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Heavy-Mineral Reconnaissance off the Gulf Coast of Northwest Florida

Heavy-Mineral Reconnaissance off the Gulf Coast of Northwest Florida

Final Report

Submitted to

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by the

Florida Geological Survey

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INTRODUCTION

The United States Minerals Management Service (MMS) in conjunction with the Texas Bureau of Economic Geology/University of Texas at Austin (BEG/UT) sponsored the Continential Margins Program in order to promote research into the occurrence of economic minerals on the continental margins of the United States. This report to MMS is the result of the third year funding through a cooperative agreement between the Florida Geological Survey and MMS/BEG/UT.

This investigation was undertaken in order to examine the depth distribution of heavy-mineral deposits off the Gulf of Mexico coast of Northwest Florida. This study also contributes valuable granulometric data needed to assess potential off-shore sand deposits. It is a continuation of the year one research effort aimed at analyzing the distribution of heavy minerals in bottom grab samples in this area. A systematic effort was made to identify areas of likely concentration of heavy minerals, using two lines of approach.

First, utilizing the results of the year one study, areas showing the greatest concentrations of heavy minerals were delineated. The recognition of these areas resulted from literature surveys and sample analyses completed for the year one investigation and surveying any more recent literature on the area.

Second, high resolution seismic profiling was utilized in order to further investigate and locate bars and shoals shown on the bathymetric charts of the area. Numerous track lines were run providing detailed vertical profiles of the features (Figure 3).

Based on the above reconnaissance, locations were selected for the collection and detailed mineralogic/sedimentologic analysis of a set of vibrocores ranging in length up to 6 meters. In combination with the previous surface mineral studies, these cores provide accurate and useful information on the potential for economic heavy-mineral resources on the Northwest Florida shelf.

Acknowledgements

The MMS provided funds for this investigation under the Continental Margins Program, Cooperative Agreement number 14-12-0001-30296. Coordination of the agreement was provided by the Texas Bureau of Economic Geology/University of Texas at Austin. We greatly appreciate the efforts of all the individuals associated with these two organizations who were involved with the project. The Florida Geological Survey particularly appreciates the efforts and the understanding of Mr. Mike Hunt

(MMS) and Mr. Doug Ratcliff and Ms. Carolyn Condon (BEG/UT).

The Florida Geological Survey greatfully acknowledges the efforts of Dr. Joseph Donoghue of Florida State University, who served as the principal investigator, and Ms. Michelle Allard, graduate student in Geology at Florida State University who served as co-investigator on the project (unpublished report to the Florida Geological Survey, 1988). Coordination of the research effort at the Florida Geological Survey was under Dr. Thomas Scott with valuable assistance from Mr. Jonathan Arthur. Much gratitude is due to Dr. Walter Schmidt, Chief of the Florida Geological Survey, for his efforts in alleviating problems which arose during the duration of this project. We also appreciate the drafting work of Mr. Jim Jones and Mr. Ted Kiper of the Florida Geological Survey.

The following people provided valuable assistance in the successful completion of this project: Mike Weinberg, of FSU Geology, who assisted in all of the field work, including the diving, and much of the preliminary heavy-mineral analysis. FSU Geology graduate students Sandee Weiterman, Shekhar Melkote, Jim Pospichal, Dave Clark, Steve Bedosky, Diane Donnally and Bob Fisher participated in the cruises and assisted with the coring and seismic work. Divers Tom Loftin, Anne Rudloe, Cathy Guinon and Carrie Philips provided essential support for the vibrocoring operation. Dean Milliken of the Florida Institute of Oceanography and Capt. Robert Millender and his crew on the R/V Bellows made the two cruises a successful and enjoyable experience. David Allison of FSU provided valuable computer help with the data reduction. Ami Kaharoeddin assisted with the settling tube analysis.

