relative Precision for the Various Test Methods

Another interesting result from these analyses is that one can compare the relative precisions of the test method for each sediment property at a particular test depth or across all test depths. A comparison of relative precision estimates for the entire test depth interval is presented in ascending order for each property at the 95 percent confidence level.

Table 18. Comparison of the Relative Precision of Different Test Methods

Sediment Property	Relative Precision (%)
Median grain size	41.4
In-Place vane test	29.0
Lab vane tests (rem.)	24.0
Lab vane tests (orig.)	22.5
Sensitivity	18.1
Water Content	11.6
Unit weight of solids	2.5
Porosity	2.0
Saturated unit weight	1.8

Part 3. Comparison of Different Test Methods

Although this study is primarily concerned with the variability of marine sediment properties, a section on the differences between field and laboratory vane tests has been included. One of the problem areas of great interest in the field of marine geotechnique is the assessment of changes introduced into sediment samples by coring procedures, pressure and temperature differences between the seafloor and the laboratory, and testing techniques. These changes can be observed by comparing in-place and laboratory measurements of the sediment property.

The principal objectives in this part of the study were to: (a) determine the differences between in-place and laboratory vane shear tests and establish whether the differences are significant; and, (b) establish if the differences between vane test methods change with test depth.

A secondary objective was to examine the various core data subsets generated by changes in handling procedures and laboratory test techniques which occurred during the four-year testing program. The purpose was to establish, whenever possible, if changes in test procedures had significantly affected the laboratory test results.

Comparison of In-Place and Laboratory Vane Results

Differences between in-place and laboratory vane test methods were determined using (1) paired in-place and laboratory measurements and (2) all in-place and laboratory vane results obtained within the test area. Statistical analysis of the paired data was performed using two-way analysis of variance. An excellent discussion on the analysis of variance for paired data is presented in Sokal and Rohlf (1969), pp. 328-333. Comparison of all in-place and laboratory vane shear results was accomplished by fitting the best least-square lines to each set of measurements and examining the differences in the slopes and intercepts for the fitted lines. The validity of the assumed linear relationship between shear strength and sediment depth was statistically verified for each set of measurements.

Approach 1. The structure of the analysis used to examine the 104 paired measurements is presented in Table 19. The distinct advantage of using paired data to determine if two methods or test techniques are significantly different is that the variability introduced by differences in geographical location, test depth, and changes in the other mass physical properties is essentially identical in both paired measurements. Therefore, any differences noted in the measurements is attributed entirely to the test method differences.

Table 19. Structure of Analysis

Pair No. (1)	In-Place Measurement (x_1) Laboratory Measurement (y_1)
.	.
.	.
.	.
Pair No. (104)	In-Place Measurement (X_{104}) Laboratory Measurement (Y_{104})

Results of the analysis of variance are summarized in Table 20. The data analyzed are believed to represent the largest quantity of paired in-place versus laboratory vane shear strength values yet to be analyzed.

Table 20. Analysis of Variance (22)

Source of Variation	df	MS	F ratio
Between Methods	1	129.96	3.07 NS
Between Pairs	104	869.01	20.54**
Error	104	42.31	
Total	209		

NS-not significant, Table value for $F_{.05(1,100)} = 3.94$.

**F ratio significant at 99% confidence level. Table value for $F_{.01(100,100)} = 1.59$.

The analysis of variance indicates that there are no significant differences between the two test methods. Therefore, laboratory vane tests conducted on DEEP QUEST cores accurately represent the field conditions. These results imply that for these particular cores, differences in testing techniques, temperature and pressure do not affect significantly the mean shear strength value. Another conclusion reached from the ANOVA results is that there are some major differences between separate pairs of in-place and laboratory vane shear measurements. This is indicated by the high F ratio value obtained for the "between pairs" class. The latter results was anticipated since the shear strength values change significantly with test depth (see Table E-1, Appendix E).

Approach 2. Results of the second approach used to compare the two test methods are presented below in the form of regression equations.

$$Y \text{ in-place } (g/cm^2) = 11.2 + .652 \times \text{depth (cm)} \tag{4}$$
based on 250 measurements

$$Y \text{ laboratory } (g/cm^2) = 9.5 + .693 \times \text{depth (cm)} \tag{5}$$
based on 375 measurements

An examination of the two equations shows that the slope and intercept values are nearly identical, thus confirming the analysis of variance results. Correlation coefficients for each of the above equations are .9077 and .8746, respectively, and are significant at the 99 percent confidence level.

To estimate the difference between the two equations, similar sediment depth values were entered into the equations and the shear strength was computed. Results are shown in Table 21 and demonstrate that the differences between vane test methods do not change significantly within the sediment depth investigated.

Table 21. Comparison of Vane Shear Test Methods

	Vane Shear Strength (g/cm^2)		Difference (g/cm^2)
Sediment depth (cm)	In-place test	Laboratory test	(in-place - Lab)
0	11.2	9.5	1.7
20	24.2	23.4	.8
40	37.3	37.2	.1
60	50.3	51.1	- .8
80	63.4	64.9	- 1.5
100	76.4	78.8	- 2.4

Analysis of Data Subsets

As a result of improvements made in the handling, storage and testing procedures during the four-year laboratory test program, the data subsets shown in Table 22 were generated.

Examination of possible effects introduced by different procedures was required prior to selecting the data to be used in the statistical analysis. Data found to be questionable or in error, e.g., measurements in grossly disturbed cores, were not used in the main analysis. Also, whenever definite differences were noticed in measurements from samples tested by alternate methods, samples were retested using the best method.

Due to the insufficiency of paired measurements within each data subset, statistical analysis was restricted to data subsets (1) and (7). Results presented for the other subsets are of a qualitative nature, based on a preliminary examination of the data.

Data Subset 1

In general, cores grossly disturbed exhibited lower shear strength values and erratic trends of shear strength and water content versus sediment depth trends. Disturbance effects were less obvious in the saturated unit weight and porosity determinations.

Shear strength differences between disturbed and undisturbed cores were examined in four paired (undisturbed-disturbed) cores using two way analysis of variance of a structure similar to that illustrated in Table 19. Results are presented in Table 23.

Table 23. Analysis of Variance (23)

Source of variation	df	MS	F ratio
Between methods	1	618.240	8.28**
Between pairs	25	646.444	8.66**
Error	25	74.665	
Total	51		

**F ratio significant at 99% confidence level.
Table value for $F_{.01(1,25)} = 7.72$, $F_{.01(24,24)} = 2.66$.

Table 22. Core Data Subsets

SUBSET #	DESCRIPTION OF DATA SHEETS
1	A: Core essentially undisturbed (good core). B: Core grossly disturbed (poor core).
2	A: Core test section removed by cutting core barrel with a "hot wire". B: Core test section extruded through top of core barrel.
3	A: Vane shear measurement made with standard Wykeham Farrance vane. Shear rate = 6°/min. B: Vane shear measurement made with modified Wykeham Farrance vane replacing torque springs with electrical strain gauges. Shear rate = 48°/min.
4	A: Core samples refrigerated at 6°C during storage prior to laboratory testing. B: Core samples stored at room temperature prior to laboratory testing.
5	A: Grain size analysis made from original wet sample. B: Grain size analysis made from dry sample that's been subsequently wetted. C: Grain size analysis made from dry sample that was ground prior to wetting and testing.
6	A: Salts removed from grain size samples via washing, allowing to settle, and decanting of wash water. B: Salts removed from grain size samples via "hot diffusion" method.
7	A: Density of solids determined by helium-pycnometer method. B: Density of solids determined by standard cylinder method.

Note that the description of these subsets corresponds to the information coded for each core under the "Remarks Key" (Appendix C). Cores in each data subset are identified in page 118 of the same appendix.

These results confirm that shear strength measurements in disturbed cores are significantly different from those measured in undisturbed areas. Average shear strength values computed for the 25 undisturbed and disturbed core measurements are 32.9 g/cm^2 and 26.0 g/cm^2, respectively. The ANOVA also indicates that significant difference exists between the various pairs. This was anticipated since the "between pairs" class includes test depth and location effects.

Data Subsets 2, 3 and 4

No major differences were noted between measurements within each of these three subsets. Testing of cores by extruding the sediment has been found to be more efficient, thus it has been adopted as the standard procedure for our cores.

In data subset 3, the modified vane shear device with the strain gauges is definitely considered the better system for testing low shear strengths and for obtaining continuous shear strength records. The only question is the effect introduced by shearing at different rotation rates. Preliminary tests conducted at Lockheed using 6°/min. and 48°/min. on specially prepared sediment mixtures have shown that differences between the highest and lowest shearing rates are less than 10 percent and are not significant, particularly in view of the test method variability noted in Part 2 for laboratory and in-place vane tests. These results are also confirmed by Halwachs (1972). Results of his study indicated that the average shear strength at 6°/min. was 10 percent higherthan at 90°/min.

For data subset 4, only a small number of cores used in this study were not refrigerated while awaiting laboratory testing. These cores were obtained early in the program before a refrigeration unit had been acquired. However, these cores were tested immediately upon returning to the laboratory and organic decomposition was very minimal and restricted to the upper 5-15 cm of sediment.

Data Subset 5

Major differences were definitely encountered between grain size determinations performed on samples initially wet or that had been subsequently wetted and dry samples ground prior to washing and testing (i.e., samples ceded A and B versus C in Table 22). To minimize problems in the statistical analysis of the data, all earlier grain size determinations based on procedure "C" were re-run using procedures A or B.

Data Subset 6

No differences were determined between the two test methods for removing the salts from the grain size sample. However, since the diffusion method is quicker and minimizes possible loss of fines during decanting of wash water, it has been adopted as the standard procedure for our cores.

Data Subset 7

Grain densities (unit weight of solids) derived from saturated unit weight measurements using the cylinder method were found to fluctuate significantly. Density results ranged from as low as 2.3 to as high as 3.1 g/cm^3, with a mean of approximately 2.74 g/cm^3. In contrast, grain density determinations using a gas-pycnometer (Beckman Instruments) method were more consistent and had a lower average value (2.53 g/cm^3). Therefore, all grain density tests were re-run using the gas-pycnometer and these results were used for this study.

For comparison purposes, grain density tests using the gas-pycnometer method were performed on the same sediment samples tested earlier by the cylinder method. Test method differences were examined using two-way analysis of variance for paired data values, and having a structure similar to that illustrated in Table 19. ANOVA results for 170 paired density determinations are presented in Table 24.

Table 24. Analysis of Variance (24)

Source of Variation	df	MS	F ratio
Between methods	1	3.482	841.571 **
Between pairs	170	0.004	0.927 NS
Error	170	0.004	
Total	341		

NS - Not significant, Table value for $F_{.05(1,150)} = 6.81$.

** F ratio significant at 99% confidence level.

Table value for $F_{.01(100,100)} = 1.59$.

These results confirm that the two test methods are significantly different. The ANOVA also indicates that grain density does not change significantly between different pairs, which implies that the grain density is relatively constant in both lateral and vertical directions within the seafloor area samples.

Part 4. Areal and Vertical Variability of Sediment Properties

The principal objectives in this part of the study were to:

1. Establish the variability contributed by horizontal and vertical changes in each sediment property within the test area.
2. Establish which sediment properties represented a single population throughout the test area.
3. Determine if any trends were apparent that related changes in sediment properties with geographical location of sampling stations.

Statistical Methods Used for Analysis

Nested analysis of variance methods were employed to examine the areal and vertical variability present in laboratory and field test results.

Analysis of the laboratory vane shear data was performed using three level nested ANOVA with unequal sample sizes in the sublevels and having the general structure shown in Table 25.

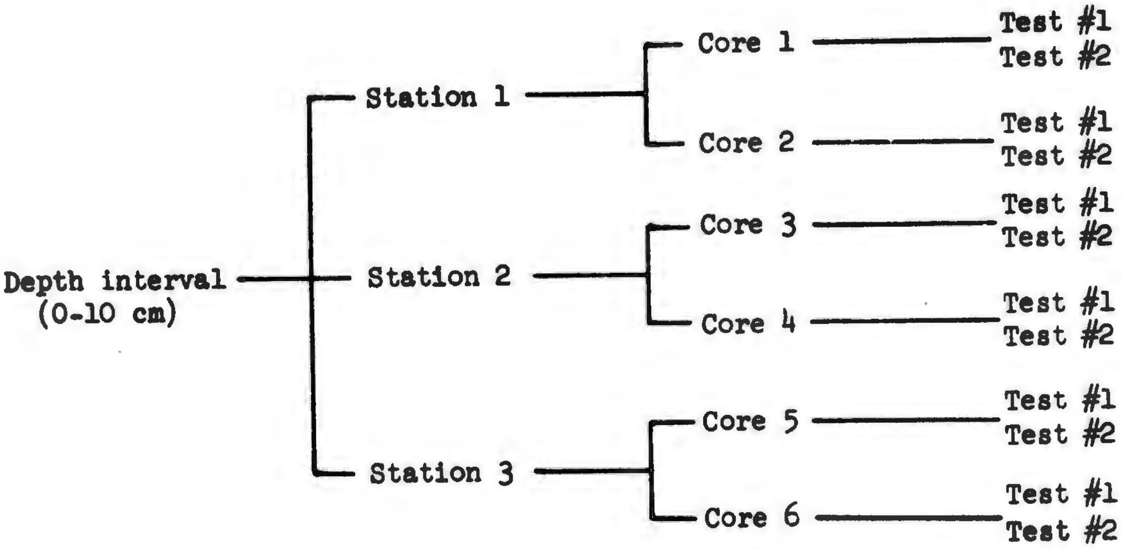
A similar model was described earlier in Table 1. This design allowed partitioning the total variability into four components: (1) test depth effects; (2) station location effects; (3) core location effects; and, (4) within core or replicate measurement effects.

Table 25. Structure of Three Level Nested ANOVA

Depth interval (1)	Stations within depth interval	Core within each station	Replicate measurements within each core (error)
.	.	.	.
.	.	.	.
	.	.	.
Depth interval (n)	.	.	.

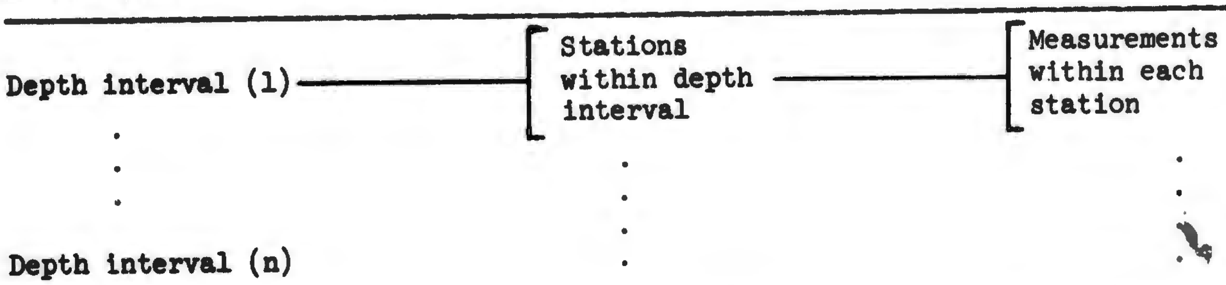
For example, using the above structure, vane shear measurements within a specific test depth interval would be grouped as shown in Table 26. Note that in this example equal sample sizes have been assumed for the sublevels.

Table 26. Example of Three Level Nested ANOVA



Analysis of the areal and vertical variability for the in-place vane shear strength and the other sediment properties measured was performed using a two level nested ANOVA with unequal sample sizes in the sublevels. In this design, the total variability for each sediment property was partitioned into three components: (1) test depth effects; (2) station location effects; and, (3) within station effects. The reason for using only a two level design is that replicate measurements are either very few or non-existent; therefore, the smallest source of variation is based on measurements made adjacent to each other within a station. The general structure of the ANOVA model is given in Table 27.

Table 27. Structure of Two Level Nested ANOVA



Sources of Variation in ANOVA Models

In the three level nested ANOVA model, the "between test depths" source of variability refers to differences obtained by comparing groups of measurements from the various test depth intervals. The "between sampling stations" refers to the differences obtained by comparing measurements from different test stations made at the same test depth intervals. The "between cores" refers to the variability between measurements in cores recovered at the same station and tested at the same depth interval, and the "within cores" refers to the smallest source of variability present. This is the variability between replicate tests made on the same core, from the same station, and same test depth.

For the two level nested ANOVA the above description also applies except that the "within core" source of variability is not known; therefore, the smallest source of variability is estimated from measurements within a test station.

Results for First Series of ANOVA Models

Results for each sediment property are summarized in Table 28. For purposes of brevity, the only information provided includes (1) the F ratio values, which enable identifying significant variability differences, and (2) the components of variance, which estimate the relative variability contributed by each source.

The components of variance are important for designing similar sampling programs because they point out at which level of the program most of the efforts should be concentrated. A discussion of their use in the design of efficient sampling programs is presented in Part 6.

In-Place Vane Shear Strength

Results of ANOVA 34 indicated that significant differences exist between sample means for different test depth intervals, and also that differences between sample means for different test stations are not statistically significant. Therefore, the test depth effects are the major items of consideration when attempting to reduce the variability of the in-place vane shear strength measurements in this seafloor area.

This is best illustrated by the components of variance which show that approximately 85 percent of the total variability noted in this sediment property is contributed by test depth effects.

Table 28. Results of Analysis of Variance for Areal and Vertical Variability

ANOVA NO.	Sediment Property	Source of Variability	Components of Variance	Components of Variance in (%)	F ratio from ANOVA Table
34	In-place vane shear strength	Between test depths	777.264	84.8	120.125**
		Between test stations	32.992	3.6	1.489 NS
		Within stations (error)	106.535	11.6	
35	Lab. vane shear strength (original)	Between test depths	458.929	83.2	29.573**
		Between sampling stations	32.617	5.9	2.153*
		Between cores	38.329	6.9	4.150**
		Within cores (error)	21.840	4.0	
36	Lab. vane shear strength (remolded)	Between test depths	117.108	82.2	26.086**
		Between sampling stations	10.864	7.6	2.617**
		Between cores	8.463	5.9	3.778**
		Within cores (error)	6.092	4.3	
37	Sensitivity	Between test depths	0.027	20.1	2.542*
		Between sampling stations	0.022	16.4	1.591 NS
		Between cores	0.044	33.5	3.242*
		Within cores (error)	0.038	29.9	
38	Water content	Between test depths	730.436	78.2	96.158**
		Between sampling stations	72.199	7.7	1.874 NS
		Within stations (error)	131.189	14.0	

**F ratio significant at 99% confidence level, *F ratio significant at 95% confidence level
NS-F ratio not significant at 95% confidence level

Table 28. Results of Analysis of Variance for Areal and Vertical Variability (Cont)

ANOVA NO.	Sediment Property	Source of Variability	Components of Variance	Components of Variance in (%)	F ratio from ANOVA Table
39	Median grain size	Between test depths	4.68×10^{-8}	4.9	1.821 NS
		Between sampling stations	33.98×10^{-8}	35.3	1.803 NS
		Within stations (error)	57.62×10^{-8}	59.8	
40	Saturated unit weight	Between test depths	1.31×10^{-3}	85.5	105.7**
		Between sampling stations	5.85×10^{-5}	3.8	1.525 NS
		Within stations (error)	16.26×10^{-5}	10.6	
41	Porosity	Between test depths	4.498	84.0	94.830**
		Between sampling stations	0.241	4.5	1.561 NS
		Within stations (error)	0.616	11.5	
42	Unit weight of solids	Between test depths	6.807×10^{-4}	32.7	10.100**
		Between sampling stations	2.128×10^{-4}	10.2	1.255 NS
		Within stations (error)	11.858×10^{-4}	57.0	

**F ratio significant at 99% confidence level
* F ratio significant at 95% confidence level
NS - F ratio not significant at 95% confidence level

These results were first suspected in Part 1, based on the inspection of the sample means and variances listed in Tables E-1 through E-6. However, only with the aid of the analysis of variance techniques could this hypothesis be definitely confirmed.

One interesting aspect of the ANOVA structure used for analyzing the in-place vane shear measurements is that the variability for the "within stations" closely resembles the value presented in Part 2, Table 6 . The difference is that in ANOVA 34 all in-place vane shear measurements were examined as opposed to just using replicate test results. Thus, ANOVA 34 also provides an estimate of the test method variability discussed in Part 2.

Laboratory Vane Shear Strength (Original and Remolded)

Results of ANOVA 35 and 36 indicated that significant differences exist for the "between test depths," "between sampling stations," and "between cores" at the 95 percent confidence level. Significant differences between sample means for different test depth intervals had been established earlier based on the correlation results shown in Table 3 and the sample statistics shown in Tables E-1 and E-4. However, significant differences between sample means for measurements from different test stations were not expected based on ANOVA results for the in-place vane tests. In explaining the above results, it should be remembered that the significant differences in the "between stations" established by the F ratio test imply that at least one sampling station is really different from the rest. Possible reasons for detecting a difference in the laboratory vane data and not in the in-place vane data are:

(1) A larger number of laboratory vane shear results were used in ANOVA 35 and 36, and these measurements provide a more complete picture of the shear strength parameter within the test area. Thus, a truly different sampling station may have been detected.

(2) The laboratory vane shear test measures strength over a smaller area of sediment, therefore, it is more sensitive to minor local differences.

Components of variance for the original and remolded vane strengths, ANOVA models 35 and 36 respectively, demonstrated that the test depth effect is the major item to consider when attempting to reduce the variability of the vane shear strength data. Variability "between sampling stations" represents less than 8 percent of the total variability and is less than the combined variability contributed by the "between cores" and "within cores"; therefore, the areal variability detected is minor.

Sensitivity Parameters

Results in ANOVA 37 indicated that significant differences exist between sample means for sensitivity values from different test depths and from cores obtained at the same station. The first result illustrates the ability of the analysis of variance to detect the difference between the average sensitivity value for the 0-10 cm depth interval which is 4.1, and the average sensitivity value for the remainder of the sediment depth examined which is approximately 2.2 (see Table E-1). The fact that the sensitivity parameter remains essentially constant with test depth below 10 cm is confirmed by the small value for the "between test depth" component of variance ($\simeq$ 20%).

Based on the magnitude of the components of variance for the "between cores" and the "within cores", it appears that the test method variability for this sediment property is the primary source of uncertainty.

Water Content

Results of ANOVA 38 showed that 78.2 percent of the variability is attributed to differences in sample means from different test depths. Vertical variability was determined to be significant at the 99 percent confidence level. These results were anticipated based on the high correlation of the water content with test depth, and the significant changes in the average water content values calculated for 10 cm and 20 cm test depth intervals shown in Tables E-1 and E-3. The results of the ANOVA simply confirm that some of these sample means are in fact different.

Analysis of the "between sampling stations" indicated that the areal effects only represent 7.7 percent of the total variability and are not significant at the 95 percent confidence level. Therefore, within an individual test depth interval, say 10 to 20 cm, the water content values represent the same populations throughout the sampled area.

Median Grain Size

The purpose of analyzing the median grain size results through analysis of variance was twofold. First, to illustrate how the analysis of variances could successfully confirm that no correlation or trends existed between median grain size and test depth. This had been shown by simple linear correlation results in Table 3. The second reason was to establish whether the areal variability was greater than the vertical variability.

Results of ANOVA 39 indicated that neither the vertical nor the areal variability are significant at the 95 percent confidence level. These results had been anticipated based on the sample statistics computed in Part 1 and the correlation results shown in Table 3. The largest variability found (59.8 percent) occurs in grain size determinations within the same station. The next largest source of variation is contributed by differences between sampling stations (35.3 percent), and the smallest variability found occurred between sample means from different test depths (4.9 percent). Therefore, the area variability, though not significant, is greater than the vertical variability.

Saturated Unit Weight and Porosity

Results of ANOVA 40 and 41 for saturated unit weight and porosity, respectively, confirmed that significant differences exist between sample means for different test depth intervals at the 99 percent confidence level. Results also demonstrated that measurements from different sampling stations are not significantly different. Therefore, the area variability is not a major factor contributing to the total variability.

Inasmuch as both these sediment properties are related to the water content parameter, variability contributed by test depth effects is of approximately the same magnitude and importance as shown for the water content variable.

Unit Weight of Solids (Grain Density)

Originally, no major lateral or vertical changes were anticipated for this sediment property. However, since simple linear correlation results (Table 3) indicated a significant correlation between grain density and test depth, it was decided to apply ANOVA methods to establish the variability components.

Results of ANOVA 42 demonstrated that a significant difference existed between the sample means determined for different test depth intervals. These results are partially confirmed by the sample means shown in Table E-1, where the average grain density in the upper 10 cm is 2.51 g/cm^3 and gradually increases with sediment depth to a maximum average value of 2.56 g/cm^3 in the 60-70 cm test depth interval and remains relatively constant below that depth.

The second conclusion reached is that variability between sampling stations is not significant, thus, the area variability effects are of no consequence.

Results for Second Series of ANOVA

Inasmuch as the only significant areal variability noted occurred in laboratory vane shear measurements, further investigation of this sediment property was undertaken through a second series of nested analysis of variance. The geotechnical test area shown in Figure 1 was subdivided into three smaller areas of equal size for purposes of examining if the vane shear strength values changed significantly in either north to south or east to west directions. An excellent discussion on the use of nested analysis of variance techniques for mapping problems is presented in Miller and Kahn (1962), Chapter 17.

Measurements within these subareas were examined at three separate depth intervals (20-30 cm, 45-55 cm, and 80-90 cm). These depth intervals were selected since (1) the largest number of vane shear measurements were made at these three depths; and, (2) the measurements are representative of the entire sediment depth investigated. The structure of the three level nested ANOVA is shown in Table 29.

Table 29. Three Level Nested ANOVA

Area (1)	Stations within area	Cores within station	Replicate measurements within cores
⋮	⋮	⋮	⋮
Area (3)			

ANOVA results for comparing vane measurements from different subareas are summarized in Table 30. Only the F ratio values and the components of variance are presented for purposes of brevity. In all cases except ANOVA 45, the largest variability noted occurs between cores recovered at the same station. The only situation where the area variability is significant occurs in ANOVA 44. Thus, excluding sediment depth effects, the next most important source of variability is introduced by local effects.

One additional approach used to examine for area trends in the vane shear strength measurements at these three depth intervals involved averaging all vane measurements for each station and contouring the data points. Results are presented in Figures 8 through 10.

Contoured data suggest that the lower shear strength values lie along a diagonal band ($\simeq$ azimuth of 225°) which divides the test area in two. Shear strength values on either side of the diagonal increase with distance from the diagonal.

Tentative direction of the trends within the test area possibly explains why ANOVA 43-48 did not demonstrate that the subareas differed significantly except in ANOVA 43 (20-30 cm depth interval).

The trends shown are only tentative as they are based on contouring both single observations and averaged values where more than one observation was available, and as the ANOVA results demonstrated, variability within a station is generally higher than between stations.

Table 30. Areal Variability of Laboratory Vane Shear Measurements

NORTH TO SOUTH AREAS

	ANOVA 43 Depth 20-30 cm Components of Variance	%	ANOVA 44 Depth 45-55 cm Components of Variance	%	ANOVA 45 Depth 89-90 cm Components of Variance	%
Between Areas	33.720*	25.9	- 9.491 NS	-8.0	-2.045 NS	- 1.6
Between Stations	21.141 NS	16.3	54.478*	45.8	54.181 NS	42.0
Between Cores	64.258**	49.4	61.178**	51.4	51.788**	40.2
Within Cores (error)	10.925	8.4	12.861	10.8	24.980	19.4

EAST TO WEST AREAS

	ANOVA 46 Depth 20-30 cm Components of Variance	%	ANOVA 47 Depth 45-55 cm Components of Variance	%	ANOVA 48 Depth 80-90 cm Components of Variance	%
Between Areas	20.268 NS	16.8	13.547 NS	10.5	6.998 NS	5.3
Between Stations	25.567 NS	21.1	41.229 NS	32.1	47.454 NS	36.2
Between Cores	64.258**	53.1	60.815**	47.3	51.788**	39.5
Within Cores (error)	10.925	9.0	12.861	10.0	24.980	19.0

NS - not significant at 95% confidence level

* significant at 95% confidence level

**significant at 99% confidence level

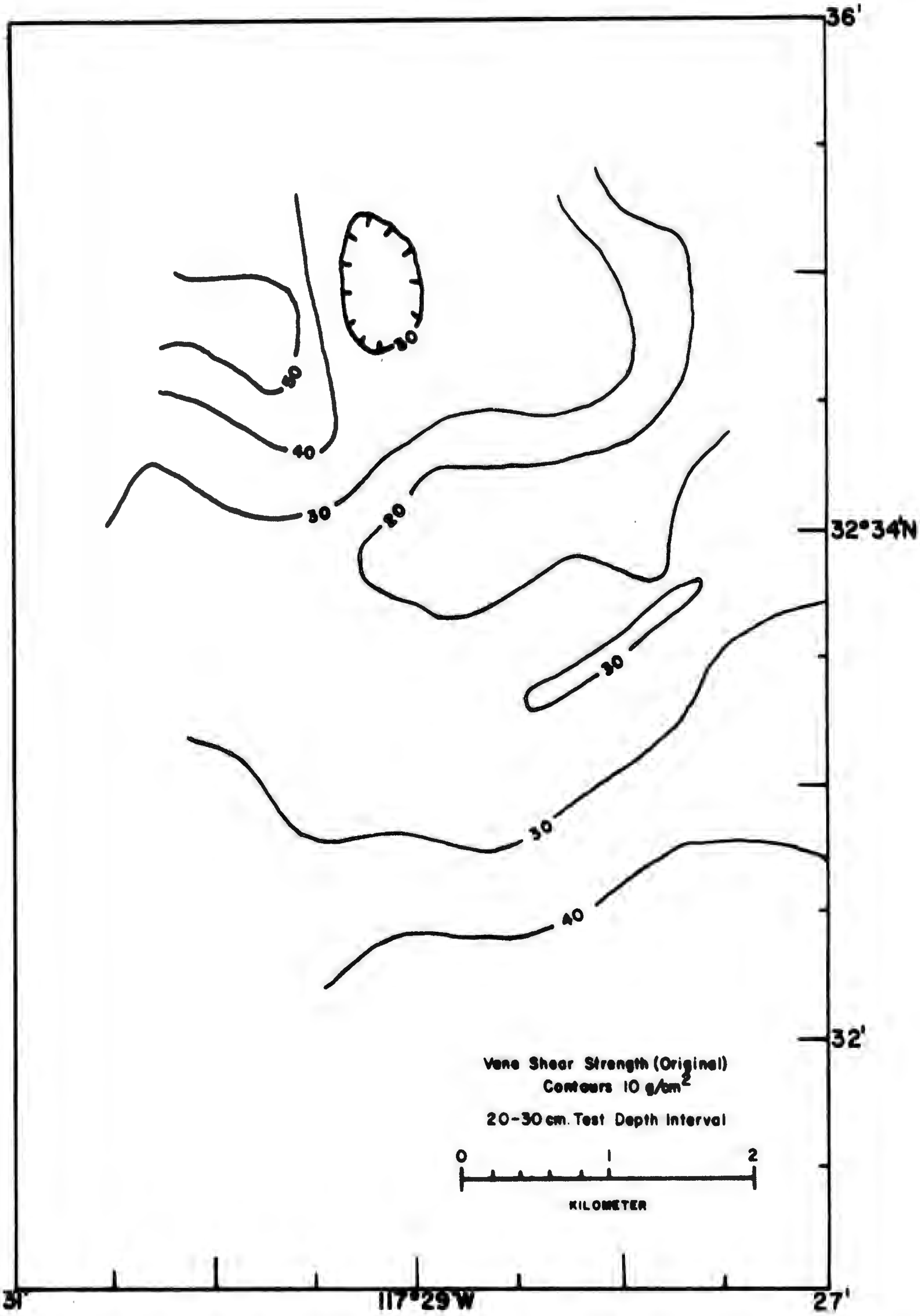


Figure 8. Vane Shear Strength (Original), 20-30 cm Depth Interval

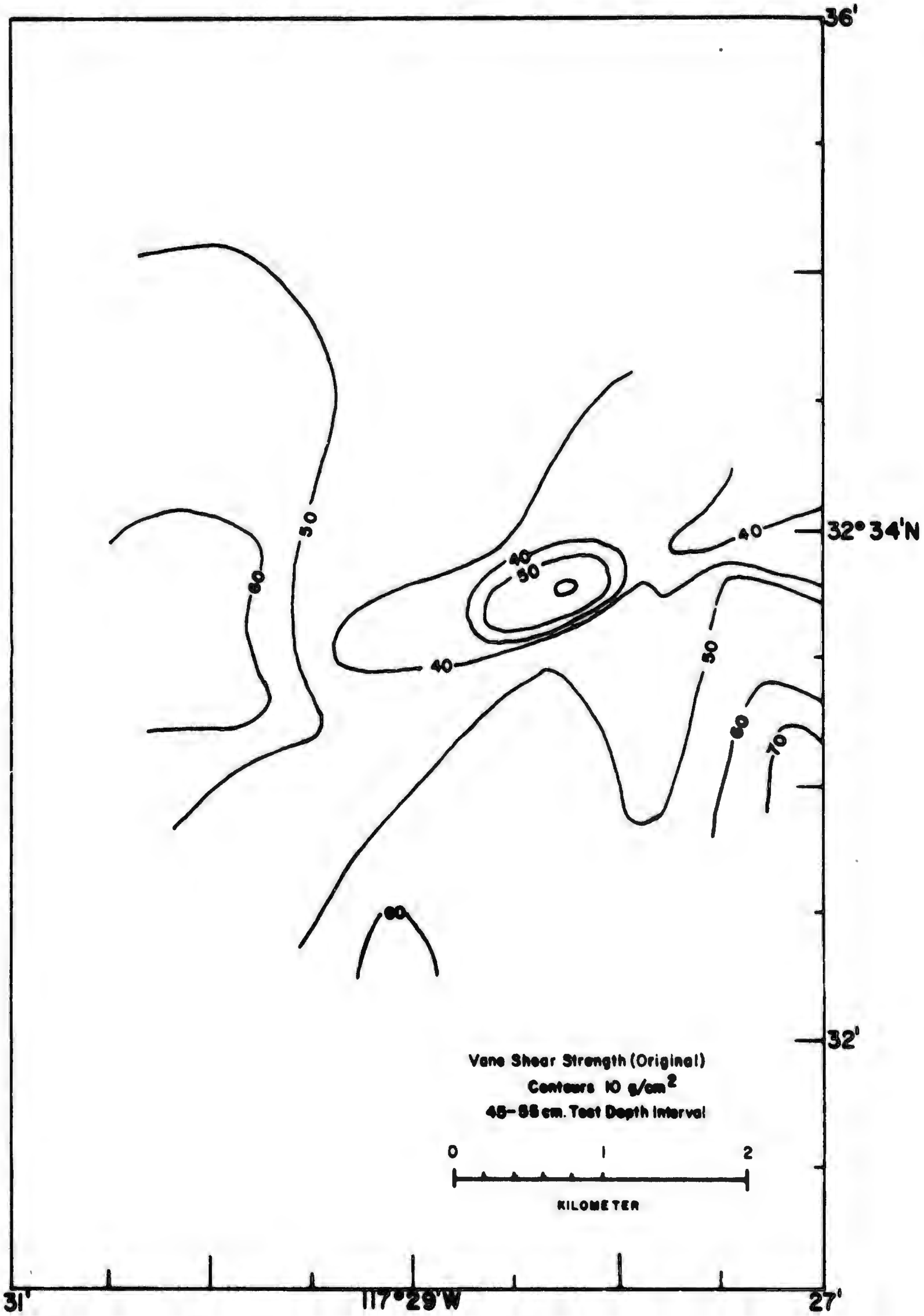


Figure 9. Vane Shear Strength (Original), 45-55 cm Depth Interval

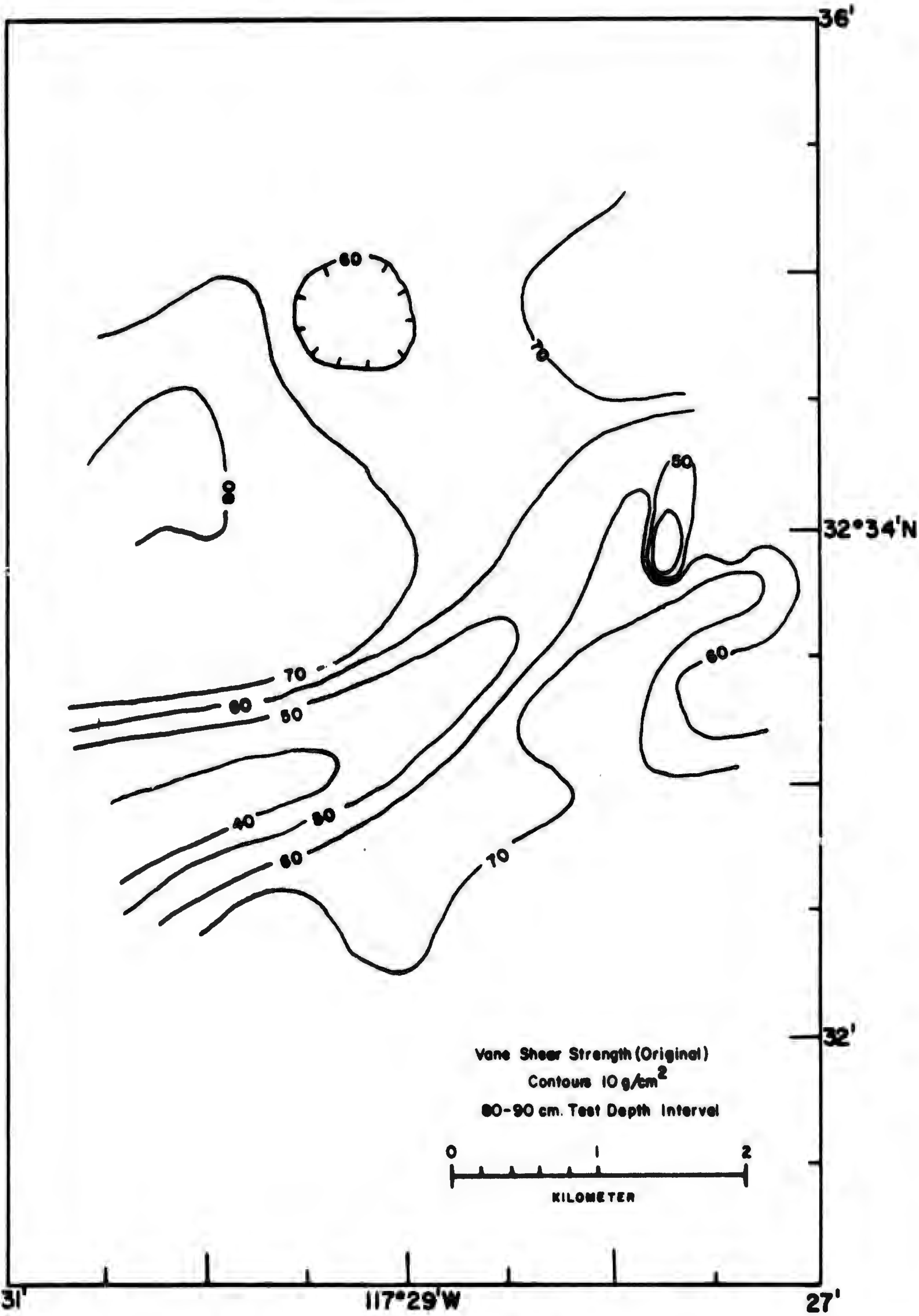


Figure 10. Vane Shear Strength (Original), 80-90 cm Depth Interval

Part 5. Multiple Relationships Between Geotechnical Properties and Predictory Equations

The primary objectives in this part of the study were to:

(1) Establish important relationships between the properties measured.

(2) Establish predictory equations for principal sediment properties, and determine the reliability of these equations over the range of values for the properties considered.

(3) Establish the importance of test depth in the regression/correlation analysis performed for each sediment property.

(4) Examine the nature of the regression residuals in the context of developing better regression models.

Data analyzed included all laboratory test results for the sediment properties listed in Table 2.

Multiple correlation and regression analysis were performed using a modified version of the UCLA BIOMED forward stepwise regression program.

The linear first order multiple regression model used can be described by the following expression:

$$Y = B_o + B_1 X_1 + B_2 X_2 + \ldots\ldots + \epsilon$$

where Y = dependent variable

$X_1 \ldots\ldots X_n$ = independent variables

$B_o \ldots\ldots B_1$ = parameters of the model

ϵ = random error with mean zero and variance σ^2 (unknown)

Second order regression models in X of the form

$$Y = B_o + B_1 X_1 + B_{11} X_1^2 + B_2 X_2 + B_{22} X_2^2 + \ldots\ldots + \epsilon$$

were also considered for the laboratory vane shear strength data. Estimates of the model parameters $B_o, \ldots\ldots B_n$ were obtained through the method of least squares.

Forward Stepwise Regression Procedure

A discussion on the use of regression analysis was presented earlier under statistical analysis methods. Some additional comments pertaining to regression procedures are included here for information. The advantages of the "forward stepwise" regression procedure over the "backward" or "forward" procedures is that at each step where a new variable is added to the regression equation, the partial correlation coefficients are recomputed, and the relative importance of all independent variables in the equation are re-evaluated. The importance of this is that it enables one to identify if any one of the variables entered in the preceding steps have become insignificant because of their relationships with the new variables added. Thus, at each step every single variable is re-examined as though it had been the most recent variable entered, irrespective of its actual point of entry into the model, and any variable which does not provide a significant contribution is removed from the model. An excellent description of the above statistical procedure and its advantages over other regression procedures is presented in Chaper 6 of Draper and Smith (1966).

Preparation of Data for Regression Analysis

One of the most serious problems encountered in undertaking multiple correlation/regression analysis of any geotechnical data is that all sediment properties listed in Table 2 are seldom ever measured at the same test depth. Also, certain properties are measured more frequently than others. Therefore, in preparing the data matrices for the regression analysis, one can expect to have numerous empty data cells and be faced with the problem of either having to generate missing values by interpolation or preliminary regression techniques, or to eliminate incomplete data subsets or entries.

For this study, a special approach was implemented to examine all data collected and avoid basing the entire regression analysis on a limited number of measurements or on data values generated by interpolation or regression results between two or three variables.

Laboratory test results were grouped into the four major data sets presented in Table 31. Each set differs from the others in the number of sediment properties it includes and the number of test results available for each property. To facilitate computer processing of data, sediment properties were grouped into data partitions. The concept of data partitions and the sediment properties grouped under each partition are presented in Appendix C.

Table 31. Data Sets Used in Regression Analysis

Data Set #	Data Partitions Included	Size of Array (nxm)
1	A,B,D,E,F	25 x 18
2	A,B,D,F	116 x 15
3	B,D,F	176 x 9
4	B,F	375 x 4

Where: n = number of measurements for each sediment property

m = number of sediment properties included in the partitions listed.

Data arrays useful for regression analysis were obtained by the procedure described below. For example, laboratory test results performed in a core usually provide a data array of the form shown in Table 32. The X denotes a set of measurements for the partition at the test depths indicated.

Table 32. Typical Data Array of Sediment Properties by Partitions

Data Partitions Information	A Grain Size	B Vane Shear	D Density	E Water Content	F Atterberg Limits
Test Depth (cm)					
0-5		X		X	
5-10			X		
10-15	X				X
15-20		X		X	
20-25			X		
25-30	X				X
30-35		X		X	
35-40			X		
40-45	X				X

From these results a complete data matrix with no empty data cells can be formed if one groups different properties measured within a reasonable test depth interval and assigns them a common test depth. For example, for the above matrix we might obtain the following:

Table 33. Completed Data Matrix for Sediment Properties

Test Depth (cm)	Grain Size	Vane Shear	Density	Water Content	Atterberg Limits
7.5	X	X	X	X	X
17.5	X	X	X	X	X
32.5	X	X	X	X	X

The assumption made in the above example is that the sediment properties do not change significantly within a 15 cm depth interval. For this study, the optimum size of the test depth interval was established from the sediment versus test depth information presented in Part 1. A similar procedure was used for generating a data matrix for data sets 2 through 4. Use of this approach permitted the examination of data at various stages of completeness (i.e., number of properties considered).

Regression analysis for the four data sets involved generating several hundred equations. In several instances, fourth and fifth sets of predictory equations were required to investigate the effects of omitting certain independent variables, transforming variables of the original data matrix, adding new variables by transgeneration of original variables (i.e., products, ratios, obtained by combining two or three independent variables), and omitting data point outliers. The end goals of these efforts were to obtain the best equation in terms of (1) the percent of variation it explained, and (2) the correctness of the regression model. Accomplishment of the latter goal involved examining the residuals for each regression equation to determine if:

(1) the variance of the regression was constant within the range of the independent variables;

(2) linear or quadratic terms should have been included in the model;

(3) or a combination of both of the above.

It should be brought out that the residual sums of squares obtained from the analyses of variance performed in conjunction with the regression can be separated into two components: (1) pure error or inherent variability of the property, and (2) lack of fit which results if the model is inadequate. In general, F tests performed for establishing the significance of the equation showed the regression to be significant. However, in several instances examination of the residual plots versus each of the independent variables indicated that the model could be improved. An excellent discussion on the importance and use of residuals for evaluating the adequateness of the regression model used is presented in Chapter 3 of Draper and Smith (1966).

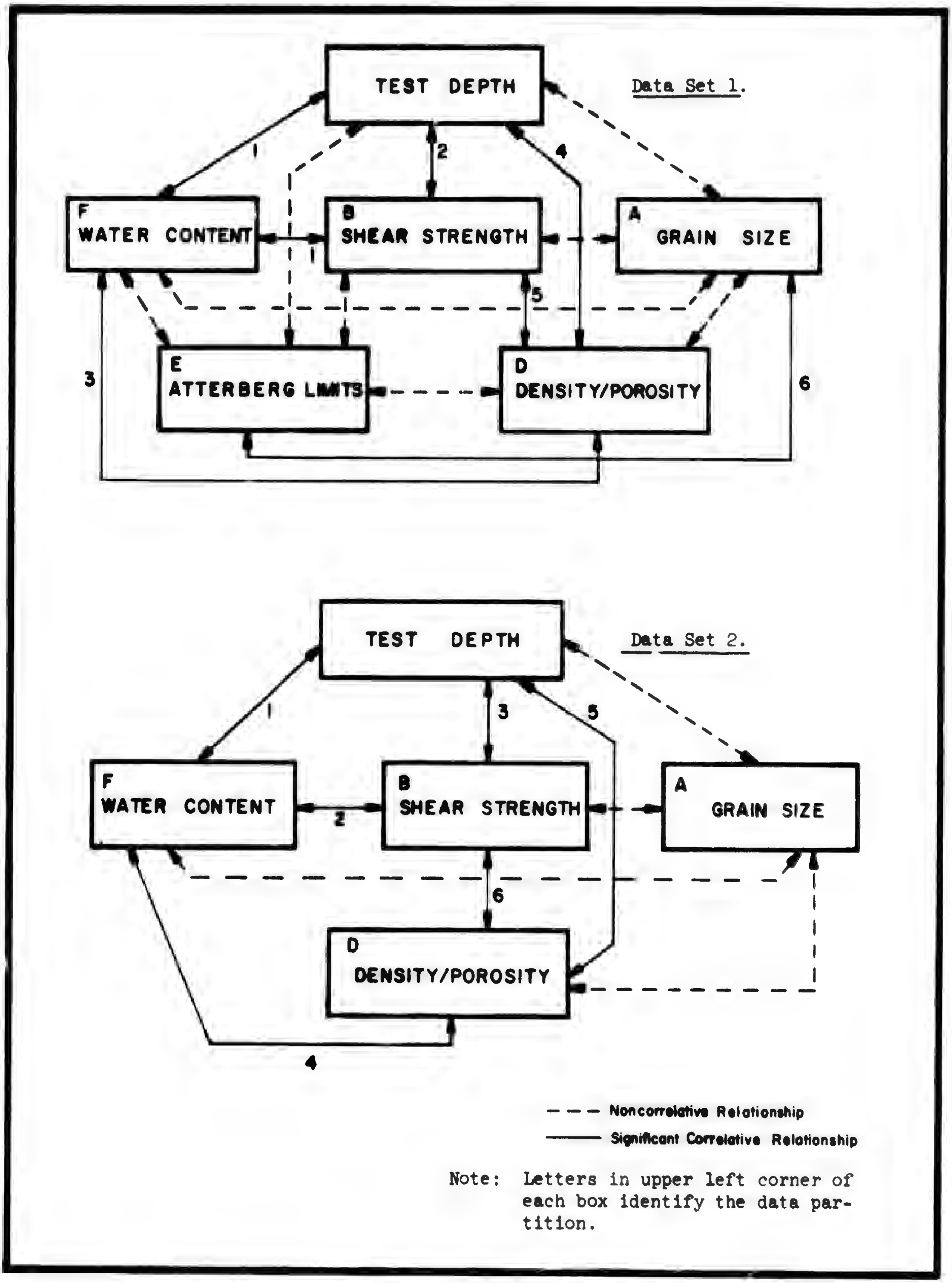
Results of Multiple Correlation

The best correlation matrix derived for each data set is presented in Tables F-1 through F-4, Appendix F. From these tables one can identify and rank pairs of variables with significant correlations, and also compare how the correlation coefficients for selected pairs of variables change between the various data sets.

An overall summary of the correlation results presented in Appendix F is provided by the four diagrams presented in Figures 11 and 12. Each diagram corresponds to one of the data sets described in Table 31. Significant correlations between data partitions are denoted by solid lines, and the numbers adjacent to the solid lines represent the order of importance. Dashed lines denote the absense of any significant correlations.

In all data sets, high correlations were always found between sediment properties within an individual data partition. This was expected, since the properties grouped in each partition are all closely interrelated and/or derived from the same laboratory test. For example, data partition A includes the following grain size parameters: median grain size diameter, Q_1, Q_3, percent sand, percent silt, and percent clay which are derived from the same cumulative frequency curve. Similarly, data partition D includes saturated unit weight, unit weight of solids, void ratio, and porosity which are all derived through arithmetic manipulation of two or three basic laboratory test results. Because of the high interrelationship between properties within each data partition, only one or two properties from each data partition were used in the regression analysis.

Multiple correlation results indicated that the sediment properties most highly related are laboratory vane shear strength (original and remolded), water content, and sediment depth. Correlation results for saturated unit weight and/or porosity versus water content are next in order of importance, and correlation results for the grain size distribution parameters or the Atterberg limits with the other sediment properties are of no statistical significance.



Note: Letters in upper left corner of each box identify the data partition.

Figure 11. Correlation Diagrams for Sediment Property Data Sets.

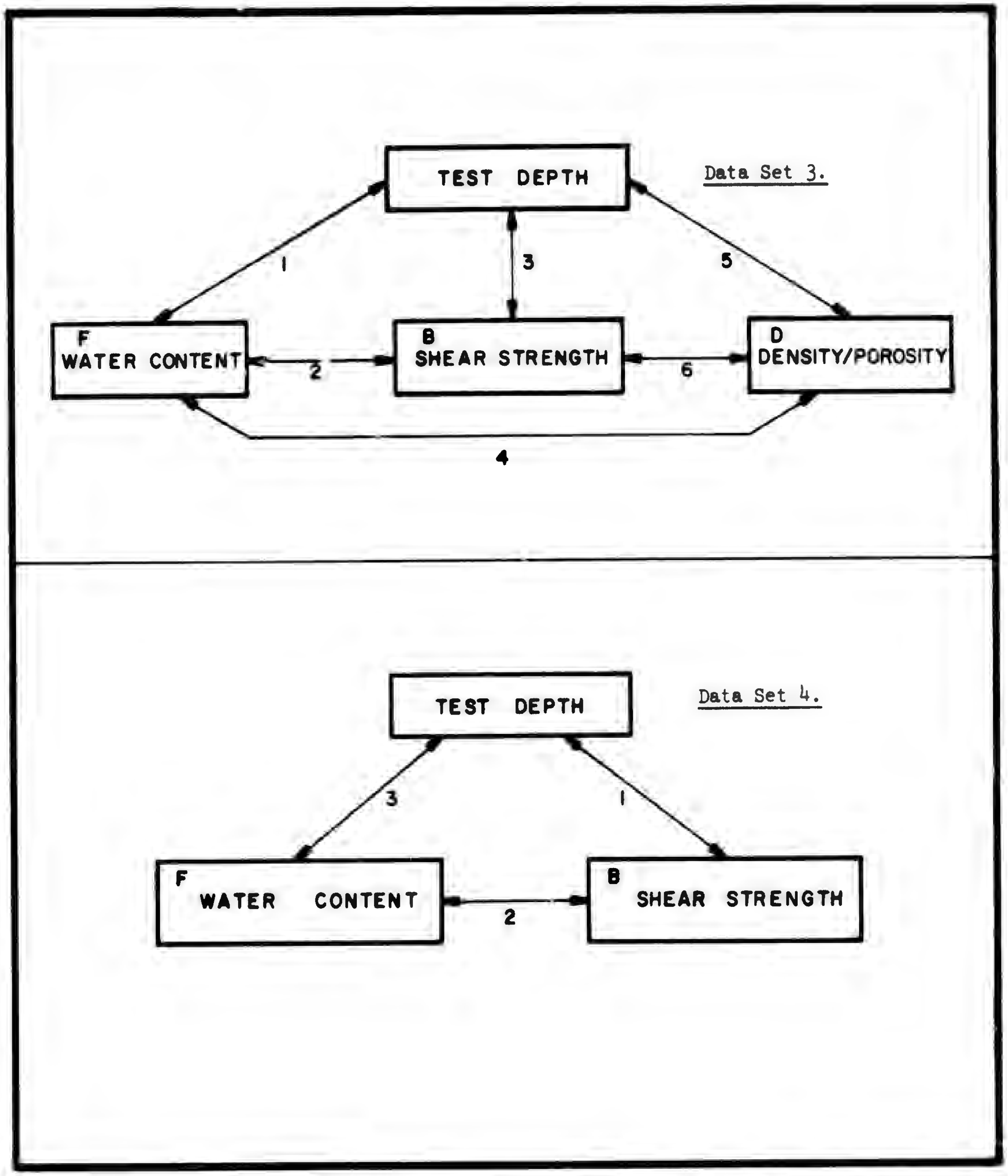


Figure 12. Correlation Diagrams for Sediment Property Data Sets.