DESCRIPTION OF THE STUDY AREA

The area of this investigation is a portion of the northeastern Gulf of Mexico on the Florida inner continental shelf, (Figure 1), extending from offshore Saint George Island,(84 deg. 52.78 min. longitude) to offshore Panama City, (85 deg.44.86 min. longitude). The area is located within the Gulf Coast province. The subsurface geology is dominated by marine to shallow marine sediments. The total stratigraphic section encompasses over 50,000 feet (Murray,1960). The area is an extension of the Gulf Coastal Plain, an accumulation of gently-dipping Cretaceous to Tertiary sediments, whose source area is the Appalachian Mountains (Stewart, 1962). From approximately 80 km north of the present coastline southward a number of Pleistocene terraces occur. Their development is correlated with interglacial highstands of the sea.

The climate of the study area is classified as humid-semitropical. The mean annual temperature is 68.9 degrees F (20.5 deg. C). Mean annual rainfall is 142.8 cm (Schnable and

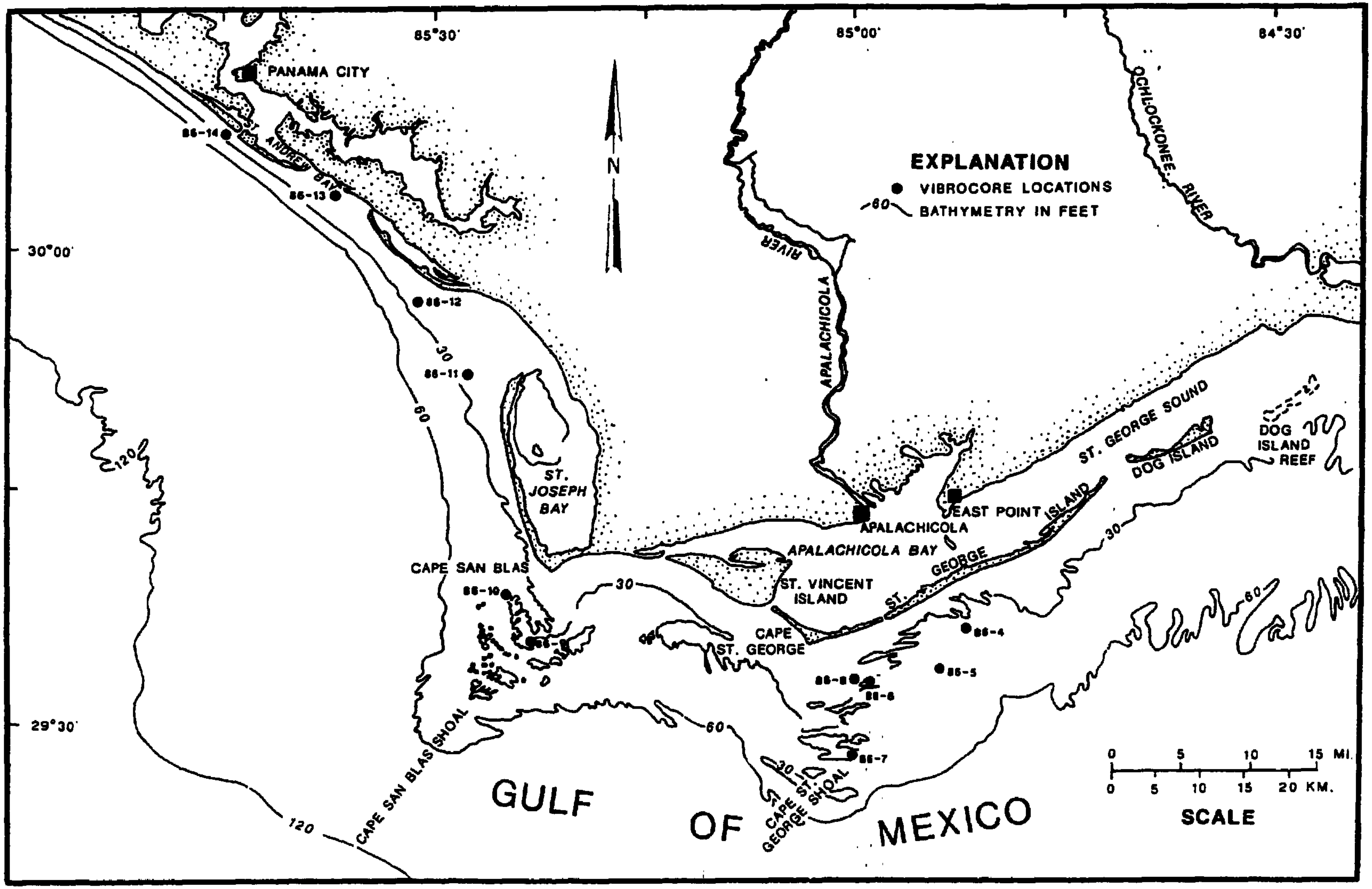

Figure 1 Regional setting showing general bathymetry and sample locations.

Goodell, 1968). Significant geomorphologic features in the study area include numerous estuaries, lagoons, and barrier islands. The northeastern Gulf of Mexico is a depositional basin for a number of coastal plain rivers, the largest in Florida being the Apalachicola River (Figure 1).

The Apalachicola River is formed 172 km north of Apalachicola Bay by the intersection of the Flint and Chattahoochee Rivers at Jim Woodruff Dam on Lake Seminole at the Florida-Georgia state line. The Flint and Chattahoochee Rivers begin in the Piedmont and Blue Ridge provinces of northern Georgia and Alabama, draining the Appalachian Piedmont and Coastal Plain regions. In the Blue Ridge the Chattahoochee River travels through mostly weathered sediments. In the Piedmont region, both rivers drain areas of Proterozoic-Paleozoic metasediments. The remainder of the drainage basin is veneered with Cretaceous to Recent sediments, comprised primarily of poorly consolidated marine sand and clays (Bedosky, 1987).

The watershed of the Apalachicola River covers an area of 50,800 square km. The drainage basin of the Apalachicola River proper covers 6,200 square km (Leitman, et al., 1982) and is 170 km long. With a flow which averages 651 m^3 sec^{-1}, the river delivers an average of 1.5 million tons of sediment to Apalachicola Bay per year (Isphording, 1985).