Note that the relative magnitude of the correlation coefficient values changes from data set 1 to data set 4. These changes reflect the effects of increasing the number of measurements available for correlation purposes and also of having these measurements more evenly distributed throughout the sediment depth investigated. Since correlation results for grain size or Atterberg limits proved unimportant, the best correlation values for sediment properties in data partition D are obtained for data set 3 (Table F-3).

For sediment properties in data parttions B and F, best correlation values are obtained from data set 4 (Table F-4).

One interesting question arising from the consistent high correlations found between vane shear strength, water content, and sediment depth is which of the latter two variables is the best indicator of shear strength changes. Assuming that the type of sediment remains fairly uniform with sediment depth, an answer to this question was obtained for the sediment depth investigated by comparing the gradients for (1) shear strength versus sediment depth, (2) water content versus sediment depth, and (3) shear strength versus water content. Results demonstrated that in the upper 40 cm of sediment the large decreases in water content values makes the property a more sensitive indicator of shear strength changes. Below 40 cm sediment depth however, since the water content only changes very slightly, the sediment depth is a better indicator of shear strength changes.

Results of Regression Analysis

The best predictory equations for laboratory vane shear strength (original and remolded), water content, unit weight of saturated sediment, and porosity are presented in Tables 34 through 36. Within each data set two equations are usually presented for each sediment property, the first is based on the original variables measured, and the second is based on the variables after certain transformations. Although equations could have been derived for each of the 18 variables listed in Table 2, the regression analysis was restricted to those variables of greatest importance. Also, obtaining predictory equations for several of the variables would be meaningless in terms of physical processes or cause and effect relationships. The purposes of including the best equations for each data set are to enable:

TABLE 34. PROPERTY: LABORATORY VANE SHEAR STRENGTH - ORIGINAL

No.	Predictory Equations: $y = f(x_1, x_2, \ldots x_n)$	Multiple Correlation Coefficient (r)	Variation Explained by Regression (r^2)x100	Standard Error of Estimate	Significance of Regression	Data Set Use for Regression	Number of Measurements in Data Set
1	$Y = 159.4 - 0.8\ w$	.9236	85.3	6.4	Yes	A,B,D,E,F	25
2	$Y = 598.1 - 112.0\ \ln\ (w)$*	.9211	84.8	6.5	Yes	A,B,D,E,F	25
3	$Y = 79.8 + 1.0\ S_u(\text{rem}) - 0.4\ w$	.9387	88.1	6.8	Yes	A,B,D,F	116
4	$Y = 320.6 + 1.0\ S_u(\text{rem}) - 59.5\ \ln(w)$	.9431	88.9	6.6	Yes	A,B,D,F	116
5	$Y = 71.4 + 1.1\ S_u(\text{rem}) - 0.3\ w$	.9451	89.3	6.4	Yes	B,D,F	176
6	$Y = 286.4 + 1.1\ S_u(\text{rem}) - 53.3\ \ln(w)$	.9476	89.8	6.3	Yes	B,D,F	176
7	$Y = 4.9 + 1.1\ S_u(\text{rem}) + 0.3Z$	.9527	90.8	7.1	Yes	B,F	375
8	$Y = 229.3 + 1.1\ S_u(\text{rem}) - 41.8\ \ln(w)$	.9552	91.2	7.0	Yes	B,F	375
9	$\ln(Y) = 13.1 + 0.4\ln(S_u(\text{rem})) - 22\ln(w)$	.9652	93.6	0.227	Yes	B,F	375

LABORATORY VANE SHEAR STRENGTH - ORIGINAL (OMITTING REMOLDED SHEAR STRENGTH VARIABLE)

No.	Predictory Equations: $y = f(x_1, x_2, \ldots x_n)$	Multiple Correlation Coefficient (r)	Variation Explained by Regression (r^2)x100	Standard Error of Estimate	Significance of Regression	Data Set Use for Regression	Number of Measurements in Data Set
10	$Y = 602.8 - 112.2\ \ln(w)$	.8779	77.1	9.4	Yes	A,B,D,F	116
11	$Y = 161.3 - 0.8\ w$	.8613	74.2	10.0	Yes	B,D,F	176
12	$Y = 630.9 - 117.7\ \ln(w)$	.8809	77.6	9.2	Yes	B,D,F	176
13	$Y = 50.1 + 0.5Z - 0.2\ w$	.9168	84.0	9.4	Yes	B,F	375
14	$Y = 257.1 + 0.4Z - 46.5\ \ln(w)$	.9236	85.3	9.0	Yes	B,F	375

NOTE: Symbols used in equations correspond to variables listed in Table 2.
* $\ln = \log_e$
Regression results are significant at the 95% confidence level.

TABLE 35. **PROPERTY: LABORATORY VANE SHEAR STRENGTH - REMOLDED**

No.	Predictory Equations: $y = f(x_1, x_2, \ldots x_n)$	Correlation Coefficient (r)	Explained by Regression $(r^2) \times 100$	Standard Error of Estimate	Significance of Regression	Data Set Used for Regression	Number of Measurements in Data Set
1	$Y = 15.4 + 0.2Z - 5.9(^{Sd}/Cl) + 0.1\, S_u(nat)$	.7340	53.9	7.3	Yes	A,B,D,E,F	25
2	$Y = -1.3 + 0.5\, S_u(nat)$	.8945	80.0	4.8	Yes	A,B,D,F	116
3	$Y = -1.1 + 0.5\, S_u(nat)$	.9265	85.8	3.9	Yes	B,D,F	176
4	$Y = -0.5 + 0.5\, S_u(nat)$	.9228	85.2	4.7	Yes	B,F	375
	LABORATORY VANE SHEAR STRENGTH - REMOLDED (OMITTING ORIGINAL SHEAR STRENGTH VARIABLE)						
5	$Y = 180.7 - 48.2 \ln(w) - 14.1 \ln(Md)$	.8297	68.8	6.0	Yes	A,B,D,F	116
6	$Y = 308.7 - 57.8 \ln(w)$	.8121	66.0	6.0	Yes	B,D,F	176
7	$Y = 108.5 + 0.2Z - 19.6 \ln(w)$	.8450	71.4	6.6	Yes	B,F	375

Regression results are significant at the 95% confidence level.

TABLE 36. PROPERTY: WATER CONTENT

No.	Predictory Equations: $y = f(x_1, x_2, \ldots x_n)$	Correlation Coefficient (r)	Explained by Regression (r^2)x100	Standard Error of Estimate	Significance of Regression	Data Set Used for Regression	Number of Measurements in Data Set
1	$Y = 184.4 - 0.34Z - 0.59\ S_u(nat)$	.9642	92.9	5.165	Yes	A,B,D,E,F	25
2	$\ln(Y) = 5.25 - 0.004\ S_u(nat) - 0.003Z$	.9645	93.0	.0372	Yes	A,B,D,E,F	25
3	$Y = 189.2 - 0.4Z - 0.5\ S_u(nat)$	.9107	82.9	9.4	Yes	A,B,D,F	116
4	$\ln(Y) = 5.26 - 0.002(Z \cdot \gamma sat) - 0.003\ S_u(nat)$	.9280	86.1	.0576	Yes	A,B,D,F	116
5	$Y = 187.7 - 0.33Z - 0.58\ S_u(nat)$	.8949	80.0	9.53	Yes	B,D,F	176
6	$\ln(Y) = 5.26 - 0.0039\ S_u(nat) - 0.0017(Z \cdot \gamma sat)$	.9090	82.6	.0610	Yes	B,D,F	176
7	$Y = 216.7 - 0.4Z - 1.0\ S_u(nat)$	.8563	73.3	21.5	Yes	B,F	375
8	$Y = 211.1 - 0.8Z - 1.0\ S_u(rem)$	.8331	69.4	23.0	Yes	B,F	375
9	$\ln(Y) = 5.38 - 0.003Z - 0.006\ S_u(nat)$	.9066	82.2	.0098	Yes	B,F	375
10	$\ln(Y) = 5.52 - 0.019\ S_u(nat) + 0.001\ S_u(nat)^2$	.9303	86.5	.0867	Yes	B,F	375
11	$\ln(Y) = 5.79 - 0.002Z - 0.19\ \ln(S_u(nat))$	.9535	90.9	.0712	Yes	B,F	375
	PROPERTY: SATURATED UNIT WEIGHT						
1	$Y = 2.01 - 0.13\ \ln(w) + 0.006Z$	.8328	69.4	.0241	Yes	A,B,D,F	116
	PROPERTY: POROSITY						
1	$Y = 83.1 + 0.04Z - 0.05\ S_u(nat)$	.7164	51.3	1.92	Yes	B,D,F	176

Regression results are significant at the 95% confidence level.

(1) comparing the independent variables selected as most important in each regression analysis performed;

(2) comparing changes in the regression coefficients derived for each of the equations whenever the same independent variables were selected in alternate regression equations;

(3) comparing the variability explained by each regression equation and examining its improvement as the number of data entries increased; and,

(4) determining the relative accuracy of each of the equations for predicting a particular sediment property.

Equations listed include only those independent variables which provided the largest reduction in the unexplained variation. All other independent variables considered have been omitted since they added little improvement to the regression equation. In general, if all independent variables are included in the equation, an additional 5 - 10 percent reduction in the unexplained variation can be obtained.

Another reason for presenting the predictory equations with only one or two independent variables is to minimize the risk of confounding the regression results by considering highly interrelated independent variables. As stated in the correlation results, variables within each partition are highly correlated because they are derived from the same laboratory test. Therefore, if one indiscriminantly treats all variables as truly "independent:, the effectiveness of the regression analysis is seriously decreased and in many instances totally voided.

Vane Shear Strength (Original)

Equations derived for laboratory vane shear strength (Table 34) indicate that the remolded vane shear strength and water content are the most important independent variables to include for prediction purposes. In all data sets, regression results were improved by using the natural logarithms of the water content values instead of the original water content values. Also, in the best regression equation obtained (No. 9), both the original and remolded shear strength values were converted to natural logarithms. The improvement in the regression was anticipated since the logarithm transformation helped to correct the slope changes for the shear strength versus sediment depth profiles which were first noted in Part 1.

An example of the accuracy of different equations derived is presented below. Selecting the mean original shear strength of 14.9 g/cm^2 and water content value of 238 for the 0-10 cm test depth interval from Table E-1 and entering these values in equations 4, 6, and 8 provided the following three estimates for the original shear strength value:

Equations No.

4 $y = 320.6 + 1.0(14.9) - 59.5 \log_e(238) = 9.9$ g/cm^2

6 $y = 286.4 + 1.1(14.9) - 53.3 \log_e(238) = 11.1$ g/cm^2

8 $y = 229.3 + 1.1(14.9) - 41.8 \log_e(238) = 16.9$ g/cm^2

Comparing the above results with the average shear strength values of 14.9 g/cm^2 determined for this depth interval,one sees that equation 8 based on data set 4 provides the best estimates of the shear strength value, with an error of less than 15 percent.

A similar procedure can be used to examine the accuracy of the equations derived for the other sediment properties and to determine changes in the accuracy as one looks at different test depth intervals, or different test depth intervals sizes.

A second series of equations was obtained for the original shear strength parameter omitting results of the remolded shear strength tests (see equations 10 through 14). The purpose of this effort was to provide an alternate method of predicting shear strength and to assess the importance of the remolded tests.

The best predictory equation obtained (No. 14) is based on data set 4 and explained 85.3 percent of the variation using test depth and the natural logarithm of the water content as the independent variables.

A comparison of equations 9 and 14 shows that if the remolded strength is not included in the equation, the unexplained variation increases by approximately 8 percent. Thus, it appears that the remolded shear strength variable is of significant importance for accurately predicting the original vane shear strength.

Vane Shear Strength (Remolded)

Regression results for the remolded shear strength (Table 35) showed that the original vane shear strength was the most important independent variable to consider in the predictory equation. Other individual sediment properties considered as independent variables proved to be of no real importance in terms of reducing the unexplained variation. Equations 2 through 4 are essentially identical; however, since equation 4 is based on the largest number of measurements and explains 85.2 percent of the variation, it is considered the best equation.

Since in many instances it may be desirable to predict the remolded vane shear strength when the original vane shear strength is not available, a second set of equations was derived omitting the original strength results. These equations are shown in Table 35.

The best predictory equation (No. 7) was obtained from data set 4 and is a function of the test depth and water content variables. The total variation explained by the regression is approximately 71 percent.

Water Content

Predictory equations for the water content variables are presented in Table 36. Equation 11 obtained from data set 4 explains the greatest percent of variability (90.9%). Principal independent variables used in the equation are test depth and original vane shear strength. In this equation both the water content and the original vane shear strength values have been transformed by use of natural logarithms. Therefore, to obtain the correct or predicted water content value one must take the antilog of the solution to the equation.

Equations 7 through 10 also have been included in Table 36 for purposes of enabling predicting the water content value if

(a) transformation by natural logarithm is not desired (equation 7),
(b) original vane shear strength measurements are not available (equation 8),
(c) only the original vane shear strength is known (equation 10).

Saturated Unit Weight and Porosity

Predictory equations for the saturated unit weight and porosity are presented in Table 36. Regression results indicated that water content and test depth are the most important variables for predicting saturated unit weight. For the porosity equation, test depth and vane shear strength (original) are the most important independent variables.

Part 6. Development of Sampling Criteria

Variability results presented in previous study parts were analyzed further in this section to provide some insight into the efficient design of sampling programs for marine sediment properties. Although the specific results obtained are applicable primarily to the seafloor area studied, the sources of variability identified and the variance estimates obtained are useful for comparing the advantages of various types of sampling plans.

Two types of problems usually encountered by an investigator when planning a marine geotechnical sampling program include: (1) selecting the method to be used for drawing the sample from the population of interest, and (2) establishing the number of samples and/or tests required to describe correctly the parameters of the population. Considerable research has been done on both the theory and practice of sampling, and the literature on this subject is extensive. Readers are referred to Cochran (1963) for a thorough discussion of sampling problems and experimental design. Chapter 17 of Snedecor and Cochran (1967) covers some of the methods for selecting a sample and establishing the optimum allocation of resources. Chapter 7 of Krumbein and Graybill (1965) is particularly appropriate as it discusses sampling problems in the geological sciences.

In general, however, the type of information required to answer the above questions involves the following. Selection of the appropriate sampling method requires that the investigator defines the population to be sampled, selects the variables to be measured, and identifies the sources of variability of principal concern. An additional requirement of considerable importance is the determination of the statistical models that will be used to examine the data once collected; e.g., the design of the analysis of variance models.

To obtain some answers regarding the number of samples necessary to estimate accurately the population parameters requires that the investigator have some information on the variability of the population he is sampling. Usually this information is obtained from previous published data applicable to the seafloor area of interest or from a preliminary sampling survey, or from an intuitive guess. Surprisingly enough, in many instances a rough estimate of the variability of the population can indicate the approximate magnitude of the sampling effort required, thus suggesting to the investigator the appropriate course of action.

In the field of marine geotechnique, development of efficient sampling programs has not been feasible due to the limited information available on marine sediment properties, and to the fact that most published data fail to provide a statistical description of the variability of the data examined. At present, most seafloor sampling programs performed can be categorized under simple random sampling or systematic sampling methods.

In simple random sampling, the investigator assumes he knows very little about the population he is sampling, thus, locations of sampling stations and sediment depths at which tests are conducted are randomly selected. Although this method is designed to prevent biasing of the results, it does not insure that the best estimates of the sample mean and variances will be obtained, particularly if the sample means and variances change significantly with test depth, geographical coordinates, or another unknown variable.

Systematic sampling is often used when the investigator wants to evenly spread the location of the sampling stations in a grid for purposes of investigating trends, or when it is the least expensive way to collect the data.

In the following discussion, some methods are presented to aid the reader in using some of the published data for purposes of developing a more efficient sampling program. The methods presented apply to data from simple random samples, stratified sampling and nested sampling. Differences in these sampling methods will become clearer through the examples given.

Sample Size-Simple Random Samples

One of the simplest procedures for determining the number of samples required to accurately estimate the mean of a population is presented below. The procedure assumes that population has a normal distribution and that an estimate of the population standard deviation, σ, is known. As stated earlier, usually this estimate is available from previous sampling of this population, or from published results for other similar populations. Essentially, the procedure requires that the investigator defines the maximum error he can allow in his estimate of the population mean and that he expresses the allowable error in terms of confidence limits. Given this information, the size of the sample

N can be obtained as follows (Snedecor and Cochran, 1967, Pg. 517):

$$N = \left[t_{P(df)} \frac{s}{E}\right]^2 \qquad (6)$$

where $t_{\underline{P}(df)}$ = t - value from Student's t distribution for the probability (P) and the degrees of freedom (df).

s = standard deviation of sample.

E = allowable error for population mean (same units as population mean).

This particular method is extremely attractive for use with marine sediment data as more authors are beginning to provide standard deviations for the data analyzed.

An example will help to clarify its usefulness:

Example 1. Suppose one wishes to estimate for the San Diego Trough the mean in-place vane shear strength for the 0-130 cm sediment depth interval, at the 95 percent confidence level. Based on hypothetical engineering requirements, the maximum error allowable is set at ± 10.9 g/cm^2, which represents ± 20 percent of the mean in-place vane shear strength reported in Table 2. The estimate of the population standard deviation is also obtained from Table 2 and is equal to 27.7 g/cm^2. Solving for N:

$$N = \left[(1.96)^{*} \left(\frac{27.7}{10.9}\right)\right]^2 = 24.8 \text{ or } 25$$

* t_{value} from Student's t distribution for ∞ degrees of freedom, at the 95% confidence level.

The above results indicate that 25 samples randomly selected within the seafloor area studied and the upper 130 cm of sediment depth are necessary to insure that the population mean lies within $\bar{X} \pm 10.9$ g/cm^2 at the 95 percent confidence level. The $\bar{X}$ value in this case is equal to 54.4 g/cm^2 and is obtained from Table 2.

An interesting aspect concerning the relationship between sample size versus the magnitude of the error allowed is that in order to reduce the error of the population mean in half, the size of the sample has to be quadrupled.

For example, if the allowable error for the in-place vane shear strength population mean was reduced to 10% or 5.4 g/cm^2, the sample size, N, required increases to 101. This illustrates the importance of realistically defining the error that is tolerable for the population mean.

Estimating The Standard Deviation

When the standard deviations for the marine sediment data are not furnished, an estimate of the standard deviation for a population which is believed to have a normal distribution can be obtained by multiplying .24 times the range (R) of the sample (i.e., highest minus lowest value). Similarly, for a skewed distribution shaped similar to a right triangle, an estimate for the standard deviation is obtained by multiplying .21 times the range (Snedecor and Cochran 1967, pg. 517).

Sample Size-Stratified Random Samples

The above method can also be used to determine sample size requirements within discrete sediment depth intervals. The purpose of sampling by depth interval is to allow division of the population into sub-populations or strata that are less variable than the original population. This method is particularly useful when the population mean is known to change significantly with sediment depth, such as is the case for vane shear strength and water content. The sample statistics presented for the 10 cm, 20 cm, and 50 cm test depth intervals (Tables E-1 through E-6) typify results of a stratified sampling program. However, within each strata samples are still assumed to be randomly selected throughout the test area.

The advantages of stratified sampling for reducing the effort required to accurately estimate the population mean is illustrated in the next example.

Example 2. Suppose one needed to determine the sample size required to estimate the population mean for each of the sediment properties examined from the San Diego Trough at a 95% confidence level. For illustration purposes, only two depth intervals are of interest--the 0-50 cm, and 50-100 cm. Also, the maximum error allowable for each sediment property is arbitrarily set at 10% of the sample mean values listed in Table E-4 for the respective depth intervals.

Using the standard deviation values listed in Table E-5 and the allowable error for the mean of each sediment property, the following sample size requirements were obtained. Note that these results pertain primarily to sampling in the San Diego Trough. However, if sediment properties in another seafloor area were believed to be roughly the same, these results would provide a good first estimate of the sampling effort required (Table 37).

Table 37. Size of Sample Required for Estimating Means Within ± 10% Error

Sediment Property	Depth Interval 0-50 cm		Depth Interval 50-100 cm	
	Error Allowed(1)	No. of Samples(2)	Error Allowed	No. of Samples
In-Place Vane Strength	2.9	107	6.0	18
Lab Vane Strength (Original)	2.7	153	6.2	17
Lab Vane Strength (Remolded)	1.2	190	2.9	33
Water Content	17.6	20	12.5	2
Saturated Unit Weight	0.14	1	0.14	1
Unit Weight of Solids	0.25	1	0.25	1
Porosity	8.0	1	7.7	1
Median Grain Size	3.8×10^{-4}	22	3.6×10^{-4}	31

Note: (1) Same units as sediment property.

(2) Number of samples specified above would be obtained by simple random sampling techniques within the entire test area and sediment depth interval under consideration.

The above results demonstrate that if the allowable error is a function of the sample mean value for these two sediment depth intervals, then substantial reduction in the sampling effort can be accomplished for several sediment properties by using a stratified sampling technique. As an example, for the vane shear strength and water content variables the number of samples required between the upper and lower 50 cm intervals decreases by a factor of six.

In those cases where the allowable error is a fixed value regardless of the changes exhibited by sample means with depth, the above described procedure can be applied also.

Sample Size - Sampling in Stages

Multistage sampling was the principal technique employed in this study to enable answering the questions posed in the previous sections.

Basically, it involves sampling in a manner which will allow partitioning the total variability into the sources of variability of major concern. This type of sampling was first illustrated in Table 1. Among the advantages of this sampling method is that with fewer samples one can assess the variability introduced by several factors. Also, the data obtained can be examined using the analysis of variance technique and components of variance derived from the ANOVA can be used in conjunction with cost information to determine the most efficient sampling program.

An example is presented below to illustrate the advantages of this sampling method and the use of the components of variance for evaluating the relative merits of alternate sampling designs.

Optimal Allocation of Resources

In Table 28, the components of variance were presented for several of the sediment properties examined in this study. As an example, results given in ANOVA 35 identify the variability within a selected depth interval attributed to (1) station location effects, (2) core location effects, and (3) within core or replicate measurement effects. Assuming that additional sampling were to be performed in the San Diego Trough area, or in another similar seafloor area, the above information could be used to optimize the sampling program relative to cost or to the variability allowed (Snedecor and Cochran, pg. 531-33).

The equation for the cost of sampling at a station is:

$$C_T = c_1 n_1 + c_2 n_1 n_2 + c_3 n_1 n_2 n_3 \qquad (7)$$

where

C_T = Total cost

c_1 = Cost of occupying a station (other than coring and core testing operations)

c_2 = Cost of taking a core

c_3 = Cost of one measurement in a core

n_1 = Number of stations at which cores are taken
n_2 = Number of cores at each station
n_3 = Number of measurements in each core

In the above expression, the total number of measurements N is equal to $(n_1)(n_2)(n_3)$.

The equation for the estimated variance $s_{\bar{y}}^2$ of the sample mean within a depth interval is:

$$s_{\bar{y}}^2 = \frac{s_1^2}{n_1} + \frac{s_2^2}{n_1 n_2} + \frac{s_3^2}{n_1 n_2 n_3} \tag{8}$$

where

s_1^2 is the component of variance due to station location effects,
s_2^2 is the component of variance due to core location effects,
s_3^2 is the component of variance due to within core measurement effects.

Two types of problems can be solved from this information. First, if one specifies a desired variance V for the sample mean (V is analogous to the allowable error for the population mean described earlier), one can determine the least expensive way to attain this value. Second, if one specifies the maximum cost allowable C_T, one can determine the smallest variance that can be expected. Both of these problems have essentially the same solution and entail minimizing the product

$$VC_T = \left(\frac{s_1^2}{n_1} + \frac{s_2^2}{n_1 n_2} + \frac{s_3^2}{n_1 n_2 n_3} \right) c_1 n_1 + c_2 n_1 n_2 + c_3 n_1 n_2 n_3 \tag{9}$$

It can be shown that this expression has the smallest value when

$$n_2 = \sqrt{\frac{c_1 s_2^2}{c_2 s_1^2}} \quad \text{and} \quad n_3 = \sqrt{\frac{c_2 s_3^2}{c_3 s_2^2}} \qquad (10) \text{ and } (11)$$

n_1 is then found by solving either the cost or the variance equation.

Example 3. Assume one wishes to investigate the vane shear strength of sediments in the San Diego Trough at a selected depth interval. The problem is to design a sampling plan that will give the highest precision for the resources to be expended. For purposes of this example, assume that the total funds available for a sampling program are \$10,000. Also assume that, based on previous at-sea operations, the cost of occupying a station is \$500, the cost of taking a core is \$125, and the cost of performing a single vane test in the core sample is \$25.

Using the components of variance given in Table 28 for the laboratory vane shear strength (original) and equations (10) and (11) given earlier, the optimum number of samples required at each level can be obtained as follows:

The optimum number of measurements within a core is calculated to be

$$n_3 = \sqrt{\frac{c_2 s_3^2}{c_3 s_2^2}} = \sqrt{\frac{(125)(21.8)}{(25)\ (38.3)}} = \underline{1.76 \text{ or } 2}$$

Also, the optimum number of cores is

$$n_2 = \sqrt{\frac{c_1 s_2^2}{c_2 s_1^2}} = \sqrt{\frac{(500)(38.3)}{(125)(32.6)}} = \underline{2.17 \text{ or } 2}$$

solving the cost equation (7) for n_1

$$n_1 = \frac{10{,}000}{(500 + (125)(2) \ + (25)(2)(2))} = \frac{10{,}000}{850} = 11.76$$

$$n_1 = 12 \text{ stations}$$

Therefore, for the amount of money allocated, the most efficient sampling program involves occupying 12 stations, taking 2 cores per station, and making 2 measurements in each core at the sediment depth of interest. Location of stations is determined by subdividing the area to be investigated into smaller units of area of approximately equal size, and randomly selecting 12 subareas to be sampled. An assumption in the above plan is that the area to be sampled represents a single population. If the investigator suspects that there is more than one vane shear strength population within the area, then a sampling plan for each population has to be defined.

For the above sampling design, the expected variance of the mean vane shear strength is:

$$s_{\bar{y}}^2 = \frac{32.6}{12} + \frac{38.3}{(12)(2)} + \frac{21.8}{(12)(2)(2)}$$

$$s_{\bar{y}}^2 = 4.8, \text{ or } s_{\bar{y}} = 2.2 \text{ g/cm}^2$$

Note that the total cost of the sampling program using the n_1, n_2, and n_3 values obtained is equal to $10,200. This is a result of round-off error in having to use integers for n_1, n_2, and n_3.

Example 4. Changing the above problem slightly, assume that the problem is to design a sampling program such that the variance of the sample means for the vane shear strength is not to be greater than $(5.4 \text{ g/cm}^2)^2$. The individual cost estimates listed above still apply, however, the total cost of the program is not known.

Using the variance equation (8) and the values for n_2 and n_3 derived earlier, one can calculate the new n_1 value:

$$29 = \frac{32.6}{n_1} + \frac{38.3}{n_1(2)} + \frac{21.8}{n_1(2)(2)}$$

$$n_1 = \frac{57.2}{29} = 1.97 \text{ or } 2$$

Therefore, if one takes 2 stations, 2 cores per station, and 2 measurements per core, the standard deviation of the sample mean will be 5.4 g/cm². The cost of this sampling design can be evaluated using equation (7) given earlier.

$$C_T = (500)(2) + (125)(2)(2) + (25)(2)(2)(2)$$

$$C_T = \$1,700$$

A comparison of the costs for sampling design used in Example (3) versus Example (4) illustrates the importance of establishing how accurately the sample means need to be known. In this example, by allowing the standard deviation of the sample mean to increase from 2.2 g/cm^2 to 5.4 g/cm^2, the sampling program required is only one-fifth as expensive.

The above examples demonstrate the advantages of sampling in stages and the importance of the components of variance for the development of an efficient sampling program.

SECTION 4. SUMMARY AND CONCLUSIONS

A comprehensive analysis of the variability of marine sediment properties from a deep ocean depositional environment was performed in this study. Although the results were obtained through analysis of sediments in the San Diego Trough test area, a practical approach was developed that is applicable for examining seafloor sediment properties in other sedimentary environments.

The study has shown that it is feasible to assess the major sources of variability in marine sediment properties through the proper design of a sampling and laboratory testing program, and the selection of appropriate statistical models for data analysis. One important requirement for the efficient analysis of large quantities of marine sediment data is the availability of a general purpose computer data management system capable of manipulating and interfacing the sediment data with widely used statistical programs. Such a data management system was developed for this study and should have broad application for the processing of marine sediment property data.

The use of a submersible capable of recovering high quality cores and performing in-place vane shear strength measurements was particularly advantageous. This approach provided the unique opportunity to select the precise location of sampling stations, and to obtain replicate cores, replicate in-place vane tests, and paired core and in-place measurements. Replicate and paired samples were essential for assessing the principal sources of variability, and for comparing the laboratory and the in-place vane test methods.

Conclusions Pertaining to The Study Approach

1. Sampling in stages was shown to be the best approach for collecting the sediment data necessary to evaluate major sources of variability in the San Diego Trough area.
2. Determination of sample description statistics for each sediment property as a function of test depth interval was found to be a valuable aspect of the overall data review. This approach enabled 1) comparison

of sample means and variances, 2) identification of sample mean and variance trends, 3) preliminary identification of regression models, and 4) preliminary estimates of sample size requirements.

3. The statistical methods found to be most applicable for the detailed examination of the sediment properties considered included analysis of variance techniques and linear multiple stepwise regression analysis. In particular, nested analysis of variance techniques were extensively used to identify important sources of variability and to provide estimates of the components of variance which are essential for the design of efficient sampling programs.
4. Use of the UCLA (BIOMED) multiple stepwise regression program proved advantageous because of its capability to 1) examine large numbers of independent variables, 2) perform numerous transformations and generation of new variables from the original data, and 3) plot the residuals.
5. Finally, development of a versatile computer data management system facilitated the efficient sorting, retrieving, and interfacing of sediment data with major statistical routines.

Conclusions Pertaining to the San Diego Trough Sediment Properties:

1. Grain Size Distribution - In the San Diego Trough area examined, the sediment within the upper 1.2 meters is classified as clayey silt. Analysis of grain size distribution demonstrated that particle size does not change significantly in either lateral or vertical directions. Of the total variability measured, the largest portion (60%) is contributed by micro-areal effects (i.e., within station differences). Evidence of the large variability in samples tested from the same station was also shown by the large uncertainty determined for a single grain size determination.

   It was determined from the above results that an increase in the accuracy of the mean median grain size requires more replicate cores within a station and replicate testing (sample splits) within each core. Results also suggest that the procedure employed for grain size determinations (i.e., hydrometer method) may be a source of inconsistent results.

2. Water Content - Profiles for the water content sample means demonstrated that this property decreases logarithmically with sediment depth, and that the greatest water content changes occur in the first 0.6 m. The best equation derived for predicting water content (expressed as the natural logarithm) is a function of test depth and the natural logarithm of the original vane shear strength (Equation 11, Table 36). This equation explained approximately 91% of the total variation measured in the upper 1.2 meters of sediment. Analysis of variance results showed that over the entire test depth range 78% of the variability determined for this property is contributed by test depth effects. However, within discrete depth intervals the variability contributed by micro-areal effects (within sampling stations) was found to be the most important source of variability. Macro-areal effects throughout the test area at similar depths were shown to be of minor importance.

   These results show that minor local variations in the sediment, combined with differences in the water content values resulting from inconsistencies in testing at the identical sediment depth, can cause larger uncertainties than those contributed by areal effects. To obtain better estimates of the mean water content value for a selected depth, laboratory tests should be performed at the same sediment depth. This is particularly important in the upper 0.6 m where the water content changes rapidly. Results also indicate that replicate coring, and replicate tests within cores should be performed to reduce the variability introduced by local effects.

3. Vane Shear Strength - Results of laboratory vane shear strength measurements (original and remolded) correlated highly with sediment depth and water content. Regression analysis for the original vane shear strength demonstrated that approximately 85% of the total variability in the upper 1.2 meters is associated with test depth and water content changes.

   These results were also confirmed by the analysis of variance conducted on the in-place and laboratory vane shear strength measurements. Components of variance for each of the properties showed that approximately

84% of the total variability determined is contributed by test depth differences. Within discrete depth intervals however, the variability contributed by micro-areal effects and the testing technique are the major factors to consider.

The above findings suggest that the test depth effects are the primary factor to consider when attempting to reduce the variance of the vane shear strength sample mean. Furthermore, when estimating the mean within a discrete depth interval greater attention should be given to the micro-areal variability. This source of variability can be reduced by replicate sampling and replicate testing of core samples.

Despite the small magnitude of the variability attributed to macro-areal effects, analysis of variance results indicated that significant differences exist in the laboratory vane shear measurements between some of the sampling stations. Contouring of the in-place and laboratory vane shear strength at three separate depth intervals showed that lower shear strength values exist along a NE-SW diagonal band which bisects the test area. Shear strength values increase with distance from both sides of this low strength band (Figures 9-10). Partly because the greatest number of vane measurements were made in central and eastern portions of the test area, the indicated trends are somewhat tentative and would require additional data for confirmation.

4. Saturated Unit Weight - This sediment property was shown to correlate best with sediment depth and water content. Descriptive statistics showed that in the upper 1.2 meters the saturated unit weight linearly increases with sediment depth in the first 0.6 meters, but remains nearly constant below this depth.

   The above relationships were confirmed by the results of the regression analysis which selected the water content and sediment depth as the two most important independent variables for predicting saturated unit weight.

   Analysis of variance results indicated that approximately 85% of the total variability is contributed by test depth effects; micro-areal differences and testing technique effects were determined to be of minor consequence. It is therefore concluded that within discrete depth intervals the saturated unit weight represents a single population throughout the sampled area.

Analysis of the test method variability of saturated unit weight (Table 18, Part 2) showed that the results from tests performed on cores from the same station are more consistent than those of other sediment properties.

5. Porosity and Void Ratio - Since these properties are calculated from results of the laboratory test for saturated unit weight, sources of variability for these properties are the same as for the saturated unit weight.

   Excluding test depth effects, both of these properties represent a single population throughout the area. Correlation results indicated that porosity and void ratio are related to the water content, sediment depth, and shear strength. Regression results for porosity indicated that the best predictory equation is a function of test depth and original vane shear strength (Table 36).

Conclusions Pertaining to Different Test Methods

Results of this study demonstrated that over the sediment depth range examined the laboratory and the in-place vane shear strength tests provided nearly identical results. Statistical analysis of a large number of paired measurements showed that at the 99% confidence level, there is no significant difference between the two test methods. Thus, laboratory vane test results on these cores accurately represent the field conditions. These findings indicate that disturbance effects in DEEP QUEST cores due to coring, pressure and temperature changes, if they exist, are not significant when final results are compared. Changes in the test results due to differences in the in-place and laboratory testing techniques used are also not detectable.

Recommendations for Future Work

The ultimate goals of these research efforts are to obtain the information necessary to understand and predict the variability of sediment properties in major depositional environments, and to determine the accuracy with which laboratory test results represent the actual field conditions.

1. Inasmuch as the majority of sediment property data resulting from various studies is obtained through the use of surface coring techniques as opposed to the highly specialized investigations undertaken by submersibles, the unknown sediment disturbance factors associated with the use of surface coring devices should be determined. It is essential to evaluate the accuracy of sediment property data resulting from these studies in order to determine actual in-place conditions, and to assess sediment property variability in other depositional environments.

   Evaluation of the uncertainties in widely used surface corers would involve a planned sampling program using a few of these devices in the now defined San Diego Trough test area, and comparing the results of sediment property tests conducted in these cores with the information available in the Geotechnical Data Bank.

2. After establishing the differences in the various sampling devices, the coring system producing the most reliable results should be used for pilot sampling studies in other major depositional environments. As shown in this study, taking replicate samples at a small number of stations can provide an adequate estimate of the existing variability. Such an approach would not only facilitate better design of future sampling plans, but would also provide a standard for comparing sediment property measurements taken in other areas or with other devices.

REFERENCES

Bennett, R. H., G. H. Keller, and R. F. Busby, Mass property variability in three closely spaced deep-sea sediment cores, *J. Sediment. Petrol.*, 40, 1038-1043, 1970.

Carius, T., and A. F. Richards, Lehigh University, Bethlehem, Pa.

Carlson, L., Determination *in-situ* of the shear strength of undisturbed clay be means of a rotating auger, *Proc. Second Annual Int'l. Conf. on Soil Mechanics and Foundation Engineering*, 1, 265-270, 1948.

Cochran, W. G., *Sampling Techniques*, John Wiley and Sons, New York, 1963.

Draper, N. R., and H. Smith, *Applied Regression Analysis*, John Wiley and Sons, New York, 1966.

Emery, K. O., W. C. Butcher, R. H. Gould, and F. P. Shepard, Submarine geology off San Diego California, *J. Geology, 60* (6), 511-548, 1952.

Garcia, W. J. Jr., Literature survey and bibliography of engineering properties of marine sediments, Univ. of Calif., Berkeley, Hydraulic Engineering Laboratory, Rept. HEL-2-27, 1971.

Halwachs, J. E., Analysis of sediment shear strength at varying rates of shear, TSPR No. 28, U.S. Naval Academy, Annapolis, Md., 1972.

Hamilton, E. L., Sound velocity, elasticity, and related properties of marine sediments, North Pacific, I. Sediment properties, environmental control, and empirical relationships, TP 143, Naval Undersea Research and Development Center, San Diego, Calif., 1969a.
II. Elasticity and elastic constants, TP 144, 1969b.
III. Prediction of *in-situ* properties, TP 145, 1969c.

Hamilton, E. L., Sediment and sound velocity measurements made *in situ* from bathyscaph *Trieste*, *J. Geophys. Res.*, 68,(21), 5991-5998, 1963.

Hirst, T. J., Vertical variability of sediment shear strength, *Marine Technology Soc. Jour.*, 7 (1), 21-24, 1973.

Holmes, C. W., and H. G. Goodall, The prediction of strength in the sediments of St. Andrews Bay, Florida, *J. Sediment Petrol.*, 34(1),

Inderbitzen, A. L., and F. Simpson, A study of the strength characteristics of marine sediments utilizing a submersible, in *Underwater Soil Sampling, Testing and Construction Control*, STP 501, 204-215, Amer. Soc. for Testing and Materials, Philadelphia, 1972.

Inderbitzen, A. L., and F. Simpson, Relationships between bottom topography and marine sediment properties in an area of submarine gullies, *J. Sediment. Petrol.*, 41 (4), 1126-1133, 1971.

Inderbitzen, A. L., F. Simpson, and G. Goss, A comparison of *in-situ* and laboratory vane shear measurements, *Marine Technology Soc. Jour.*, 5 (4), 24-34, 1971.

Keller, G. H., and R. H. Bennett, Variations in the mass physical properties of selected submarine sediments, *Marine Geology*, 9 (3), 215-223, 1970.

Krumbein, W. C., and F. A. Graybill, *An Introduction to Statistical Models in Geology*, McGraw-Hill, San Francisco, 1965.

Miller, R. L., and J. S. Kahn, *Statistical Analysis in the Geological Sciences*, John Wiley and Sons, New York, 1962.

Noorany, I., Underwater soil sampling and testing, in STP 501, 3-41, Am. Soc. for Testing and Materials, Philadelphia, 1972.

Noorany, I., and S. F. Gizienski, Engineering properties of submarine soils, state-of-the-art review, *J. Soil Mechanics and Foundation Div.*, *ASCE*, 96 (SM5), 1735-1762, 1970.

Perlow, M. Jr., and A. F. Richards, Geotechnical variability measured in place from a small submersible, *Marine Technology Soc. Jour*., 7 (4), 27-32, 1973.

Richards, A. F., and G. H. Keller, Water content variability in a silty clay core from off Nova Scotia, *Limnology and Oceanography*, 7 (3), 426-427, 1962.

Shepard, F. P., and G. Einsele, Sedimentation in the San Diego Trough and contributing submarine canyons, *Sedimentology*, 1, 81-133, 1962.

Shepard, R. P., Nomenclature based on sand-silt-clay ratios, *J. Sediment. Petrol*. 24 (3), 151-158, 1954.

Simpson, F., A. L. Inderbitzen, and A. Singh, Initial penetration and settlement of concrete blocks into marine sediments, in *Deep Sea Sediments: Physical and Mechanical Properties*, edited by A. L. Inderbitzen, Plenum Press, New York, 1974.

Simpson, F., and A. L. Inderbitzen, Shear strength and slope stability of marine sediments in a gullied area, *UNESCO/NSF/Univ. Washington Proceedings of the International Symposium on the Engineering Properties of Sea-Floor Soils and their Geophysical Identification*, Seattle, Wn., July 25, 1971.

Snedecor, G. W., and W. G. Cochran, *Statistical Methods*, Iowa State Univ. Press, Ames, Iowa, 6th ed., 1967.

Sokal, R. R. and F. J. Rohlf, *Biometry*, W. H. Freeman and Co., San Francisco, 1969.

Anonymous, BMD Computer Programs, UCLA Publication in Automatic Computation No. 2 (1968) and X-Series Supplement No. 3 (1969). Health Sciences Computing Facility, Dept. of Biomathematics, University of California at Los Angeles, California, 90024.

Table A-1. Summary of LMSC Geotechnical Data Collected in The San Diego Trough Using DEEP QUEST

Station No./ DEEP QUEST Dive	Latitude Longitude	Depth[a] (meters)	Lockheed Equipment Vane Test	Lockheed Equipment Core No.	Year Collected
1-111	32°33.9'N 117°27.3'W	1230	1[b]	22	1970
1-112	32°34.1' 117°27.7'	1234	2,3,4,5,6	23,24,25,26,27[c]	"
1-114	32°33.9' 117°27.3'	1230	---	28	"
2-114	32°34.1' 117°28.0'	1230	---	29[c]	"
1-121	32°34.1' 117°28.0'	1230	7	---	"
1-122	32°33.9' 117°27.3'	1230	8	---	"
1-124	32°33.9' 117°27.3'	1230	---	30,31	"
2-124	32°33.9' 117°27.4'	1235	9	32	"
3-124	32°33.9' 117°27.6'	1235	10	33	"
4-124	32°33.8' 117°27.8'	1236	11	34	"
5-124	32°33.9' 117°27.3'	1240	12	---	"
1-135	32°33.9' 117°27.3'	1230	13	35	1971
2-135	32°33.8' 117°27.4'	1231	14	---	"
1-136	32°33.9' 117°27.6'	1234	---	36	"
2-136	32°34.1' 117°28.0'	1230	---	37	"
1-137	32°33.4' 117°27.3'	1236	---	38	"
2-137	32°33.0' 117°27.1'	1236	---	39,40	"
1-138	32°33.8' 117°27.7'	1239	---	41,42	"
2-138	32°33.8' 117°28.3'	1240	---	43,44,45	"
3-138	32°33.2' 117°28.8	N.A.	f	f	"

Preceding page blank

Table A-1 (Cont)

Station No./ DEEP QUEST Dive	Latitude Longitude	Depth[a] (meters)	Lockheed Equipment		Year Collected
			Vane Test	Core No.	
1-139	32°34.4' 117°27.5'	1325	f	f	1971
2-139	32°34.9' 117°28.0'	1325	f	f	"
3-139	32°35.4' 117°27.4'	1325	f	f	"
1-146	32°33.9' 117°28.6'	1219	---	52,53,54	1972
1-150	32°33.9' 117°27.3'	1230	---	(55),56[d],57[e] 58[e],(59),60[d]	
1-151	32°33.8' 117°27.4'	1219	15	(61)	"
2-151	32°33.8' 117°27.4'	1250	16	(62),(63)	"
3-151	32°33.2' 117°28.8'	1250	17	(64)	"
4-151	32°33.1 117°28.0'	1234	18	(65)	"
1-152	32°33.6' 117°27.9'	1250	19	(66),(67)	"
2-152	32°33.3' 117°28.4'	1250	20	(68),(69)	"
3-152	32°33.0' 117°28.9'	1250	21	(70),(71)	"
1-153	32°33.5' 117°29.3'	1210	22	(72),(73)	"
2-153	32°33.5' 117°29.9'	1210	23	(74),(75)	"
3-153	32°33.5' 117°30.6'	1219	24	---	"
1-154	32°34.5' 117°28.0'	1250	---	76	"
2-154	32°35.0' 117°28.1'	1244	---	77	"
3-154	32°34.9' 117°28.8'	1244	---	78	"
4-154	32°34.9' 117°29.3	1247	---	79	"

Table A-1 (Cont)

Station No./ DEEP QUEST Dive	Latitude Longitude	Depth[a] (meters)	Lockheed Equipment Vane Test	Lockheed Equipment Core No.	Year Collected
5-154	32°34.8' 117°29.8'	1249	---	80	1972
1-166	32°33.4' 117°27.3'	1221	f	f	"
2-166	32°32.8' 117°27.9'	1226	(33)	(103),(104)	"
3-166	32°32.5' 117°28.5'	1223	34	(105),(106)	"
4-166	32°32.4' 117°29.1'	1219	35	(107),(108)	"
1-167	32°34.4' 117°29.5'	1234	(36)	(109),(110)	"
2-167	32°34.3' 117°30.3'	1234	37	111,112	"
3-167	32°34.3' 117°30.7'	1230	38	(113),(114)	"
1-168	32°33.1' 117°29.2'	1233	39	---	"
2-168	32°32.5' 117°29.5	1234	40	---	"
3-168	32°32.8' 117°30.2'	1235	41	---	"
2-175	32°35.4' 117°28.4'	1216	---	(115),(116)	July/August 1973
1-178	32°35.1' 117°30.2'	1217	42,43,44, 45,46,47	---	"
1-179	32°35.0' 117°30.3'	N/A	---	117,118,119 120,121,122	November 1973
1-180	32°34.4' 117°29.7'	1234	---	123,124	"
2-180	32°33.6' 117°30.1'	1231	---	125,126	"
3-180	32°33.2' 117°30.4'	1234	---	127,128	"
1-181	32°33.0' 117°28.4'	1234	---	129,130	"
2-181	32°33.9' 117°28.6'	1220	---	131,132,133	"
1-182	32°34.8' 117°29.1'	1219	---	134,135	"

Table A-1 (Cont)

a - Depth measured from DEEP QUEST

b - Penetration test only

c - Cores given to UCLA

d - Cores badly disturbed - not used in analysis

e - Cores not tested

f - Dive devoted to Lehigh University, LMSC geotechnical equipment inoperative

NOTE:

1. Number in parenthesis indicate that replicate vane tests were conducted in these cores or at these test stations.
2. In-place tests 2, 3, 4, 5, 6 are approximately 6.1 meters apart.
3. In-place tests, 42, 43, 44, 45, 46, 47 are approximately 6.1 meters apart.
4. Legend of test stations at Site 1 and Site 2:

   Site 1 includes stations 1-111, 1-114, 1-122, 1-124, 1-135, 1-150 which are within a 12 meter radius of the location marker.

   Site 2 includes stations 2-114, 1-121, 2-136 which are within a 6 meter radius of the location marker.
5. All cores collected during November 1973 dives have not been tested yet.

Laboratory Test Procedures

As stated in Section 1, laboratory testing procedures used in this study are in general agreement with accepted standard methods. However, because different core handling operations and methods for determining sediment properties have been compared, some further description of these techniques seems appropriate.

Core Handling

The possibility of core disturbance could be observed at several stages between sampling and laboratory testing. These were while experiencing difficulty during sampling, after jarring of cores during handling on deck, upon initial inspection aboard ship, in the laboratory before testing, and upon extrusion for testing.

Cores numbered through 66 were tested or subsampled in the core barrel without extrusion. A fresh core section was exposed for testing by cutting through the coring tube with a hot wire and removing the overlying section of coring tube containing the previously tested sediment. The faster method of extruding the sediment upward after each test to the next test level, and removing the sediment above the top of the coring tube was established at core 67.

Laboratory Vane Shear

Sediment strength was tested with a laboratory vane shear device manufactured by Wykeham-Farrance Engineering, Ltd. The vane blades are 1.27 cm in length and width, and the vane was inserted with its shaft parallel to the longitudinal axis of the sediment core. Shear strength was computed from shearing resistance by the usual formula (Carlson, 1948).

Before modification of the laboratory vane shear device, the motorized vane rotated at 6 degrees/minute and the shearing resistance was computed from the torsion developed in a standard factory-calibrated spring. After modification, the vane tests were run at a rate of 48 degrees/minute, and the shearing resistance was determined from the output of an electrical strain

Preceding page blank

guage. The strain guage was calibrated before testing began on each new group of cores. This change in methods took place after core 34. Remolded tests were performed in each of the above methods by manually turning the vane through several revolutions without changing the vane position within the sediment mass, and then immediately retesting the shearing resistance.

Water Content

Water content was determined from the weight of samples before and after drying for 24 hours at 105°C. It is defined as the weight loss (water) in drying divided by the dry sample weight, expressed as a percentage. Results have been corrected for salt content by assuming a pore water salinity of 35 ppt.

Unit Weights

Before acquiring the gas-comparison pycnometer, saturated unit weight was determined from the weight of an 80 cm^3 sample obtained by pushing a stainless steel ring into the core. Dry unit weight (grain density), was computed from the above test by assuming grain interstices to be completely filled with 35 ppt sea water (100 percent pore water saturation).

In later testing using helium gas and the pycnometer, the volume of a known weight of dry sediment was measured directly.

Porosity and Void Ratio

The values for both porosity and void ratio were computed from water content and density measurements by assuming 100 percent pore water saturation.

Grain Size Analysis

All grain size determinations were made according to the ASTM technique of wet seiving the total sample through a standard 0.062 mm seive followed by hydrometer analysis of the fine fraction. Differences existing in the comparative tests were due only to preparation of the samples for wet seiving. Early samples were washed several times by stirring the sample with distilled water, allowing time for settlement, and decanting the supernatant wash water.

In addition, samples that had been oven-dried prior to size analysis were broken up with mortar and pestle prior to seiving. The innovation of washing the salts from samples by allowing them to diffuse into distilled water at a temperature just less than 100°C reduced the possibility of sample loss during decantation of wash water. Because this process also softened dried samples, grinding became unnecessary. After comparative tests the technique was adopted for all grain size determinations.

APPENDIX C

1) Data Format and Data Entry
2) Core Summary Data Card Format
3) Laboratory Core Analysis Remarks Key
4) In-Place Data Card Format
5) In-Place Test Remarks Key
6) Data Record Structure

1. DATA FORMAT AND DATA ENTRY

All data from in-place vane shear measurements and from the laboratory testing of the cores recovered were reviewed, cataloged, organized, and prepared for key punching onto standard 80 column Hollerith cards. The data were keypunched in a format which allowed their being later read by a large scale digital computer for generation of data files. The types and number of parameters obtained from the in-place tests and the laboratory analyses of the cores required two somewhat different format styles for data entry. These specially designed formats are given under the Core Data Card Format and the In-Place Data Card Format sections.

A brief description of these formats follows. The first card for each core includes the core number, special case flag, station number, dive number, project titles, date and location of sampling station, water depth and core length. The first card for each series of in-place tests includes the test number, special case flag, station number, dive number, project title, date and location of the test series, water depth and number of corresponding cores.

Following the first card for either the core or the in-place data decks are two cards into which remarks and other supplementary data are punched. Certain phrases which are used repeatedly to describe test conditions have been assigned a code letter to avoid repetitious key punching and to obtain more efficient utilization of card space and computer storage. All pertinent code characters are entered as a block into the leading portion of the first remarks card, the first occurrence of a space is used as the delimiter for the coded phrases. The cards containing the measured parameters of the in-place shear strength data or the results from the laboratory analyses of the cores then follow the second remarks card.

For the in-place data set, the next cards are those containing the in-place shear strength data which contain the sediment test depth and the corresponding shear strength values. These cards are followed by a set of cards describing cores recovered close to the in-place vane shear test location.

Each of these cards lists the core number, station number, dive number, distance and true bearing from the in-place series to that core, and the core length.

The wider variety of measurements available from the core analyses necessitated special consideration in the design of data card format and data storage. The concept of data partitions was introduced for the storage of these values from the laboratory core analyses. Since certain tests were always done together at identical depths, it was efficient to group parameters into six data partitions. For convenience, these are called "Partition A" through "Partition F". A partition is defined as a data set of certain collections of parameters and their correspondent core depth (in cm). A list of the sediment properties included in each partition is presented in the Core Summary Data Card Format section.

The concept of partitions was incorporated for efficiency of data entry and storage procedures. The partition concept also allows for growth in that future parameters not now allowed for can be added to the standard data record block as additional partitions. This would not affect those partitions now in use in the data file, nor necessarily change the size or format of the existing record block of the file.

As part of the overall data file management and processing system, certain programs were written which pack, unpack, retrieve, and store data within the standard records block formats. Examples of computer outputs for core and in-place data are presented in Appendix D.

2. CORE SUMMARY DATA CARD FORMAT

CARD 1:

Data Item	Format Fortran	Type of Element	Card Columns
1. Core Number	I4	Integer	1-4
2. Special Case Flag	A1	Alpha	5
3. Station Number	I5	Integer	6-10
4. Dive Number	I5	Integer	11-15
5. The word: "CORE"	A4	Alpha	17-20
6. Project Title	5A4*	Alpha	21-40
7. Month	A4	Alpha	41-44
8. Day	I2	Integer	46-48
9. Year	I2	Integer	49-51
10. Lat. Deg	I2	Integer	52-54
11. Lat. Tenths of Min	F5.1	Real Float	55-59
12. Hemisphere (North or South)	A1	Alpha	60
13. Long. Deg	I2	Integer	62-64
14. Long. Tenths of Min	F5.1	Real Float	65-69
15. Hemisphere (East or West)	A1	Alpha	70
16. Water Depth (meters)	I5	Integer	71-75
17. Core Length (cm)	F5.0	Real Float	76-80

*Adjustable to comply with computer word size. The above is for an IBM 360. For an 1108 the format 4A5 may be more efficient, although to maintain Program compatibility the 1108 can use 5A4 with no difficulty.