Major embayments in the study area are Apalachicola Bay/East Bay, a delta-estuary system at the mouth of the Apalachicola River, and Saint Joseph Bay on the west. Apalachicola Bay is separated from the Gulf of Mexico by three barrier islands: from east to west, Dog Island, St. George Island, and St. Vincent Island. Two other barriers occur in the Panama City area: Crooked Island and Shell Island.

Offshore shoals in the study area are extensively developed near St. George Island and Cape San Blas (Figure 1). These shoals, Cape San Blas Shoal and Cape St. George Shoal, extend to the southwest offshore from Cape San Blas and St. George Island, respectively. The western portion of the region is barren of shoals, possibly due to an increase of unidirectional wave energy in that region.

PREVIOUS INVESTIGATIONS

Several recent heavy-mineral studies have been completed in Florida and the northeastern Gulf of Mexico. Goldstein (1942) described the heavy-mineral assemblage characteristic of the Eastern Gulf Province. He reported that the assemblage consists of low- and high-rank metamorphic and igneous minerals transported by river systems draining the Appalachian Piedmont and Coastal Plain regions. Van Andel and Poole (1960) studied the sedimentary provinces of the Gulf of Mexico and their respective source areas. Rivers draining the southern Appalachians were considered primarily responsible for the sediments of the Eastern Gulf Province. The first phase of the present MMS/FGS study, a heavy-mineral reconnaissance of surface sediment along the coast of the northeastern Gulf of Mexico (Arthur et al., 1986) found the surface heavy-mineral suite to consist of ilmenite, kyanite, staurolite, tourmaline, zircon, and rutile, with minor amounts of epidote, sphene, amphibole, magnetite, sillimanite, leucoxene, and garnet. The samples in that study were retrieved using a Shipek grab sampler along shore-transverse transects from Pensacola eastward to Apalachee Bay.

Brenneman (1957) found a significantly larger proportion of heavy minerals in the fine-sand fractions than in the coarse fraction from off shore St. George Island. He explained the presence of heavy minerals as being due to a lack of current strength to remove the heavy minerals from the sediment.