The format of the remainder of each data partition card is as shown below. Note that all fields in these areas are read by Fortran format F10.3

Partition	Data Item	Field 1 Card Column	Field 2 Card Column	Field 3 Card Column
A	Depth (cm)	11-20		
	Grain Size (mm)	21-30		
	Q_1 (mm)	31-40		
	Q_3 (mm)	41-50		
	Sd (%)	51-60		
	St (%)	61-70		
	Cl (%)	71-80		
B	Depth (cm)	11-20	41-50	
	Vane (original) (g/cm^2)	21-30	51-60	
	Vane (remolded) (g/cm^2)	31-40	61-70	
C	Depth (cm)	11-20	41-50	
	Cohesion (gm/cm^2)	21-30	51-60	
	Phi (degrees)	31-40	61-70	
D	Depth (cm)	11-20		
	Den. Sat (g/cm^3)	21-30		
	Den. Solids (g/cm^3)	31-40		
	Den. Submerged (g/cm^3)	41-50		
	n (porosity)	51-60		
	e (void ratio)	61-70		
E	Depth (cm)	11-20		
	W_P (%)	21-30		
	W_L (%)	31-40		
	I_P (%)	41-50		
F	Depth (cm)	11-20	31-40	51-60
	Water Content (%)	21-30	41-50	61-70

CARD 2:

Data Item	Format Fortran	Type of Element	Card Columns
Remarks (1 thru 60)	60A1	Alpha	21-80

CARD 3:

Data Item	Format Fortran	Type of Element	Card Columns
Remarks (61 thru 120)	60A1	Alpha	21-80

Following the above cards are those containing the data for partitions A thru F. The partition cards must be in alphabetical sequence. On all partition data cards fields 1, 2, and 3 are as shown below.

Field	Data Element	Card Column
1	Core Number	1 thru 4
2	Special Case Flag	5
3	Partition Identification and Card Sequence	6, 7, 8
4	Null Partition Flag	9, 10

The null partition flag is set to -1 to denote a null partition and to go to the next partition in the alphabetical sequence. The last data of each non-empty partition will be flagged by a negative depth. The computer will sense this, and assume the end of the partition. The next card read will be treated as the next partition of the alphabetical sequence.

3. LABORATORY CORE ANALYSIS REMARKS KEY

A: Core essentially undisturbed (good core)

B: Core slightly disturbed (fair core)

C: Core grossly disturbed (poor core)

D: Homogeneous appearance

E: Layered appearance

F: Shells or shell fragments incorporated in core sample

G: Core test section removed by cutting entire core barrel with a "hot wire".

H: Core test section extruded through top of core barrel. Bottom of sediment column sealed with styrofoam plug and pressure applied to force sediment column upward.

I: Vane shear measurement made with mechanical torque wrench rotating at 6°/min.

J: Vane shear measurement made with electrical strain gauge rotating at 48°/min.

K: Core samples refrigerated at 6°C during storage prior to laboratory testing.

L: Core samples stored at room temperature prior to laboratory testing.

M: Grain size analysis made from original wet sample.

N: Grain size analysis made from dry sample that has been subsequently wetted.

O: Grain size analysis made from dry sample that was ground prior to wetting and testing.

P: Salts removed from grain size samples via washing, allowing to settle, and decanting of wash water.

Q: Salts removed from grain size samples via "hot diffusion" method.

R: Adjacent to Lehigh's in-situ vane shear measurement.

S: Adjacent to Lehigh's nuclear densitometer probe.

T: Adjacent to Lockheed's in-situ vane shear measurement.

U: Q_1 in grain size data determined via extrapolation for size determinations smaller than .001 mm.

V: Density of solids determined by air-pycnometer method using helium.

4. IN-PLACE DATA CARD FORMAT

CARD 1:

Data Item	Format Fortran	Type of Element	Card Columns
1. In place test number	I4	Integer	1-4
2. Special Case Flag	A1	Alpha	5
3. Station Number	I5	Integer	6-10
4. Dive Number	I5	Integer	11-15
5. The Word: "SITU"	A4	Alpha	17-20
6. Project Title	5A4*	Alpha	21-40
7. Month	A4	Alpha	41-44
8. Day	I2	Integer	46-48
9. Year	I2	Integer	49-51
10. Lat. deg	I2	Integer	42-54
11. Lat. Tenths of Min.	F5.1	Real Float	55-59
12. Hemisphere (North or South)	A1	Alpha	60
13. Long. Deg	I2	Integer	62-64
14. Long. Tenth of Min.	F5.1	Real Float	65-69
15. Hemisphere (East or West)	A1	Alpha	70
16. Water Depth (meters)	I5	Integer	71-75
17. Number of Corresponding Cores	I5	Integer	76-80

*Adjustable to comply with computer word size. The above is for an IBM 360. For an 1108 the format 4A5 may be more efficient, although to maintain Program compatibility the 1108 can use 5A4 with no difficulty.

Data Item	Fortran Format	Type of Element	Card Columns
CARD 2:			
Remarks (1 thru 60)	60 A1	Alpha	21-80
CARD 3:			
Remarks (61 thru 120)	60 A1	Alpha	21-80

The next cards are those containing the in-place shear strength data.

The format of the cards containing the DELFAC fields is as follows:

Data Element	Fortran Format	Card Col. Left Field	Card Col. Center Field	Card Col. Right Field
Depth of Test (cm)	F5.1	21-25	41-45	61-65
Field Shear Strength (g/cm^2)	F5.1	26-30	46-50	66-70

The last depth is flagged by its entry as a negative depth. If no data exist, a blank card must be inserted.

The next set of cards contain information of corresponding cores to the In-place test. Item 17 of card one gives the number of corresponding cores. Their format is as follows:

Data Element	Fortran Format	Card Columns
Core Number	I4	1-4
Station Number	I5	6-10
Dive Number	I5	11-15
Core Distance	F10.3	20-29
Core Bearing	F10.3	30-39
Core Length	I10	41-50

5. IN-PLACE TEST REMARKS KEY

A: Axial load reading only. No vane measurements recovered.

B: Unusually high axial load encountered.

C: Test adjacent to Lehigh University's in-situ vane test.

D: Test adjacent to Lehigh University's nuclear densitometer measurement.

E: Distance to sediment surface observed.

F: Distance to sediment surface assumed.

G: Vane test run simultaneous with Lehigh's nuclear densitometer probe.

H: Depth of vane read from depth counter in DEEP QUEST.

I: Depth of vane calculated from running "extend vane" mode for a known duration.

6. DATA RECORD STRUCTURE

Core Summary File Structure	Word		In Place File Structure
Core #	1		In place Test #
Special Case	2		Special Case
Station #	3		Station #
Dive #	4		Dive #
"CORE"	5		"SITU"
PROJECT	6-10		PROJECT
	11		
Date	12		Date
	13		
	14		
Geographic Position	15		Geographic Position
	16		
	17		
	18		
	19		
Core Sample Length	20		Water Depth
Extra Flag	22		Extra Flag
Remarks	23-52		Remarks
No. of Partition A	53		Number of levels in Profile
No. of Partition B	54		Number of Corresponding Cores
No. of Partition C	55	55-94	D (40)
No. of Partition D	56	95-134	F (40)
No. of Partition E	57	135-154	Core # (20)
No. of Partition F	58	155-174	STATION # (20)
ARRAY (1)	59	175-194	DIVE # (20)
.	.	195-214	CORE DIS. (20)
.	.	215-234	CORE BEAR (20)
ARRAY (196)	254	235-254	CORE LENGTH (20)
SPARE	255		SPARE
SPARE	256		SPARE

APPENDIX D

1) Examples of Computer Outputs for Core and In-Place Data Summaries
2) Examples of Computer Outputs for Special Data Subsets
3) Examples of Computer Plots for Geotechnical Data

Table D-1. Computer Output of Core Data Summary

```
                                            C O R E   D A T A   S U M M A R Y

DEPTH IN   GRAIN SIZE          MED    VANE SHEAR    SENSIT  WATER CONTENT  UNIT WEIGHT     POROSITY   VOID . PL--LL--PI
CORE,(CM)  SD-ST-CL            DIA     STRENGTH                PERCENT       G/CM**3       PERCENT    RATIO
                               MM      G/CM**2                             SATUR-  DRY
                                      NAT    REM                            ATED

CORE  78
   2.0                                 2.9    1.7    1.7        304
  12.0                                14.7    5.2    2.6        197
  18.0     1- 60- 38          .0035
  23.0                                                          165       1.34   2.52     81.1      4.29
  29.0                                36.6   16.6    2.3        154
  34.0                                                          146       1.37   2.51     79.3      3.84
  52.0                                46.5   22.8    2.1        133
  57.0                                                          140       1.36   2.53     78.4      3.62
  62.0                                46.9   21.8    2.2        136
  67.0                                                          128       1.41   2.55     77.0      3.35
  73.0                                57.9   24.5    2.4        126
  78.0     2- 55- 43          .0030
  85.0                                62.0   29.7    2.1        130
  90.0                                                          125       1.41   2.56     76.6      3.27
  96.0                                51.2   24.9    2.1        125

  STATION    3    CORE   78 , DIVE  154    JUNE  7 1972
  GEOGRAPHIC POSITION  32 34.9N  117 28.6W    WATER DEPTH  1220 M  CORE LENGTH  105    IR-72LEHIGH
  APPLICABLE STANDARD REMARKS, A, D, F, J, K, M, Q, S, U, V,
   STORED 61 DAYS, SLIGHT SURFACE SULFIDE

CORE  79
  12.0                                12.4    3.5    3.5        186
  18.0     1- 61- 38          .0037
  23.0                                                          166       1.33   2.50     81.4      4.39
  29.0                                26.2   12.2    2.3        165
  35.0                                                          146       1.38   2.52     79.5      3.88
  52.0                                                          140
  57.0                                                          137       1.39   2.53     78.4      3.63
  63.0                                57.4   30.1    1.9        154
  67.0                                                          124
  68.0                                                                    1.42   2.55     76.7      3.30
  73.0                                62.4   29.2    2.1        122
  78.0     2- 55- 43          .0031
  85.0                                56.9   23.8    2.5        118
  90.0                                                          117       1.44   2.55     75.8      3.13

  STATION    4    CORE   79 , DIVE  154    JUNE  7 1972
  GEOGRAPHIC POSITION  32 34.9N  117 29.3W    WATER DEPTH  1219 M  CORE LENGTH   96    IR-72LEHIGH
  APPLICABLE STANDARD REMARKS, A, D, F, H, J, K, M, Q, S, U, V,
          STORED 63 DAYS, SLIGHT SULFIDE
```

Table D-2. Computer Output of In-Place Test Information.

```
 SAMPLE TEST NUMBER     45

IN PLACE SAMPLE     45       STATION      1 , DIVE  178
  AUG  1 1973    GEOGRAPHIC POSTION    32 35.0N  117 30.1W    WATER DEPTH  1217 M
  IR-73LEHIGH
 APPLICABLE STANDARD REMARKS, D, E, H,

INDEX      DEPTH        SHEAR STRENGTH
           (CM)           (GM/CM**2)
    1       6.70             12.50
    2      27.00             37.30
    3      47.30             43.20
    4      67.60             53.30
    5      88.00             69.50
    6     108.30             70.40
    7     128.00             89.50
          THERE ARE NO CORES CORRESPONDING TO THIS IN PLACE SAMPLE


 SAMPLE TEST NUMBER     46

IN PLACE SAMPLE     46       STATION      1 , DIVE  178
  AUG  1 1973    GEOGRAPHIC POSTION    32 35.0N  117 30.1W    WATER DEPTH  1217 M
  IR-73LEHIGH
 APPLICABLE STANDARD REMARKS, D, E, H,

INDEX      DEPTH        SHEAR STRENGTH
           (CM)           (GM/CM**2)
    1       6.70              4.30
    2      27.00             27.20
    3      47.30             45.30
    4      67.60             56.10
    5      88.00             62.40
    6     108.30             72.60
    7     123.00             78.40
          THERE ARE NO CORES CORRESPONDING TO THIS IN PLACE SAMPLE
```

Table D-3. Computer Output of Special Data Subset Request.

```
                                                                         Remarks
CORE  STATION  DIVE  DATE           GEOG POSITION         A B C D E F G H I J K L M N O P Q R S T U

 22      1      111  JULY 12 1970    32 33.9N  117 27.3W  A         F     I     L   N     Q     T
 23      1      112  JULY 15 1970    32 34.1N  117 27.7W  A     D     G   I     L   N   P       T U
 24      1      112  JULY 15 1970    32 34.1N  117 27.7W  A           G   I     L   N   P       T
 25      1      112  JULY 15 1970    32 34.1N  117 27.7W  A           G   I     L   N   P       T
 26      1      112  JULY 15 1970    32 34.1N  117 27.7W  A           G   I     L   N   P       T

 27      1      112  JULY 15 1970    32 34.1N  117 27.7W                                      T
 28      1      114  JULY 17 1970    32 33.9N  117 27.3W  A           G   I     L   N   P
 29      2      114  JULY 17 1970    32 34.1N  117 28.0W
 30      1      124  DEC  11 1970    32 33.9N  117 27.3W  A           G   I     L   N   P       T
 31      1      124  DEC  11 1970    32 33.9N  117 27.3W  A           G   I     L   N   P       T

 32      2      124  DEC  11 1970    32 33.9N  117 27.4W  A           G   I     L   N   P       T
 33      3      124  DEC  11 1970    32 33.9N  117 27.6W  A           G   I     L   N   P       T
 34      4      124  DEC  11 1970    32 33.8N  117 27.6W  A           G   I     L   N   P       T
 35      1      135  OCT   6 1971    32 33.9N  117 27.3W  A     D     G     J K   M     P   R S T
 36      1      136  OCT   7 1971    32 33.9N  117 27.6W  A     D     G     J K   M     P   R     U

 37      2      136  OCT   7 1971    32 34.1N  117 28.0W      C D     G     J K   M     P   R     U
 38      1      137  OCT  10 1971    32 33.4N  117 27.3W  A     D     G     J K   M     P   R S   U
 39      2      137  OCT  10 1971    32 33.0N  117 27.1W    B   D     G     J K   M     P   R S   U
 40      2      137  OCT  10 1971    32 33.0N  117 27.1W      B D     G     J K   M     P   R S   U
 41      1      138  OCT  11 1971    32 33.6N  117 27.7W  A     D     G     J K   M     P   R S   U

 42      1      138  OCT  11 1971    32 33.6N  117 27.7W    B   D     G     J K   M     P   R S   U
 43      2      138  OCT  11 1971    32 33.6N  117 28.3W  A     D     G     J K   M     P   R S   U
 44      2      138  OCT  11 1971    32 33.8N  117 28.3W  A     D     G     J K   M     P   R S   U
 45      2      138  OCT  11 1971    32 33.6N  117 28.3W    B   D     G     J K   M     P   R S   U
 52      1      146  MAR  14 1972    32 33.9N  117 28.6W  A     D     G     J K   M       Q

 53      1      146  MAR  14 1972    32 33.9N  117 28.6W  A     D     G     J K   M       Q
 54      1      146  MAR  14 1972    32 33.9N  117 28.6W  A     D     G     J K   M       Q
 55      1      150  MAY  30 1972    32 33.9N  117 27.3W  A     D     G     J K   M       Q
 56      1      150  MAY  30 1972    32 33.9N  117 27.3W      C D     G     J K   M       Q
 57      1      150  MAY  30 1972    32 33.9N  117 27.3W      C

 58      1      150  MAY  30 1972    32 33.9N  117 27.3W      C
 59      1      150  MAY  30 1972    32 33.9N  117 27.3W    B   D     G     J K   M       Q
 60      1      150  MAY  30 1972    32 33.9N  117 27.3W
 61      1      151  JUNE  2 1972    32 33.8N  117 27.4W  A     D   F G     J K   M       Q   S T
 62      2      151  JUNE  2 1972    32 33.4N  117 27.7W    B   D     G     J K   M       Q R S T
```

Table D-3 (Continued)

CORE	STATION	DIVE	DATE	GEOG POSITION		Remarks																				
						A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U
63	2	151	JUNE 2 1972	32 33.4N	117 27.7W	A			D			G			J	K		M				Q	R	S	T	
64	3	151	JUNE 2 1972	32 33.2N	117 27.6W	A			D			G			J	K		M				Q		S	T	U
65	4	151	JUNE 2 1972	32 33.1N	117 28.0W	A			D			G			J	K		M				Q		S	T	U
66	1	152	JUNE 5 1972	32 33.0N	117 27.9W	A			D			G			J	K		M				Q	R	S	T	
67	1	152	JUNE 5 1972	32 33.0N	117 27.9W	A			D				H		J	K		M				Q	R	S	T	
68	2	152	JUNE 5 1972	32 33.3N	117 28.4W	A			D				H		J	K		M				Q	R	S	T	
69	2	152	JUNE 5 1972	32 33.3N	117 28.4W	A			D				H		J	K		M				Q	R	S	T	
70	3	152	JUNE 5 1972	32 33.0N	117 28.9W	A			D				H		J	K		M				Q	R	S	T	
71	3	152	JUNE 5 1972	32 33.0N	117 28.9W	A			D				H		J	K		M				Q	R	S	T	
72	1	153	JUNE 6 1972	32 33.5N	117 29.3W	A			D				H		J	K		M				Q	R	S	T	
73	1	153	JUNE 6 1972	32 33.5N	117 29.3W	A			D				H		J	K		M				Q	R	S	T	
74	2	153	JUNE 6 1972	32 33.5N	117 29.9W	A			D				H		J	K		M				Q	R	S	T	
75	2	153	JUNE 6 1972	32 33.5N	117 29.9W	A			D				H		J	K		M				Q	R	S	T	
76	1	154	JUNE 7 1972	32 34.5N	117 28.0W	A			D				H		J	K		M				Q		S		U
77	2	154	JUNE 7 1972	32 35.0N	117 28.1W	A			D				H		J	K		M				Q	R	S		U
78	3	154	JUNE 7 1972	32 34.9N	117 28.6W	A			D				H		J	K		M				Q		S		U
79	4	154	JUNE 7 1972	32 34.9N	117 29.3W	A			D		F		H		J	K		M				Q		S		U
80	5	154	JUNE 7 1972	32 34.8N	117 29.8W	A			D				H		J	K		M				Q		S		U
103	2	166	AUG 14 1972	32 32.8N	117 27.9W	A			D				H		J	K		M				Q		S	T	U
104	2	166	AUG 14 1972	32 32.8N	117 27.9W	A			D				H		J	K		M				Q		S	T	U
105	3	166	AUG 14 1972	32 32.5N	117 28.5W	A			D				H		J	K		M				Q		S	T	U
106	3	166	AUG 14 1972	32 32.5N	117 28.5W	A			D				H		J	K		M				Q		S	T	U
107	4	166	AUG 14 1972	32 32.4N	117 29.1W	A			D				H		J	K		M				Q		S	T	U
108	4	166	AUG 14 1972	32 32.4N	117 29.1W	A			D				H		J	K		M				Q		S	T	U
109	1	167	AUG 15 1972	32 34.4N	117 29.5W	A			D				H		J	K		M				Q	R	S	T	
110	1	167	AUG 15 1972	32 34.4N	117 29.5W	A			D				H		J	K		M				Q	R	S	T	
111	2	167	AUG 15 1972	32 34.3N	117 30.3W	A			D				H		J	K		M				Q	R	S	T	
112	2	167	AUG 15 1972	32 34.3N	117 30.3W	A			D				H		J	K		M				Q	R	S	T	
113	3	167	AUG 15 1972	32 34.3N	117 30.7W	A			D				H		J	K		M				Q	R	S	T	
114	3	167	AUG 15 1972	32 34.3N	117 30.7W	A			D				H		J	K		M				Q	R	S	T	
115	1	175	JUL 25 1973	32 35.6N	117 27.5W	A			D				H		J	K		M				Q				
116	2	175	JUL 25 1973	32 35.6N	117 27.5W	A			D				H		J	K		M				Q				

Table D-4. Computer Output for In-Place Test Results and Supplementary Information

```
IN PLACE STATION DIVE DATE            GEOG POSITION          A B C D E F G H I

    1     1     111  JULY 12 1970     32 33.9N  117 27.3W    A
    2     1     112  JULY 15 1970     32 34.1N  117 27.7W            E       I
    3     1     112  JULY 15 1970     32 34.1N  117 27.7W            E       I
    4     1     112  JULY 15 1970     32 34.1N  117 27.7W            E       I
    5     1     112  JULY 15 1970     32 34.1N  117 27.7W      B     E       I

    6     1     112  JULY 15 1970     32 34.1N  117 27.7W            E       I
    7     1     121  OCT  25 1970     32 34.1N  117 28.0W          D E     H
    8     1     122  NOV  10 1970     32 33.9N  117 27.3W            E     H
    9     2     124  DEC  11 1970     32 33.9N  117 27.3W            E     H
   10     3     124  DEC  11 1970     32 34.3N  117 27.3W            E     H

   11     4     124  DEC  11 1970     32 34.3N  117 27.3W            E     H
   12     5     124  DEC  11 1970     32 33.9N  117 27.3W            E     H
   13     1     135  OCT  16 1971     32 33.9N  117 27.3W        C D E       I
   14     2     135  OCT  16 1971     32 33.8N  117 27.4W        C   E       I
   15     1     151  JUNE  2 1972     32 33.8N  117 27.4W          D E     H

   16     2     151  JUNE  2 1972     32 33.4N  117 27.7W        C D E     H
   17     3     151  JUNE  2 1972     32 33.2N  117 27.8W          D E     H
   18     4     151  JUNE  2 1972     32 33.1N  117 28.0W          D E   G H
   19     1     152  JUNE  5 1972     32 33.6N  117 27.9W        C D E     H
   20     2     152  JUNE  5 1972     32 33.3N  117 28.4W        C D E   G H

   21     3     152  JUNE  5 1972     32 33.0N  117 28.9W        C D E   G H
   22     1     153  JUNE  6 1972     32 33.5N  117 29.3W        C D E     H
   23     2     153  JUNE  6 1972     32 33.5N  117 29.5W        C D E     H
   24     3     153  JUNE  6 1972     32 33.5N  117 30.6W        C D E     H
   33     2     166  AUG  14 1972     32 32.8N  117 27.9W          D E   G H

   34     3     166  AUG  14 1972     32 32.5N  117 28.5W          D E   G H
   35     4     166  AUG  14 1972     32 32.4N  117 29.1W          D E   G H
   36     1     167  AUG  15 1972     32 34.4N  117 29.5W        C D E     H
   37     2     167  AUG  15 1972     32 34.3N  117 30.3W        C D E   G H
   38     3     167  AUG  15 1972     32 34.3N  117 30.7W          D E   G H

   39     1     168  AUG  16 1972     32 33.1N  117 29.2W      B C D E   G H
   40     2     168  AUG  16 1972     32 32.5N  117 29.6W        C D   F G H
   41     3     168  AUG  16 1972     32 32.6N  117 30.2W      B C D   F G H
   42     1     178  AUG   1 1973     32 35.0N  117 30.1W          D E     H
   43     1     178  AUG   1 1973     32 35.0N  117 30.1W          D E     H

   44     1     178  AUG   1 1973     32 35.0N  117 30.1W          D E     H
   45     1     178  AUG   1 1973     32 35.0N  117 30.1W          D E     H
   46     1     178  AUG   1 1973     32 35.0N  117 30.1W          D E     H
   47     1     178  AUG   1 1973     32 35.0N  117 30.1W          D E     H
```

Table D-5. Computer Output for Special Data Subsets - Number of Tests in Data Partitions per cm Depth

INDEX	PART A	PART B	PART C	PART D	PART E	PART F
1	0	0	0	0	0	0
2	0	7	0	0	0	10
3	0	26	0	0	0	27
4	0	2	0	0	0	2
5	0	5	0	0	0	8
6	0	0	0	0	0	0
7	0	5	0	0	0	4
8	0	19	0	0	0	17
9	0	1	0	0	0	1
10	2	22	0	0	0	23
11	3	0	0	0	0	0
12	6	7	0	0	0	7
13	15	2	0	0	0	2
14	2	0	0	0	0	0
15	13	9	0	1	0	8
16	5	0	0	0	0	0
17	0	2	0	0	0	1
18	7	0	0	0	0	5
19	0	0	0	0	0	0
20	2	26	0	2	2	24
21	0	1	0	2	0	3
22	2	0	0	11	0	7
23	0	3	0	6	0	10
24	0	1	0	2	0	2
25	0	6	0	12	0	16
26	0	0	0	2	0	3
27	0	2	1	1	0	3
28	2	20	0	1	0	16
29	0	3	0	2	0	5
30	3	15	0	6	0	20
31	0	7	0	0	0	7
32	1	2	0	0	0	3
33	0	2	0	11	0	11
34	0	0	0	2	0	1
35	0	8	0	1	3	9
36	0	0	0	1	3	2
37	0	4	0	2	0	5
38	0	3	0	4	0	4
39	0	2	0	1	0	1
40	1	4	0	0	0	1
41	0	0	0	1	0	1
42	0	13	0	1	0	15
43	0	5	0	2	0	5
44	0	1	0	2	0	3
45	3	2	3	0	0	6
46	0	0	0	0	0	0
47	0	8	0	2	4	7
48	3	5	1	8	2	6
49	0	16	0	0	0	8
50	0	2	0	1	0	3

INDEX	PART A	PART B	PART C	PART D	PART E	PART F
51	0	4	0	2	0	7
52	3	7	0	2	1	9
53	0	2	0	1	0	3
54	0	6	0	0	0	6
55	1	1	0	0	0	1
56	0	1	0	0	0	1
57	0	0	0	3	0	3
58	1	2	0	0	0	2
59	1	0	0	3	0	3
60	2	7	0	2	2	7
61	2	0	1	1	0	0
62	3	2	5	3	0	3
63	0	6	1	0	0	14
64	0	1	0	0	0	1
65	4	1	2	5	0	8
66	1	0	0	1	0	1
67	1	5	0	3	0	6
68	0	2	0	5	1	6
69	1	9	0	0	0	10
70	1	15	0	1	0	12
71	1	5	0	0	1	4
72	1	5	0	2	0	6
73	0	5	0	4	0	8
74	1	0	0	0	0	0
75	2	6	0	3	0	12
76	6	5	0	2	0	7
77	0	1	0	1	0	2
78	0	3	0	1	0	3
79	2	0	1	0	0	0
80	4	6	0	1	3	7
81	1	2	0	3	0	4
82	0	4	0	3	1	5
83	3	10	2	4	0	9
84	3	0	1	6	0	5
85	2	5	1	3	1	9
86	0	6	0	0	1	2
87	2	5	0	3	1	6
88	2	15	0	3	0	10
89	6	12	0	0	0	8
90	5	4	1	5	0	9
91	1	3	0	2	0	5
92	0	3	0	1	0	2
93	0	3	0	1	0	4
94	2	1	0	2	0	3
95	1	3	0	1	1	5
96	2	4	0	1	0	5
97	0	1	0	2	0	3
98	1	3	0	0	1	2
99	0	0	0	4	0	4
100	1	3	0	0	0	3

INDEX	PART A	PART B	PART C	PART D	PART E	PART F
101	1	0	0	0	1	0
102	0	0	0	0	0	0
103	0	3	0	0	0	3
104	0	0	0	0	0	0
105	0	1	0	0	0	1
106	0	0	0	0	0	0
107	0	0	0	1	0	1
108	0	0	0	0	0	0
109	0	0	0	0	0	0
110	1	0	0	0	0	0
111	0	0	0	0	0	0
112	0	0	0	0	0	0
113	0	1	0	0	0	1
114	0	0	0	0	0	0
115	1	0	0	0	0	0
116	0	0	0	0	0	0
117	0	0	0	0	0	0
118	0	0	0	0	0	0
119	0	0	0	0	0	0
120	0	0	0	0	0	0
121	0	0	0	0	0	0
122	0	0	0	0	0	0
123	1	0	0	0	0	0
124	0	0	0	0	0	0
125	0	0	0	0	0	0
126	0	0	0	0	0	0
127	0	0	0	0	0	0
128	0	0	0	0	0	0
129	0	0	0	0	0	0
130	0	0	0	0	0	0
131	0	0	0	0	0	0
132	0	0	0	0	0	0
133	0	0	0	0	0	0
134	0	0	0	0	0	0
135	0	0	0	0	0	0
136	0	0	0	0	0	0
137	0	0	0	0	0	0
138	0	0	0	0	0	0
139	0	0	0	0	0	0
140	0	0	0	0	0	0
141	0	0	0	0	0	0
142	0	0	0	0	0	0
143	0	0	0	0	0	0
144	0	0	0	0	0	0
145	0	0	0	0	0	0
146	0	0	0	0	0	0
147	0	0	0	0	0	0
148	0	0	0	0	0	0
149	0	0	0	0	0	0
150	0	0	0	0	0	0

CORE NUMBER. 111
STATION 2 DIVE. 167 DATE 15 AUG 1972 PROJECT IA-72LEHIGH
GEOG. POSITION. 32/34.3N 117/30.3W WATER DEPTH 1219 M CORE LENGTH 107 CM
REMARKS ADHJKMQRSTUV STORED 49 DAYS

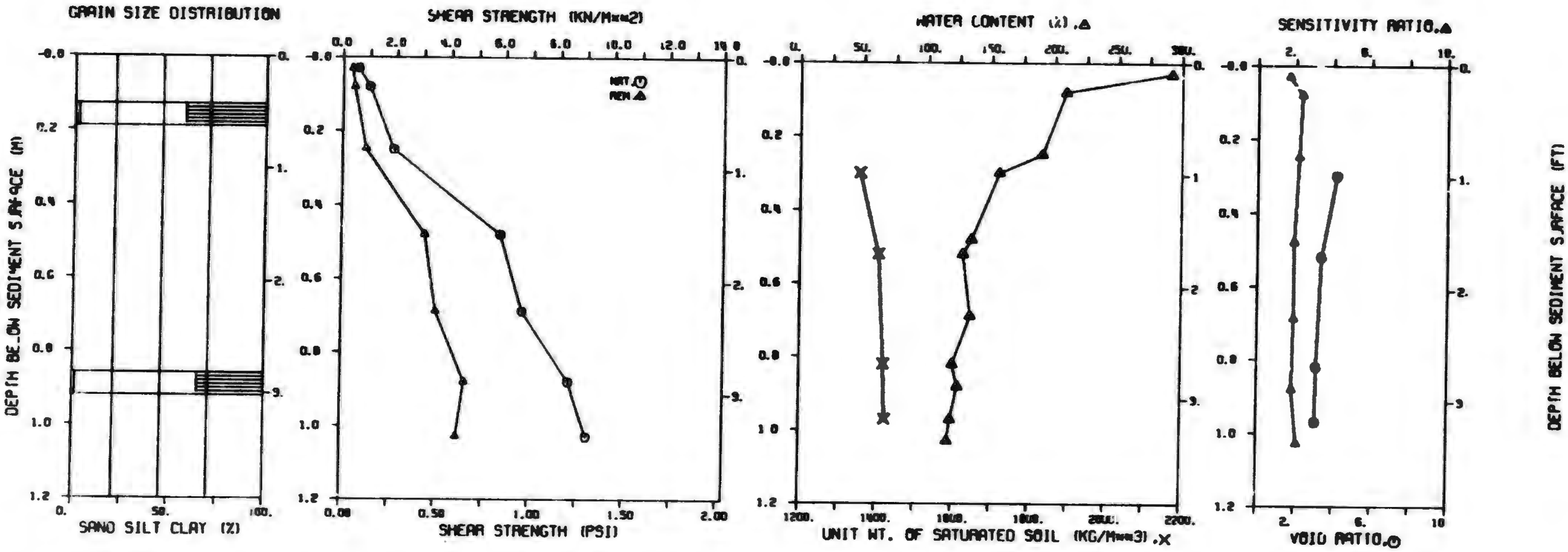


Figure D-1. Computer Plots of Geotechnical Data

APPENDIX E

1) Description Sample Statistics
2) Profiles of Sediment Properties with Test Depth

Table E-1. Average Values of Soil Properties for 10 cm Depth Intervals/Number of Tests

DEPTH INTERVAL(cm)	0-10	10-20	20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-100	100-110	110-120	120-130
In-place Vane Shear (g/cm^2)	11.9/25	16.9/9	31.6/26	29.4/10	46.4/30	47.1/8	55.3/21	56.4/18	67.7/20	65.9/14	81.2/25	78.3/10	94.0/31
Lab. Vane Shear-Orig. (g/cm^2)	14.9/62	15.9/50	31.5/70	33.1/43	47.8/54	47.9/25	59.2/33	59.8/45	68.3/63	65.3/25	74.5/7	61.4/1	—
Lab. Vane Shear-Rem. (g/cm^2)	3.6/62	6.5/50	13.8/70	15.1/43	23.2/54	22.0/25	29.8/33	28.4/45	32.0/63	29.0/25	33.8/7	28.8/1	—
Water Content (%)	238/69	182/46	163/89	153/63	140/52	134/38	130/54	126/54	120/65	120/42	116/8	119/1	—
Median Grain Size (mm)	—	.0037/53	.0049/6	.0043/4	.0038/7	.0033/6	.0038/14	.0033/14	.0037/23	.0038/12	.0026/2	.0035/2	—
25th Percentile (Q_1)(mm)	—	.011/53	.014/6	.013/4	.010/7	.011/6	.021/14	.011/14	.011/23	.012/12	.0086/2	.013/2	—
75th Percentile (Q_3)(mm)	—	.0008/53	.0014/6	.0013/4	.0009/7	.0007/6	.0009/14	.0007/14	.0008/23	.0008/12	.0004/2	.0006/2	—
Sorting (Q_1-Q_3/2)(mm)	—	.0053/53	.0063/6	.0058/4	.0048/7	.0049/6	.0099/14	.0052/14	.0053/23	.0056/12	.0041/2	.0060/2	—
% Sand	—	2.04/53	2.03/6	2.63/4	1.71/7	1.70/6	2.13/14	1.94/14	2.31/23	1.66/12	1.60/2	2.35/2	—
% Silt	—	59.6/53	67.3/6	62.3/4	57.9/7	58.7/6	59.8/14	59.4/14	61.8/23	62.4/12	51.9/2	55.6/2	—
% Clay (< 2 μm)	—	38.4/53	30.7/6	35.1/4	40.8/7	39.6/6	38.1/14	38.7/14	35.8/23	35.9/12	47.5/2	42.2/2	—
Bulk Density	—	1.33/1	1.35/40	1.37/27	1.38/8	1.40/12	1.41/27	1.43/13	1.44/26	1.43/19	1.43/1	—	—
Grain Density	—	2.51/1	2.50/39	2.52/27	2.53/8	2.54/12	2.56/26	2.54/14	2.55/23	2.56/19	2.54/1	—	—
Porosity (%)	—	81.3/1	81.2/40	79.90/27	79.0/8	77.7/12	77.5/27	77.0/13	76.1/26	76.1/19	76.9/1	—	—
Void Ratio	—	4.34/1	4.33/40	4.01/27	3.80/8	3.50/12	3.45/27	3.39/13	3.20/26	3.19/19	3.33/1	—	—
Atterberg Limits*	—	—	—	—	—	—	—	—	—	—	—	—	—

*Omitted from this table as number of measurements per 10 cm depth interval are very few.

Table E-2. Standard Deviation of Soil Properties for 10 cm Depth Intervals

DEPTH INTERVAL (cm)	0-10	10-20	20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-100	100-110	110-120	120-130
In-place Vane Shear (g/cm^2)	6.3	5.1	7.2	4.8	9.2	11.9	13.7	6.9	11.5	7.6	13.9	7.5	19.9
Lab Vane Shear-Orig. (g/cm^2)	3.3	6.8	10.5	8.5	11.0	11.6	9.9	9.8	11.7	12.3	12.8	--	--
Lab Vane Shear-Rem. (g/cm^2)	1.7	2.7	5.5	5.3	7.0	5.9	6.6	8.8	8.3	8.2	9.7	--	--
Water Content (%)	33.9	18.9	10.9	8.5	8.7	9.2	7.3	6.7	5.8	4.9	6.0	--	--
Median Grain Size (mm)	--	.0009	.0005	.0014	.0014	.0007	.0009	.0008	.0011	.0010	.0001	.0004	--
25th Percentile (Q_1)(mm)	--	.0023	.0022	.0014	.0030	.0014	.0232	.0023	.0030	.0035	.0012	.0021	--
75th Percentile (Q_3)(mm)	--	.0004	.0004	.0010	.0004	.0004	.0005	.0006	.0005	.0006	.00004	.00007	--
Sorting (Q_1-Q_3/2) (mm)	--	.0011	.0012	.0005	.0014	.0008	.0116	.0011	.0014	.0016	.0006	.0011	--
% Sand	--	0.9	0.7	0.4	0.6	0.5	0.1	0.6	1.2	0.4	0.4	0.5	--
% Silt	--	4.4	5.0	10.3	9.6	6.6	5.4	6.6	6.6	7.3	.5	.6	--
% Clay ($<2\mu m$)	--	4.7	4.6	10.1	9.7	6.7	5.5	6.6	6.9	7.4	.4	.2	--
Bulk Density (g/cm^3)	--	--	.017	.016	.015	.017	.013	.015	.013	.012	--	--	--
Grain Density (g/cm^3)	--	--	.057	.018	.014	.014	.033	.029	.024	.019	--	--	--
Porosity (%)	--	--	.885	.967	1.3	.63	.565	1.240	1.10	.71	--	--	--
Void Ratio	--	--	.249	.255	.30	.12	.121	.235	.20	.13	--	--	--
Atterberg Limits*	--	--	--	--	--	--	--	--	--	--	--	--	--

*Omitted from this table as number of measurements per 10 cm depth interval are very few.

Table E-3. Coefficients of Variation of Soil Properties in Percent for 10 cm Depth Intervals

DEPTH INTERVAL (cm)	0-10	10-20	20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-100	100-110	110-120	120-130
In-place Vane Shear (g/cm^2)	52.9	30.2	22.8	16.3	19.8	25.3	24.8	12.2	1.7	11.5	17.1	9.6	21.2
Lab Vane Shear-Orig. (g/cm^2)	22.1	42.8	33.3	25.7	23.0	24.2	16.7	16.4	17.1	18.8	17.2	--	--
Lab Vane Shear-Rem. (g/cm^2)	47.2	41.5	39.9	35.1	30.2	26.8	22.2	31.0	25.9	28.3	28.7	--	--
Water Content (%)	14.3	10.4	6.7	5.5	6.2	6.9	5.6	5.3	4.9	4.1	5.2	--	--
Median Grain Size (mm)	--	24.3	10.2	32.6	36.8	21.2	23.7	24.2	29.7	26.3	3.9	11.4	--
25th Percentile (Q_1)(mm)	--	20.9	15.7	10.8	30.0	12.7	110.5	20.9	27.3	29.2	14.0	16.2	--
75th Percentile (Q_3)(mm)	--	50.0	28.6	76.9	44.4	57.1	55.6	85.7	62.5	75.0	10.0	11.7	--
Sorting (Q_1-Q_3/2) (mm)	--	20.8	19.1	8.6	29.2	16.3	117.2	21.2	26.4	28.6	14.6	18.3	--
% Sand	--	42.0	35.7	14.6	36.4	28.3	5.0	30.6	51.0	25.7	26.5	21.0	--
% Silt	--	7.4	7.4	16.5	16.6	11.2	9.0	11.1	10.7	11.7	1.06	1.1	--
% Clay ($<2\mu m$)	--	12.2	15.0	28.8	23.8	16.9	14.4	17.1	19.3	20.6	0.8	0.5	--
Bulk Density (g/cm^3)	--	--	1.3	1.2	1.1	1.2	0.9	1.1	0.9	0.8	--	--	--
Grain Density (g/cm^3)	--	--	2.3	0.7	0.6	0.6	1.3	1.1	0.9	0.7	--	--	--
Porosity (%)	--	--	1.1	1.2	1.7	0.8	0.7	1.6	1.5	0.9	--	--	--
Void Ratio	--	--	5.9	6.4	7.9	3.4	3.5	6.9	6.8	4.1	--	--	--
Atterberg Limits*	--	--	--	--	--	--	--	--	--	--	--	--	--

*Omitted from this table as number of measurements per 10 cm depth interval are very few.

Table E-4. Average Values of Soil Properties for 20 cm, 50 cm and Entire Depth Intervals/Number of Tests

DEPTH INTERVAL (cm)	0-20	20-40	40-60	60-80	80-100	100-120	0-50	50-100	0-130
In-Place Vane Shear (g/cm^2)	13.5/36	31.0/36	46.5/38	55.8/40	66.9/34	80.4/35	29.4/102	59.6/82	54.4/250
Lab Vane Shear-Orig. (g/cm^2)	11.2/112	32.1/113	47.9/79	59.5/78	67.5/88	72.8/8	26.8/279	61.7/191	41.5/478
Lab Vane Shear-Rem. (g/cm^2)	4.9/112	14.3/113	22.8/79	29.0/78	31.1/88	33.1/8	12.2/279	29.1/191	19.3/478
Water Content (%)	215/115	159/152	137/90	128/108	120/107	117/9	176/319	125/253	153/581
Median Grain Size (mm)	.0037/53	.0046/10	.0036/13	.0036/28	.0037/35	.0027/3	.0038/70	.0036/69	.0037/142
25th Percentile (Q_1) (mm)	.011/53	.014/10	.010/13	.016/28	.012/35	.009/3	.016/70	.013/69	.012/142
75th Percentile (Q_3) (mm)	.0008/53	.0014/10	.0008/13	.0008/28	.0008/35	.0005/3	.0009/70	.0008/69	.0008/142
Sorting (Q_1-Q_3/2) (mm)	.005/53	.006/10	.005/13	.008/28	.005/35	.004/3	.005/70	.006/69	.006/142
% Sand	2.0/53	2.3/10	1.7/13	2.0/28	2.1/35	1.7/3	2.0/70	2.0/69	2.0/142
% Silt	60.0/53	65.3/10	58.2/13	60.0/28	62.0/35	53.2/3	60.2/70	60.7/69	60.3/142
% Clay (< 2µm)	38.4/53	32.5/10	40.0/13	38.4/28	35.8/35	45.7/3	37.8/70	37.2/69	37.7/142
Bulk Density	1.31/1	1.36/67	1.39/20	1.42/40	1.43/45	1.43/1	1.36/76	1.42/97	1.40/174
Grain Density	2.51/1	2.51/66	2.54/20	2.56/40	2.56/42	2.54/1	2.51/75	2.55/94	2.53/170
Porosity (%)	81.3/1	80.7/67	78.2/20	77.3/40	76.1/45	76.9/1	80.5/76	76.8/97	78.4/174
Void Ratio	4.3/1	4.2/67	3.6/20	3.4/40	3.2/45	3.3/1	4.2/76	3.3/98	3.7/174
Plastic Limit	--	--	--	--	--	--	50.0/13	49.0/14	50.0/27
Liquid Limit	--	--	--	--	--	--	108.0/13	109.0/14	109.0/27
Plasticity Index	--	--	--	--	--	--	56.0/13	59.0/14	58.0/27

Table E-5. Standard Deviation of Soil Properties for 20 cm, 50 cm and Entire Depth Intervals

DEPTH INTERVAL (cm)	0-20	20-40	40-60	60-80	80-100	100-120	0-50	50-100	0-130
In-Place Vane Shear (g/cm^2)	6.4	6.6	9.7	11.2	10.0	12.3	15.2	12.6	27.7
Lab Vane Shear-Orig. (g/cm^2)	6.9	9.8	11.1	9.8	11.9	12.7	16.6	12.3	23.1
Lab Vane Shear-Rem. (g/cm^2)	2.8	5.5	6.7	7.8	8.4	9.1	8.4	8.4	11.9
Water Content (%)	39.8	11.1	9.3	7.2	5.4	5.7	39.3	8.5	39.1
Median Grain Size (mm)	.0009	.0009	.0011	.0009	.0011	.0004	.0009	.0010	.0010
25th Percentile (Q_1) (mm)	.0023	.0019	.0023	.0017	.0031	.0017	.0024	.011	.0079
75th Percentile (Q_3) (mm)	.0004	.0006	.0004	.0006	.0005	.0001	.0004	.0005	.0005
Sorting (Q_1-$Q_3/2$) (mm)	.0011	.0010	.0011	.0084	.0015	.0008	.0013	.0055	.004
% Sand	0.9	0.7	0.5	0.9	1.0	0.4	0.8	0.9	0.9
% Silt	4.4	7.5	8.0	5.9	6.7	2.4	5.8	6.5	6.2
% Clay (<2μm)	4.7	7.2	8.1	6.0	6.9	3.2	6.1	6.6	6.4
Bulk Density	--	.021	.019	.015	.013	--	.022	.019	.037
Grain Density	--	.046	.015	.032	.021	--	.045	.025	.044
Porosity (%)	--	1.40	1.12	.86	.94	--	1.28	1.15	1.22
Void Ratio	--	.17	.25	.17	.17	--	.32	.25	.49
Plastic Limit	--	--	--	--	--	--	8.8	9.5	9.0
Liquid Limit	--	--	--	--	--	--	18.8	6.2	13.5
Plasticity Index	--	--	--	--	--	--	12.8	12.2	12.3

Table E-6. Coefficient of Variation of Percent for 20 cm, 50 cm and Entire Depth Intervals

DEPTH INTERVAL (cm)	0-20	20-40	40-60	60-80	80-100	100-120	0-50	50-100	0-130
In-Place Vane Shear (g/cm^2)	47.3	21.3	20.9	20.1	14.9	15.3	51.8	21.2	50.9
Lab Vane Shear-Orig. (g/cm^2)	61.7	30.6	23.2	16.5	17.7	17.4	62.1	20.8	55.8
Lab Vane Shear-Rem. (g/cm^2)	32.7	38.5	29.2	27.4	26.9	27.5	69.1	26.9	61.6
Water Content (%)	18.5	6.9	6.8	5.6	4.5	4.9	22.3	6.8	25.6
Median Grain Size (mm)	24.3	19.6	30.6	25.0	29.7	14.8	23.7	27.5	27.0
25th Percentile (Q_1) (mm)	20.9	13.6	23.0	10.6	25.8	18.9	15.0	84.6	65.8
75th Percentile (Q_3) (mm)	50.0	42.9	50.0	75.0	62.5	20.0	44.4	62.5	62.5
Sorting (Q_1-$Q_3/_2$) (mm)	22.0	16.7	22.0	105.0	30.0	20.0	26.0	91.7	66.7
% Sand	45.0	30.4	29.4	45.0	47.6	23.5	40.0	45.0	45.0
% Silt	7.3	11.5	13.8	9.8	10.9	4.5	9.7	10.6	10.2
% Clay (< 2μm)	12.3	22.1	20.2	15.6	19.4	7.0	16.3	17.7	16.9
Bulk Density	--	1.5	1.4	1.1	0.9	--	1.6	1.3	2.6
Grain Density	--	1.8	0.6	1.3	0.8	--	1.8	1.0	1.7
Porosity (%)	--	1.7	1.4	1.1	1.2	--	1.6	1.5	1.6
Void Ratio	--	4.0	7.0	5.0	5.3	--	7.7	7.6	13.2
Plastic Limit	--	--	--	--	--	--	17.5	19.3	18.0
Liquid Limit	--	--	--	--	--	--	17.3	5.6	12.4
Plasticity Index	--	--	--	--	--	--	22.7	20.6	21.3

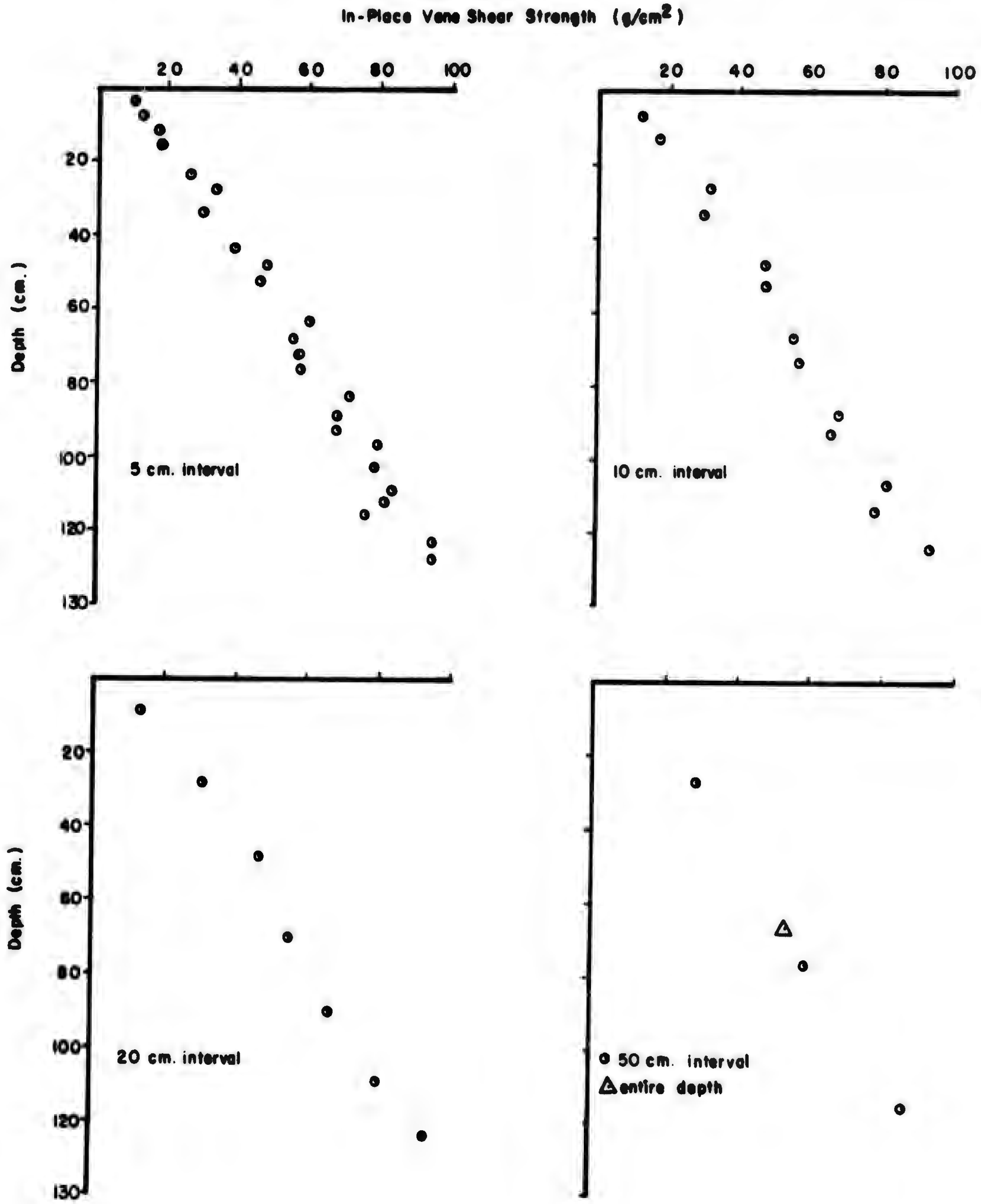


Figure E-1. In-Place Vane Shear Strength Profiles - Average Values

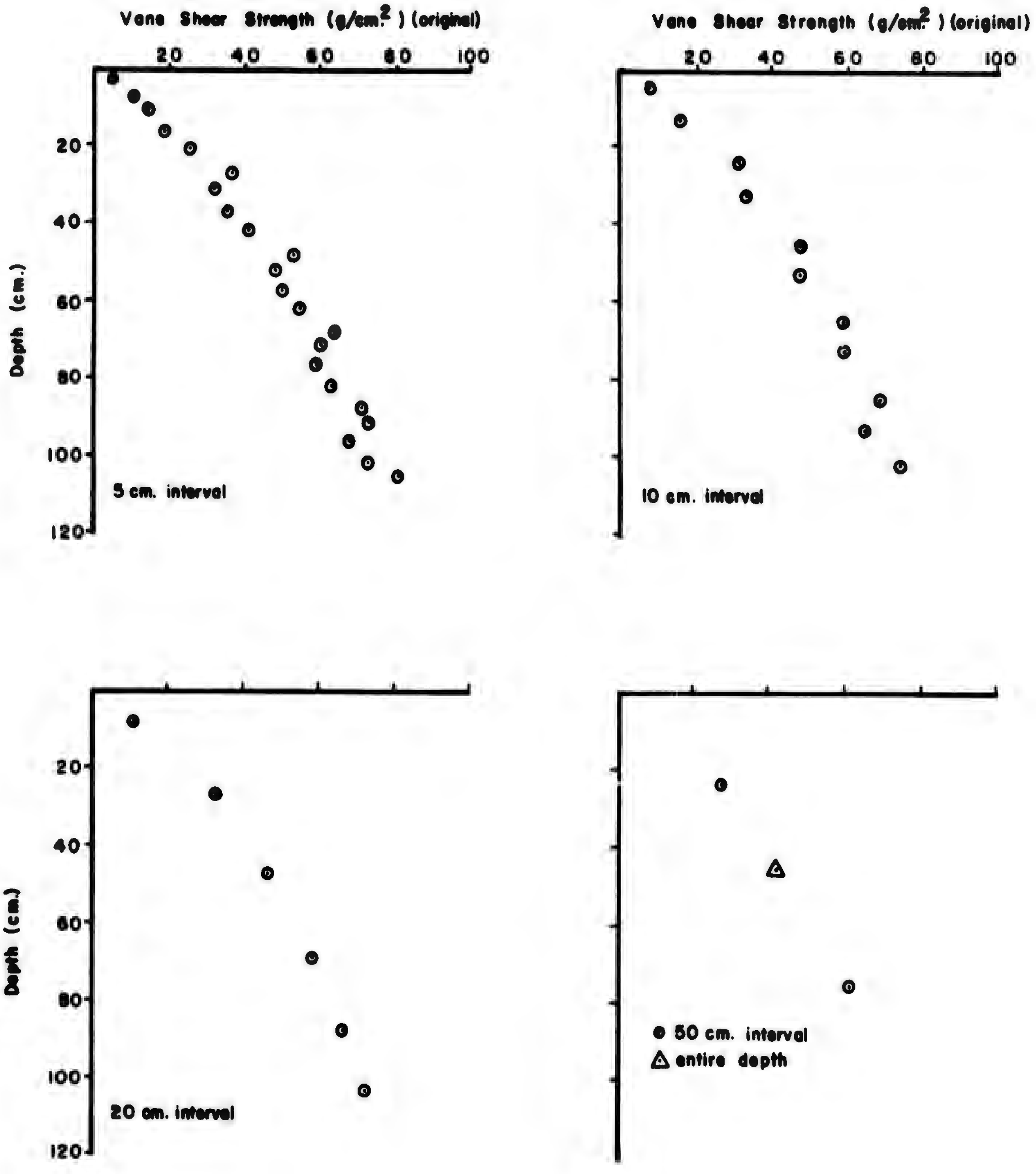


Figure E-2. Original Laboratory Vane Shear Strength Profiles - Average Values

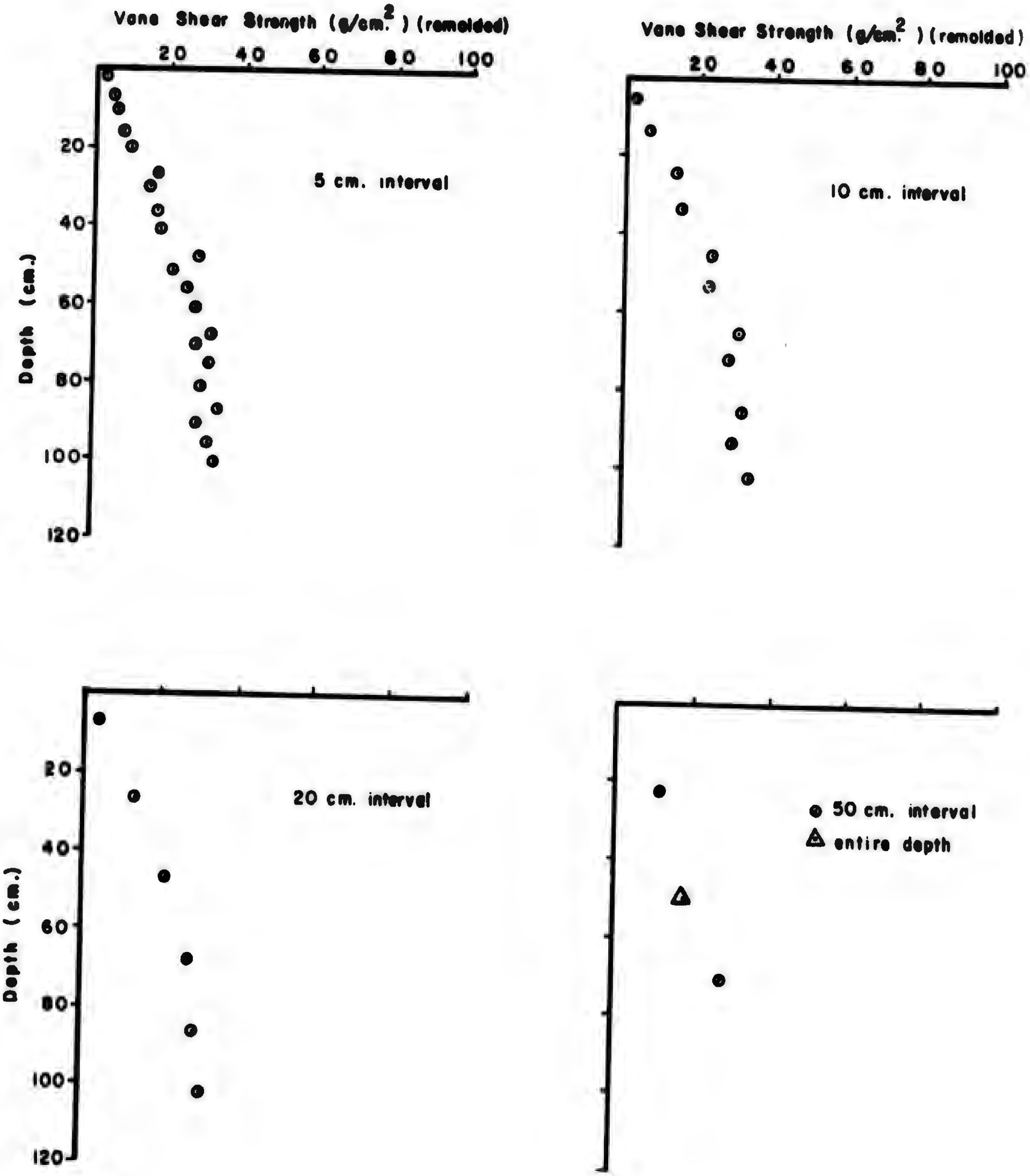


Figure E-3. Remolded Laboratory Vane Shear Strength Profiles - Average Values

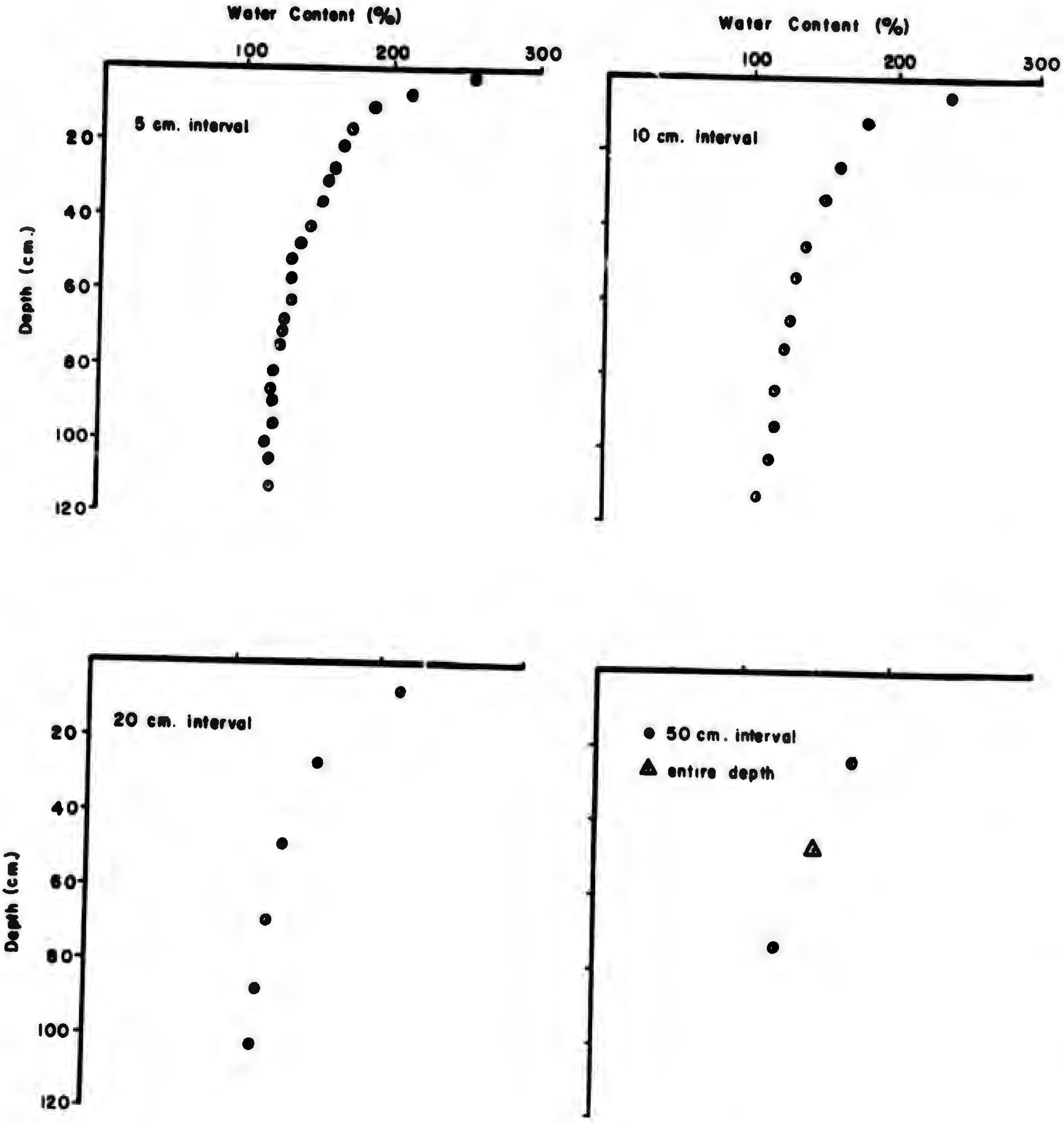


Figure E-4. Water Content Profiles - Average Values

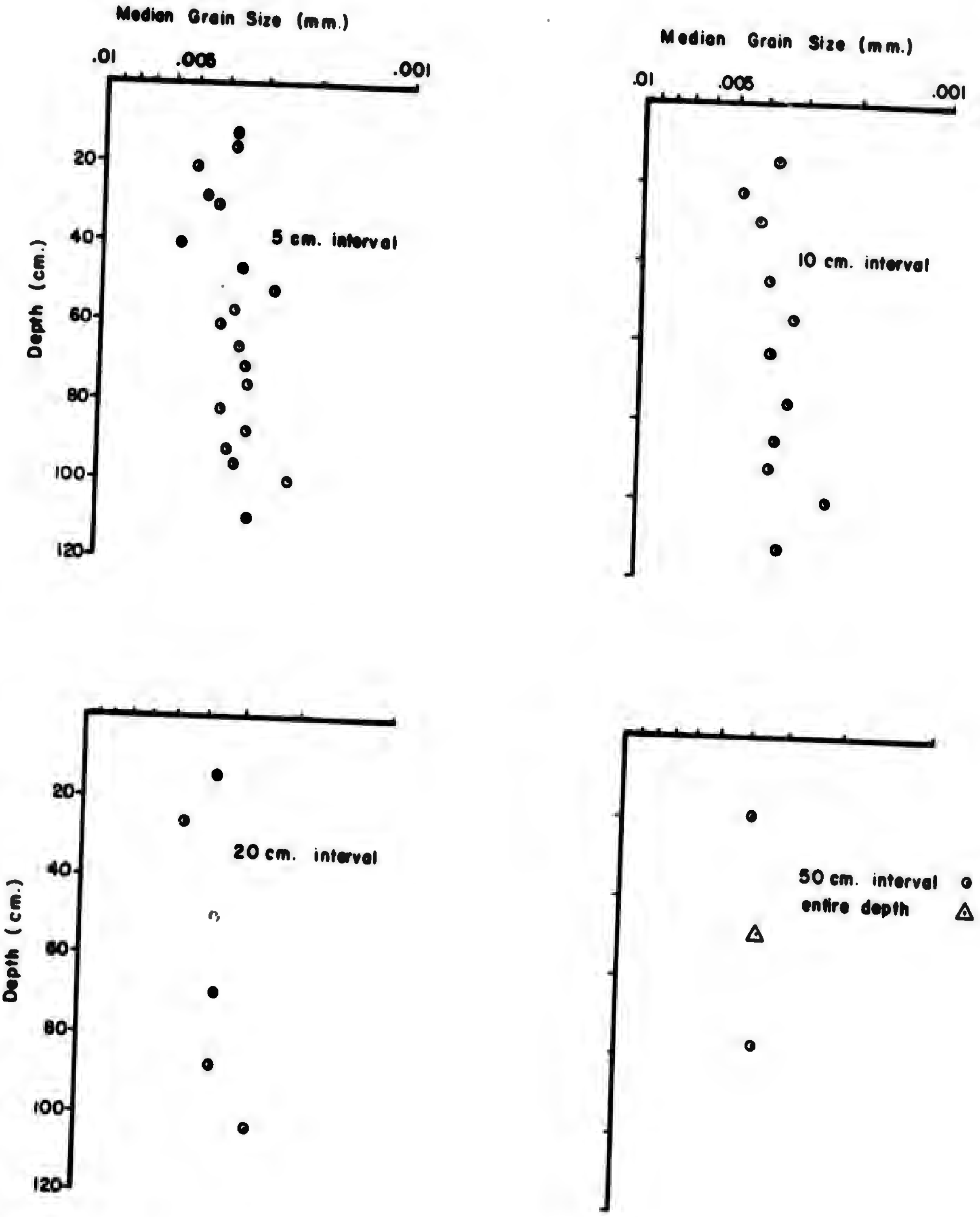


Figure E-5. Median Grain Size - Average Values

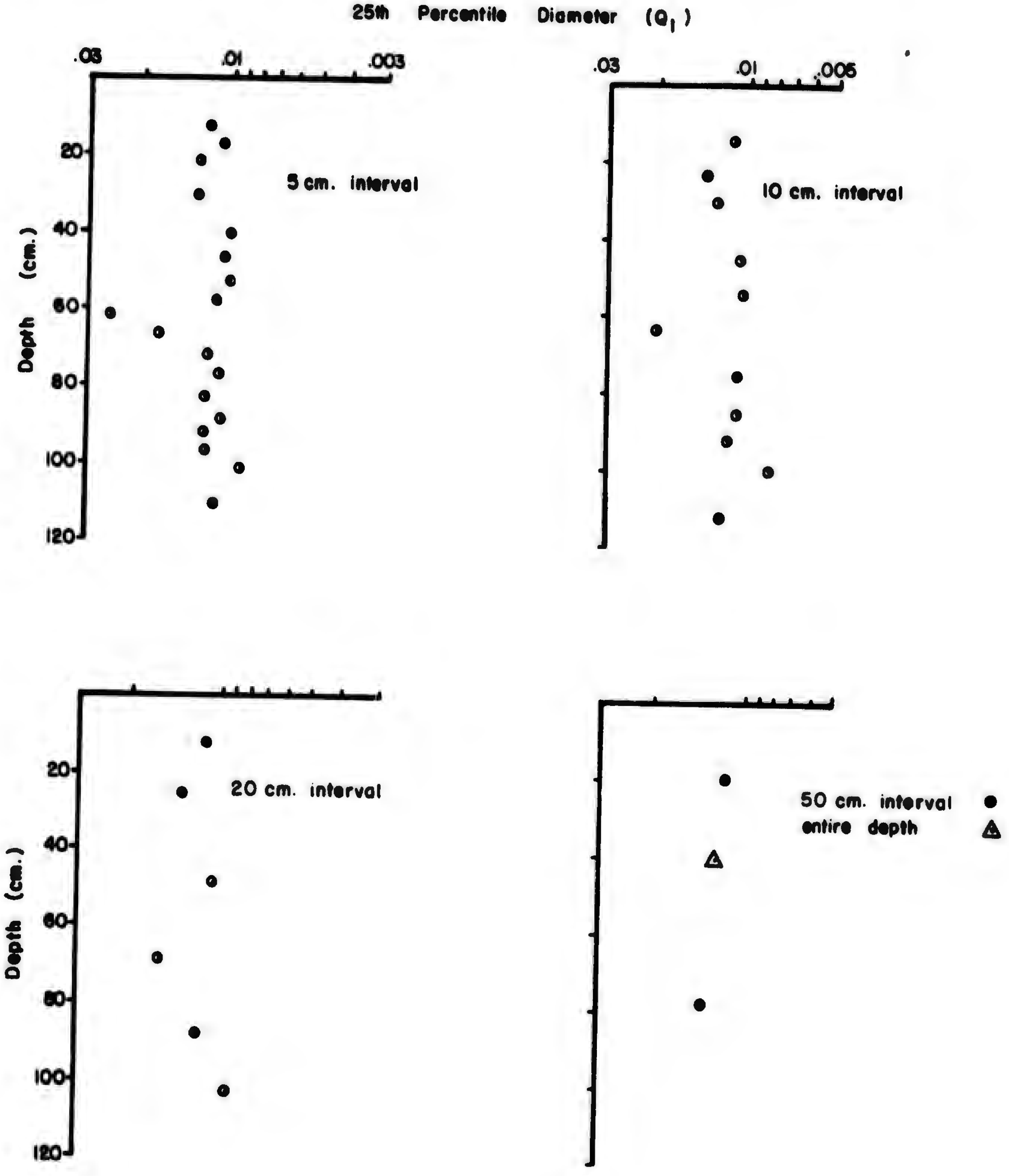


Figure E-6. Grain Size - 25th Percentile (Q_1) Diameter - Average Values

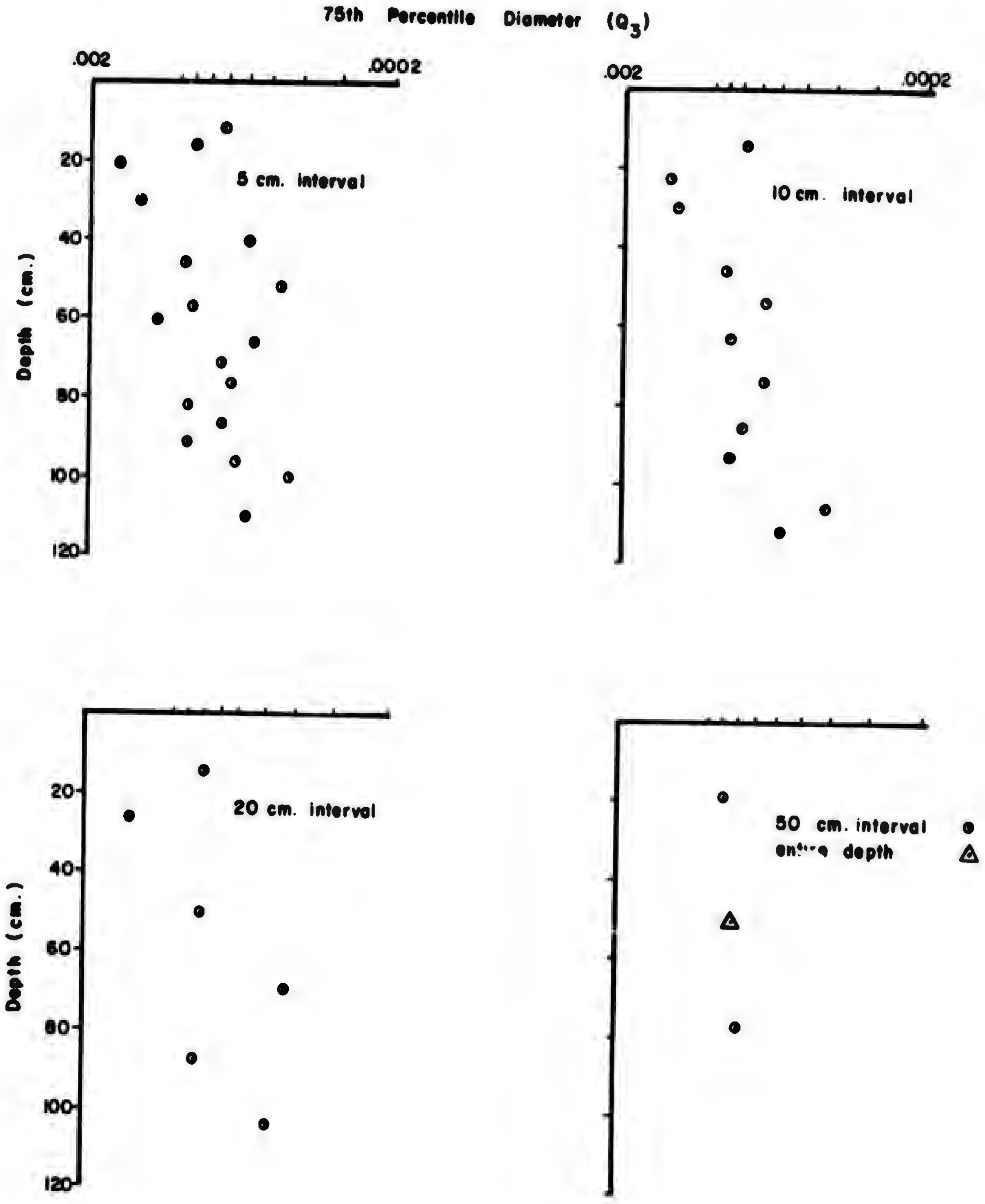


Figure E-7. Grain Size - 75th Percentile (Q_3) Diameter - Average Values

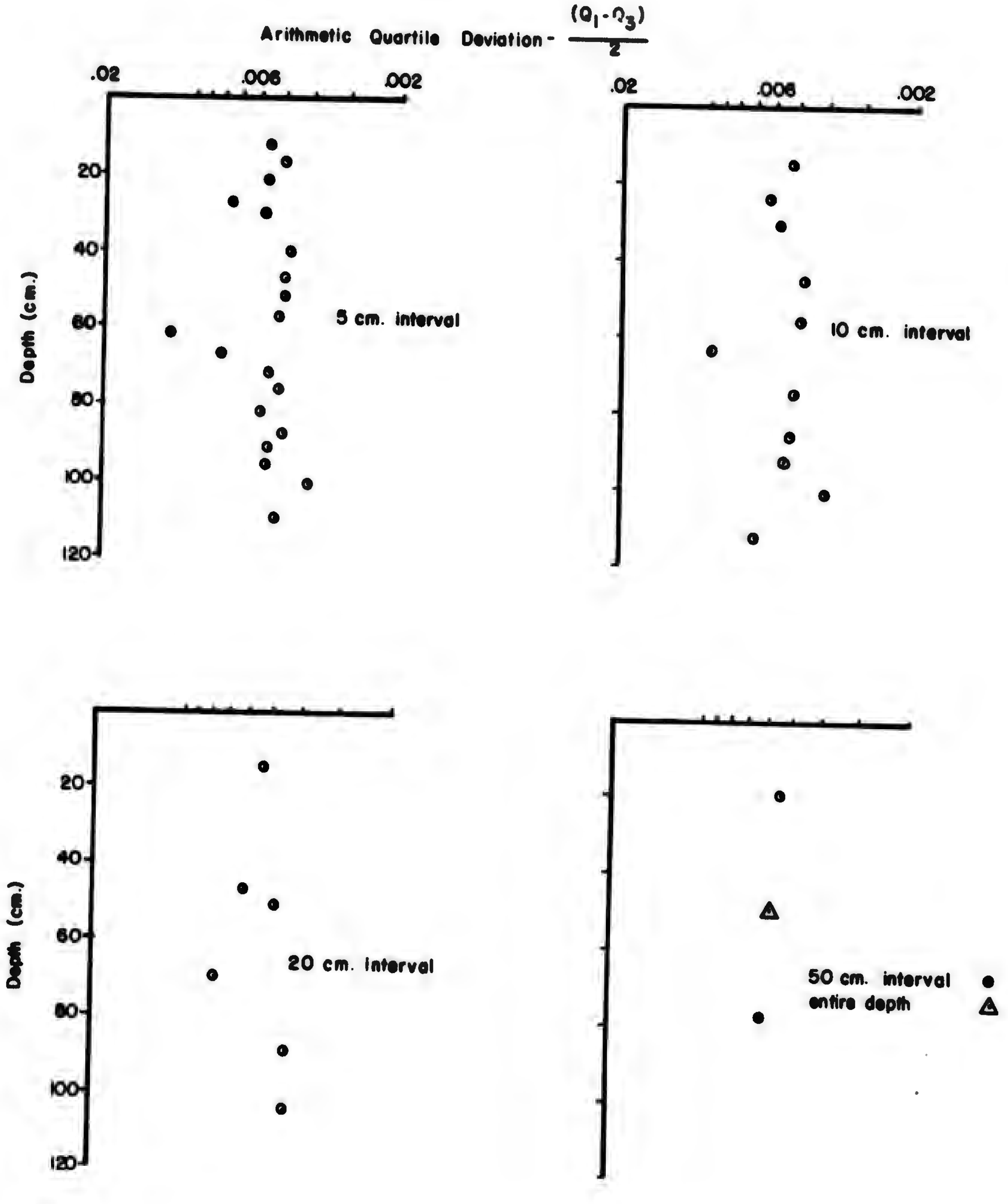


Figure E-8. Grain Size Sorting - Average Values

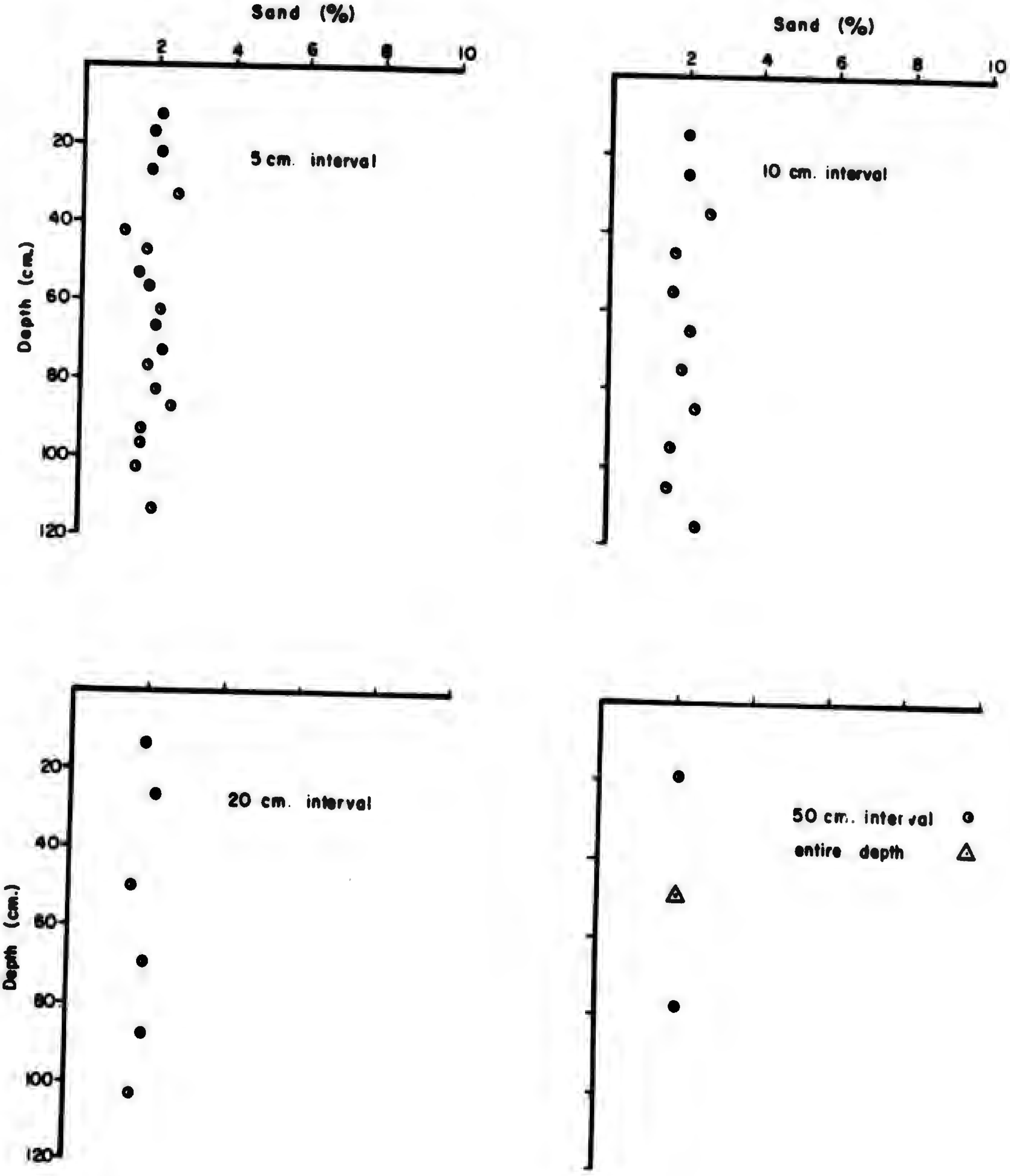


Figure E-9. Sand Percentage - Average Values

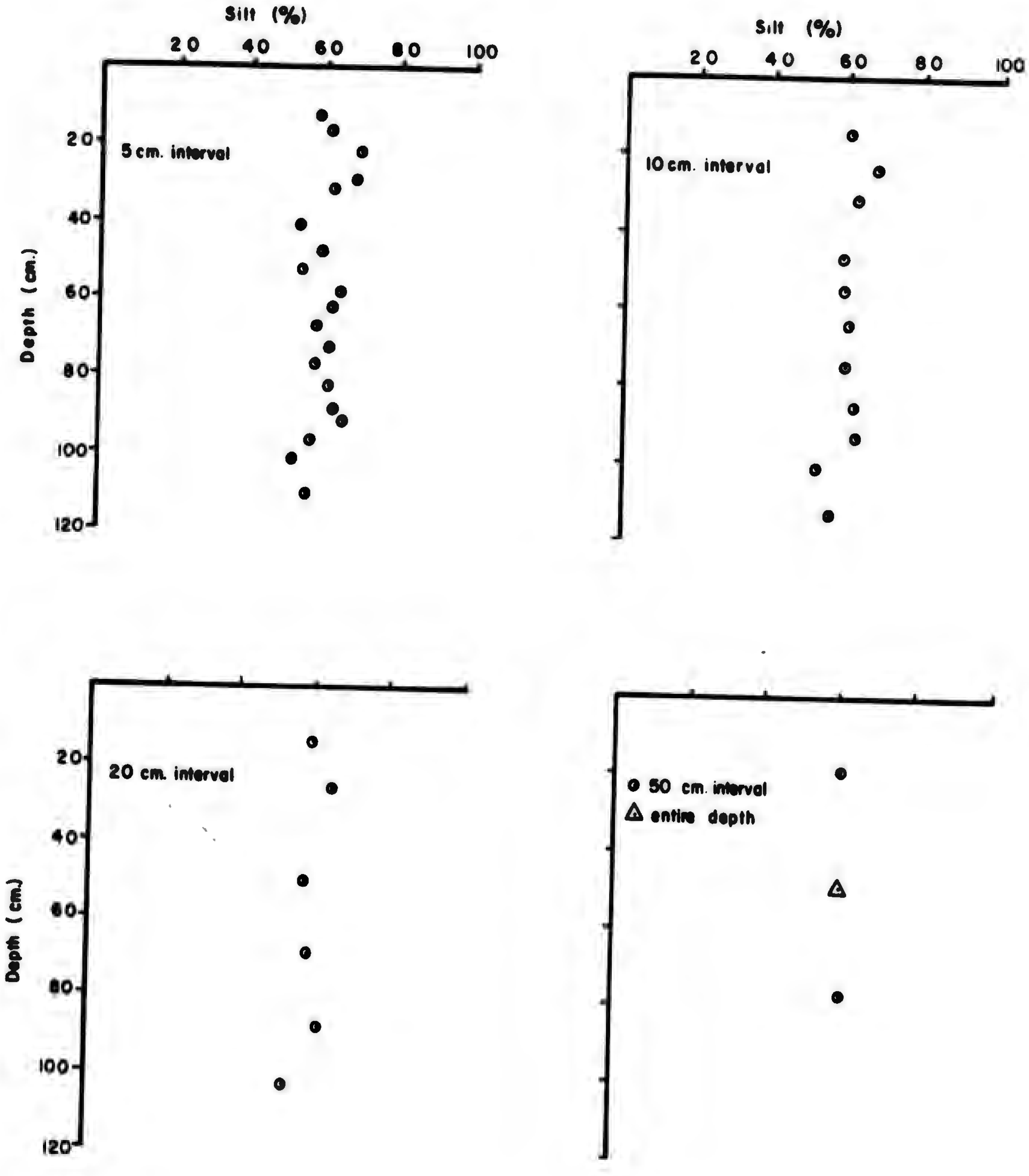


Figure E-10. Silt Percentage - Average Values

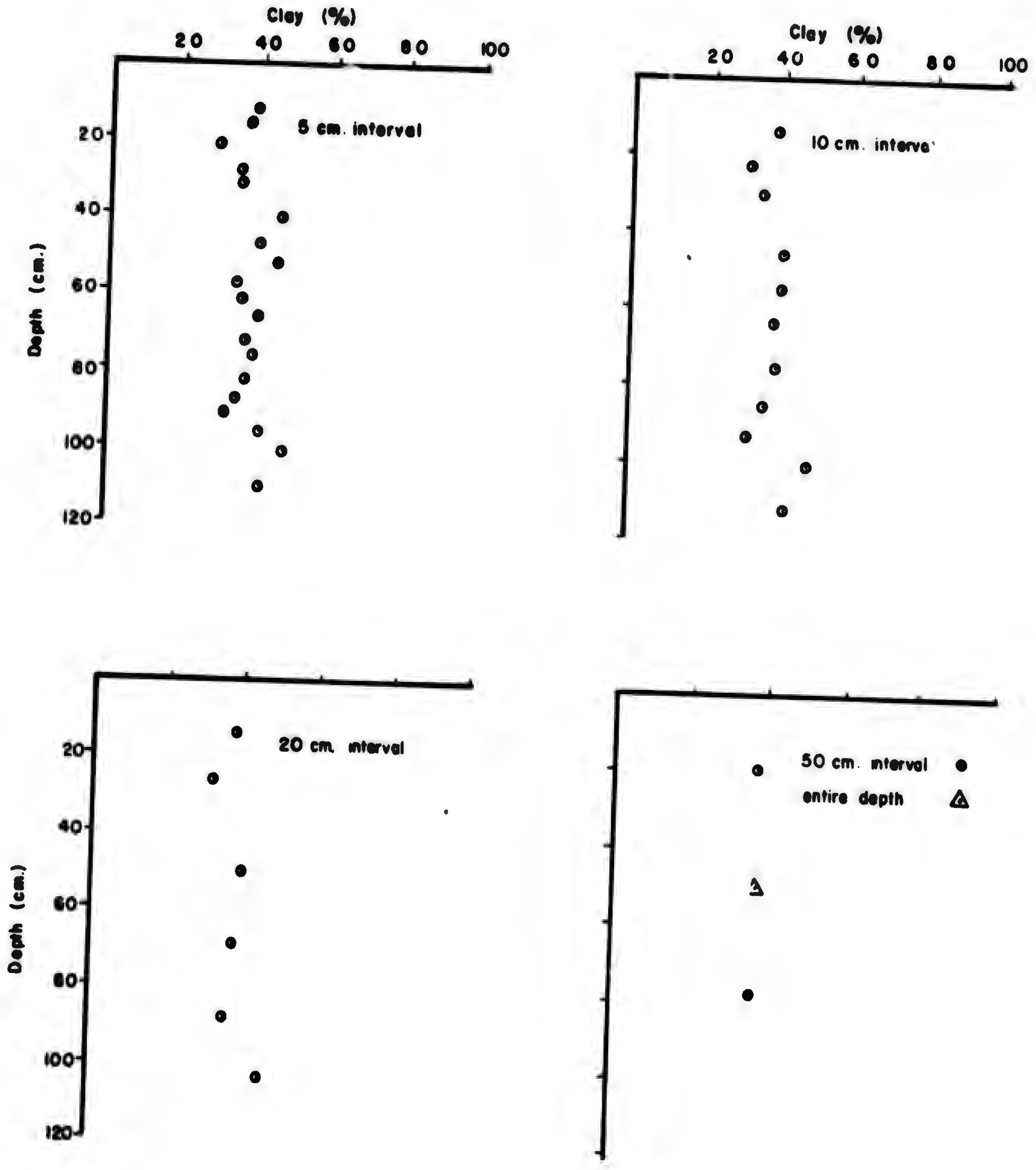


Figure E-11. Clay (<2μm) Percentage - Average Values

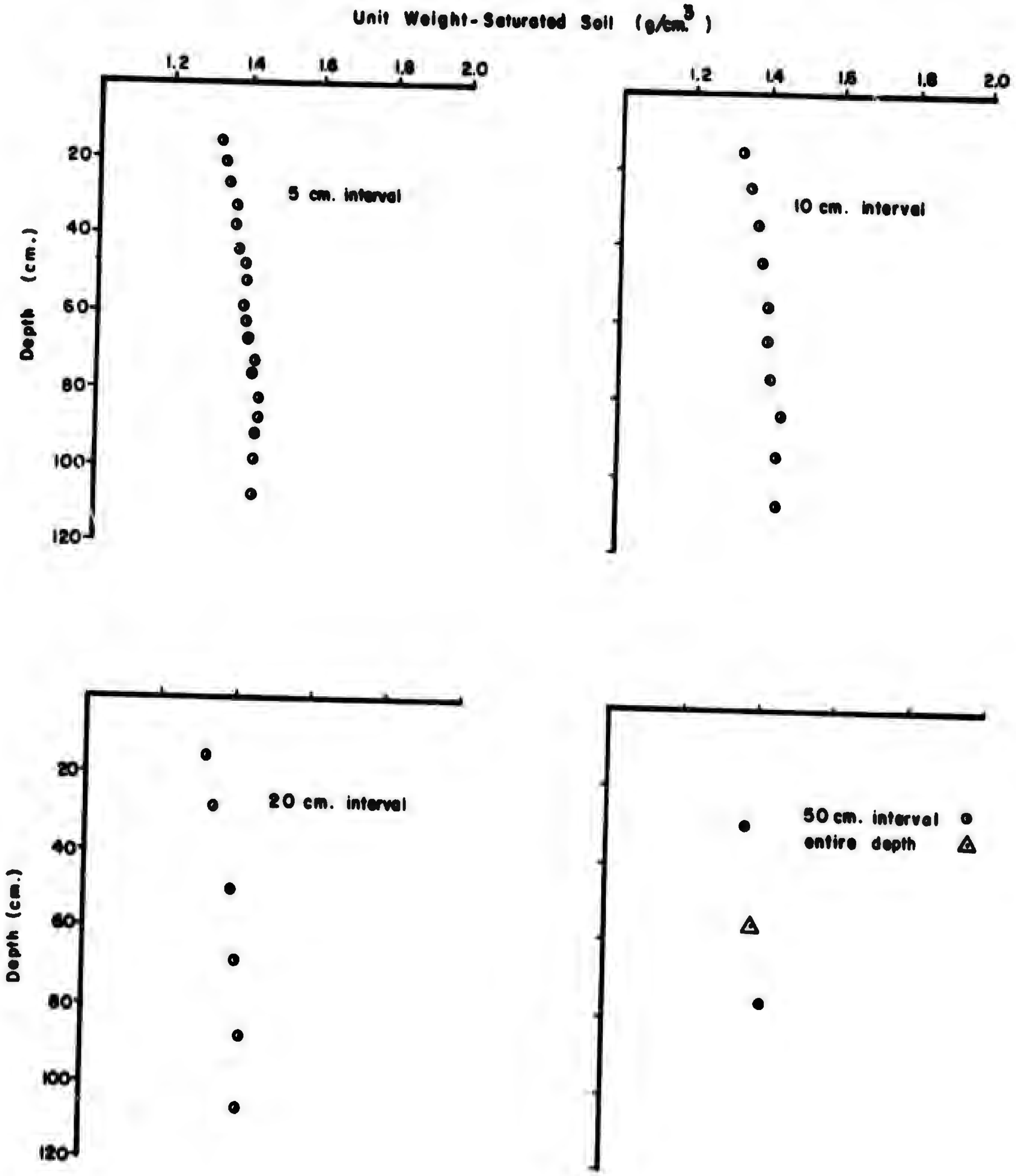


Figure E-12. Saturated Unit Weight - Average Values

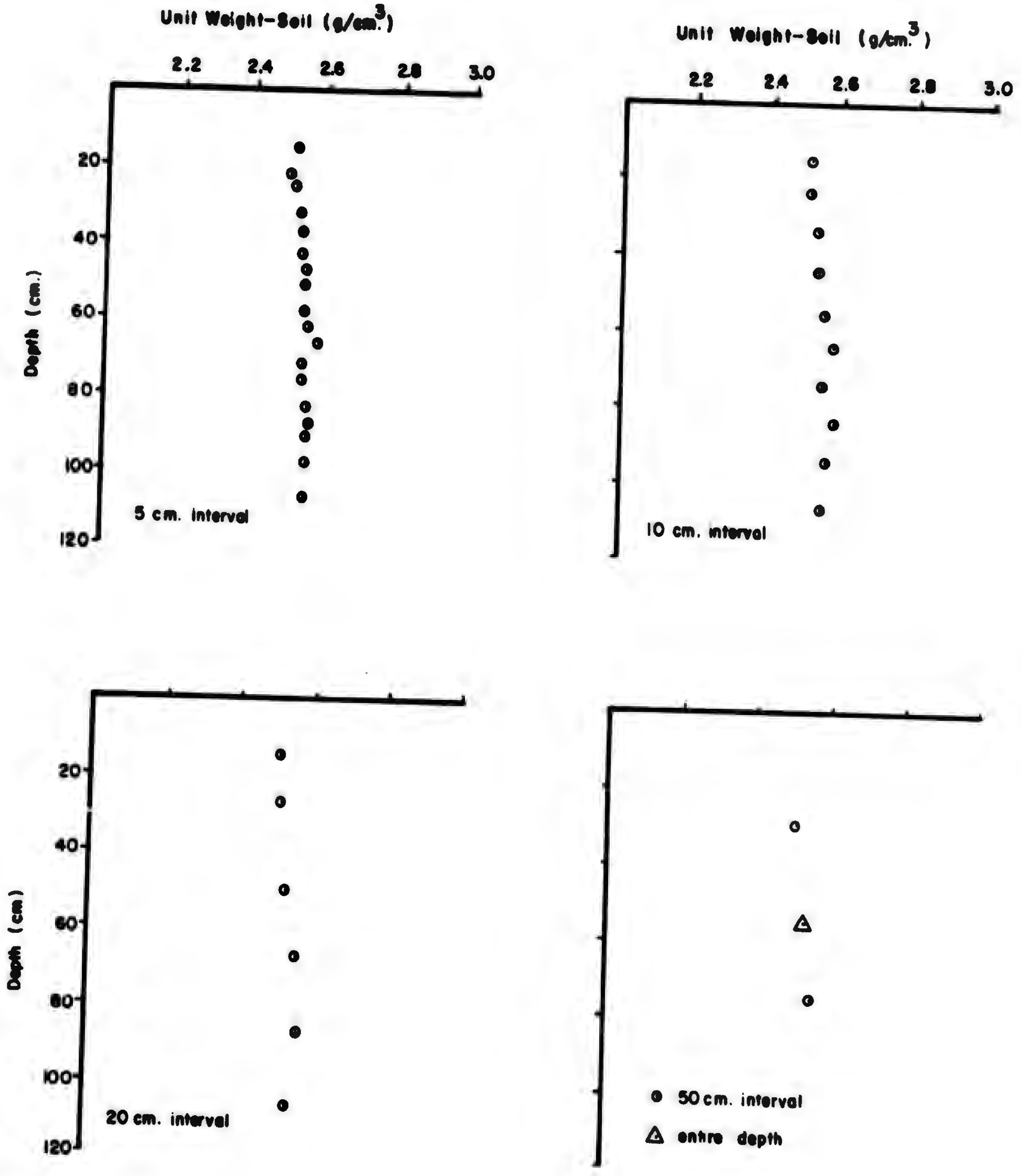


Figure E-13. Unit Weight (Dry) - Average Values

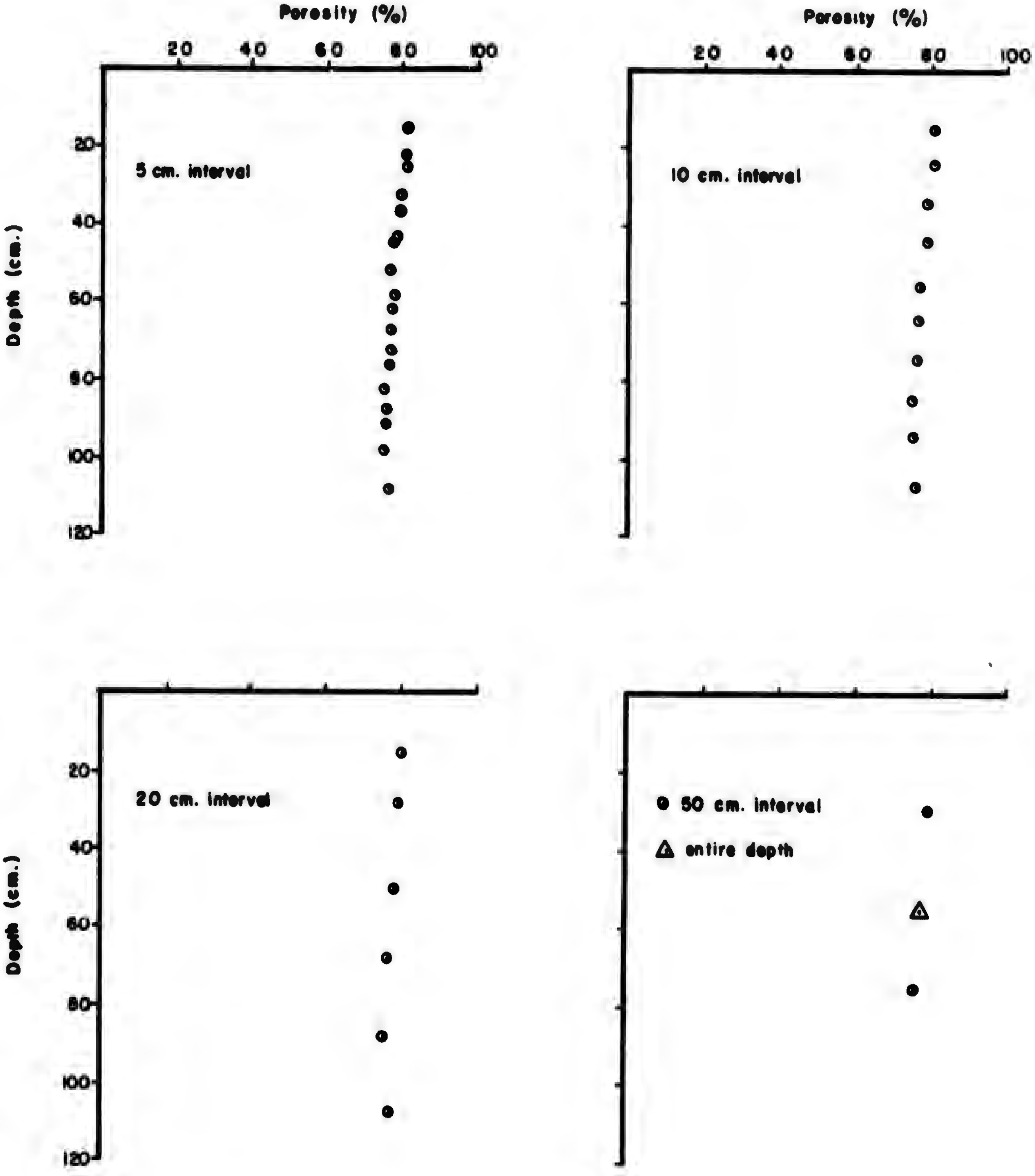


Figure E-14. Porosity - Average Values

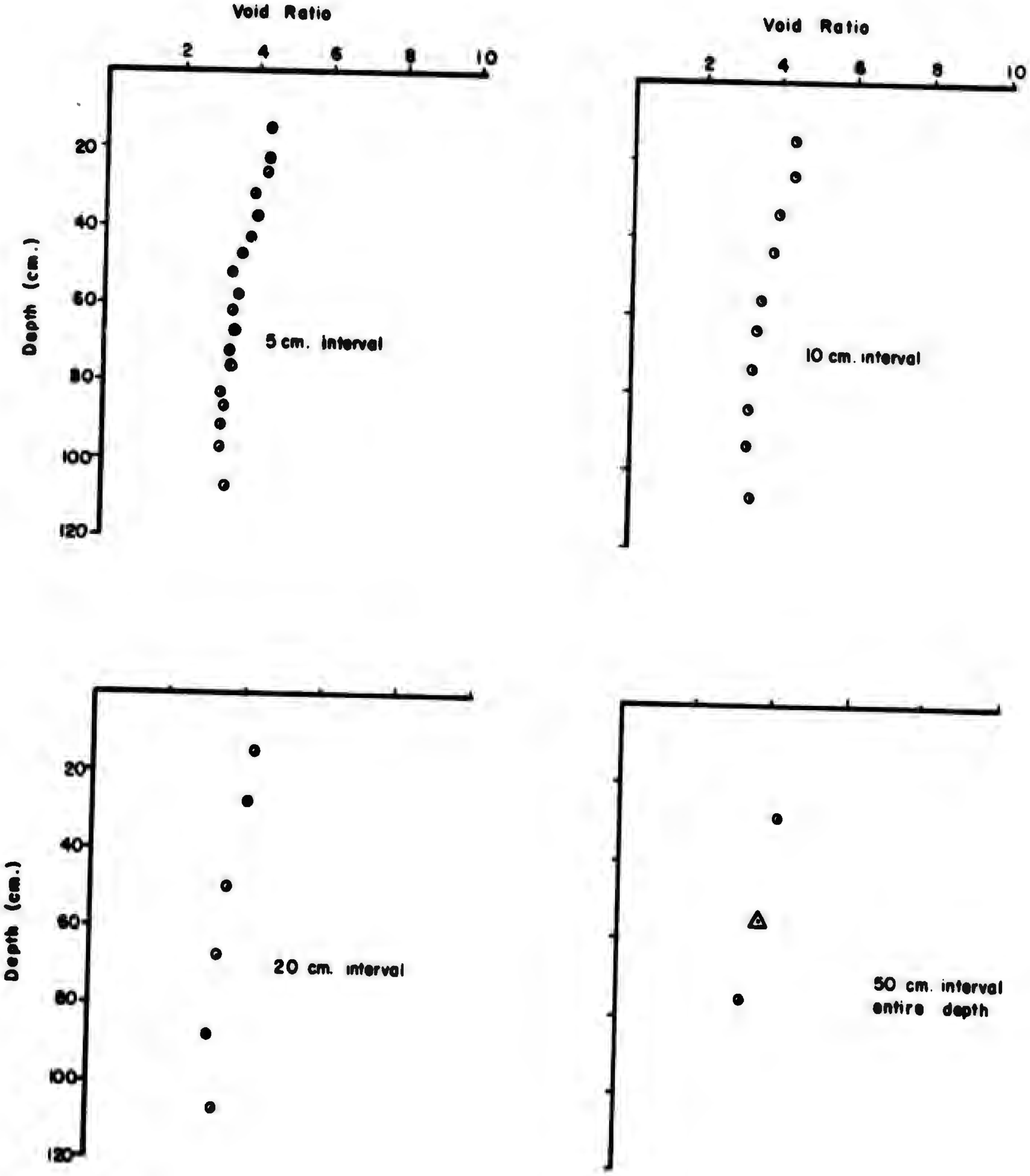


Figure E-15. Void Ratio (e) - Average Values

APPENDIX F

Correlation Matrices
For All Sediment Properties

TABLE F-1. CORRELATION MATRIX FOR DATA SET 1 (N = 25)

Variable	z	Md	Q_1	Q_3	Sd	St	Cl	Su (nat)	Su (rem)	γ_{sat}	γ	n	e	W_P	W_L	I_P	w
z	1.0	NS	NS	NS	NS	NS	NS	.826	.619	.893	.524	-.859	-.857	NS	NS	NS	-.919
Md		1.0	.922	.598	NS	.933	-.942	NS	-.435	NS	NS	NS	NS	NS	NS	NS	NS
Q_1			1.0	NS	NS	.900	-.903	NS	-.389	NS	NS	NS	NS	NS	NS	NS	NS
Q_3				1.0	NS	.596	-.604	NS	NS	NS	NS	NS	NS	.468	NS	NS	NS
Sd					1.0	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
St						1.0	-.997	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Cl							1.0	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Su (nat)								1.0	.625	.829	.618	-.820	-.836	NS	NS	NS	-.924
Su (rem)									1.0	.623	.589	-.555	-.559	NS	NS	NS	-.625
γ_{sat}										1.0	.540	-.946	-.955	NS	NS	NS	-.912
γ											1.0	-.559	-.579	NS	NS	NS	-.779
n												1.0	.989	NS	NS	NS	.886
e													1.0	NS	NS	NS	.903
W_P														1.0	NS	NS	NS
W_L															1.0	.763	NS
I_P																1.0	NS
w																	1.0

NOTE: Symbols for soil properties are defined in Table 2.
NS - correlation coefficient is not significant at the 95% confidence level.

TABLE F-2. CORRELATION MATRIX FOR DATA SET 2 (N = 116)

Variable	**z**	**Md**	Q_1	Q_3	**Sd**	**St**	Cl	Su (nat)	Su (rem)	γ_{sat}	γ	**n**	**e**	**w**
z	1.0	NS	NS	NS	NS	NS	NS	.818	.721	.805	.331	-.770	-.826	-.871
Md		1.0	.856	NS	.359	-.714	-.748	-.362	-.453	NS	NS	.276	.289	.201
Q_1			1.0	NS	.227	.742	-.751	-.352	-.445	NS	NS	.264	.272	.191
Q_3				1.0	.196	NS	NS	NS	NS	NS	NS	NS	NS	NS
Sd					1.0	NS	-.275	NS	NS	NS	NS	NS	NS	NS
St						1.0	-.988	NS	-.256	NS	NS	NS	NS	NS
Cl							1.0	NS	.254	NS	NS	NS	NS	NS
Su (nat)								1.0	.894	.734	.260	-.758	-.807	-.866
Su (rem)									1.0	.635	.245	-.683	-.716	-.759
γ_{sat}										1.0	.362	-.601	-.698	-.795
γ											1.0	-.300	-.325	-.282
n												1.0	.980	.751
e													1.0	.808
w														1.0

TABLE F-3. CORRELATION MATRIX FOR DATA SET 3 (N = 176)

Variable	z	Su (nat)	Su (rem)	γ_{sat}	γ	n	e	w
z	1.0	.798	.727	.736	.296	-.683	-.756	-.834
Su (nat)		1.0	.915	.694	NS	-.676	-.760	-.861
Su (rem)			1.0	.610	NS	-.633	-.700	-.781
γ_{sat}				1.0	.239	-.397	-.548	-.754
γ					1.0	-.186	-.201	-.181
n						1.0	.974	.657
e							1.0	.751
w								1.0

TABLE F-4. CORRELATION MATRIX FOR DATA SET 4 (N = 375)

Variable	z	Su (nat)	Su (rem)	w
z	1.0	.895	.824	-.816
Su (nat)		1.0	.923	-.846
Su (rem)			1.0	-.767
w				1.0