Tanner et. al (1961) reported the heavy-mineral content in offshore shoals near the Apalachicola River delta. They hypothesized that the heavy-mineral abundance increases with depth in the shoals, and noted that this concentration with depth might prove to be economically viable. This investigation identified essentially the same heavy-mineral suite as Arthur et al.(1986).

Kofoed and Gorsline (1963) reported that the coarse sediment fraction off Apalachicola Bay was comprised of reworked relict quartz sand with minor percentages of transported heavy minerals or calcareous material derived locally. Fine-grained material in the area was believed to be a contribution of the Apalachicola River. Ware and Kirkpatrick (1981) conducted a shallow drilling project on Cape St. George Shoal. Percentages of heavy minerals present in twenty test wells ranged from 0.04% to 2.83%. Only 5 samples out of 95 total contained heavy-mineral percentages greater than 1%. The heavy-mineral suite reported in their study, and in Stapor's (1973) study mentioned below, is in general agreement with the suite described in Arthur et al.(1986).

Lader (1974) investigated the heavy-mineral distribution offshore from Cape San Blas. He hypothesized that the greatest heavy-mineral content would be in areas of highest energy and that heavy minerals would be sorted with respect to their mass densities. Conclusions from his work refuted that hypothesis, however, indicating an inverse relationship between mean grain size and heavy-mineral content. He concluded that size, rather than weight, was a significant factor relating to heavy-mineral abundance. Stapor (1973a,b) researched the delivery processes responsible for the deposition of heavy minerals in the vicinity of Apalachicola, Florida. In the Gulf of Mexico a fine-grained, heavy-mineral-rich sand is concentrated and later deposited on the beach as a result of transport processes in the Gulf which remove the coarse material from the original sediment. In the bays and sounds, fines are removed and coarser deposits remain. This is due to the lower energy conditions in these areas.

Grosz and Escowitz (1983) conducted a heavy-mineral reconnaissance of Florida's Atlantic continental shelf. The survey focused on economic minerals, specifically titanium oxide minerals, and zirconium/hafnium and rare-earth bearing minerals derived from igneous and metamorphic terranes of the Appalachians and transported by fluvial and long shore processes. Flores and Shideler (1978) studied the outer continental shelf offshore from Texas. They related heavy-mineral variations to provenance and ascribed local variability to genetic differences in sea-floor sediments. Other regional heavy-mineral projects completed offshore from Mississippi and Alabama include Hsu (1960), Foxworth et al. (1962), Drummond and Stow (1979), and Doyle and Sparks (1980). Saffer (1955), reported the heavy-mineral content in river and beach sand samples of northwest Florida, Georgia, and Alabama.

METHODS

Seismic Profiling In June of 1986, two research cruises were carried out on the R/V Bellows. The first cruise collected data utilizing the high-resolution GEOPULSE sub-bottom seismic profiler. The GEOPULSE system has a high-resolution sound source, which at 350 joules produces an acoustic source level of 120 dB, and generates a freqency spectrum of 400 Hz to 14 kHz. A catamaran towed behind the vessel serves as a lightweight platform for the sound source. The instrument can profile sub-bottom stratigraphy with a resolution of one meter to a depth of about 50 meters. Approximately 320 km of transects were run from Dog Island Reef, Florida westward to Panama City, Florida (Figure 2). Sedimentary structures, such as sand bodies and paleo-channels, were mapped as potential locations for vibrocoring on the second cruise. Examples are shown in Figure 3.

Vibrocoring Eleven 7.6 cm diameter vibrocores were retrieved on the second five-day cruise, ranging in length from 2 to 6 meters. Figures 1 and 2 show the coring locations. Details of the locations are given in Appendix A. Core logs for each core are presented in Appendix B.

Laboratory Methods

A flowchart of laboratory procedures is shown in Figure 4. The cores were initially split and logged. Core logs are detailed in Appendix B. Samples weighing approximately 100 grams each were taken at 20 cm. intervals from the centers of the cores. The samples were then oven-dried at 40 degrees Celsius and a split

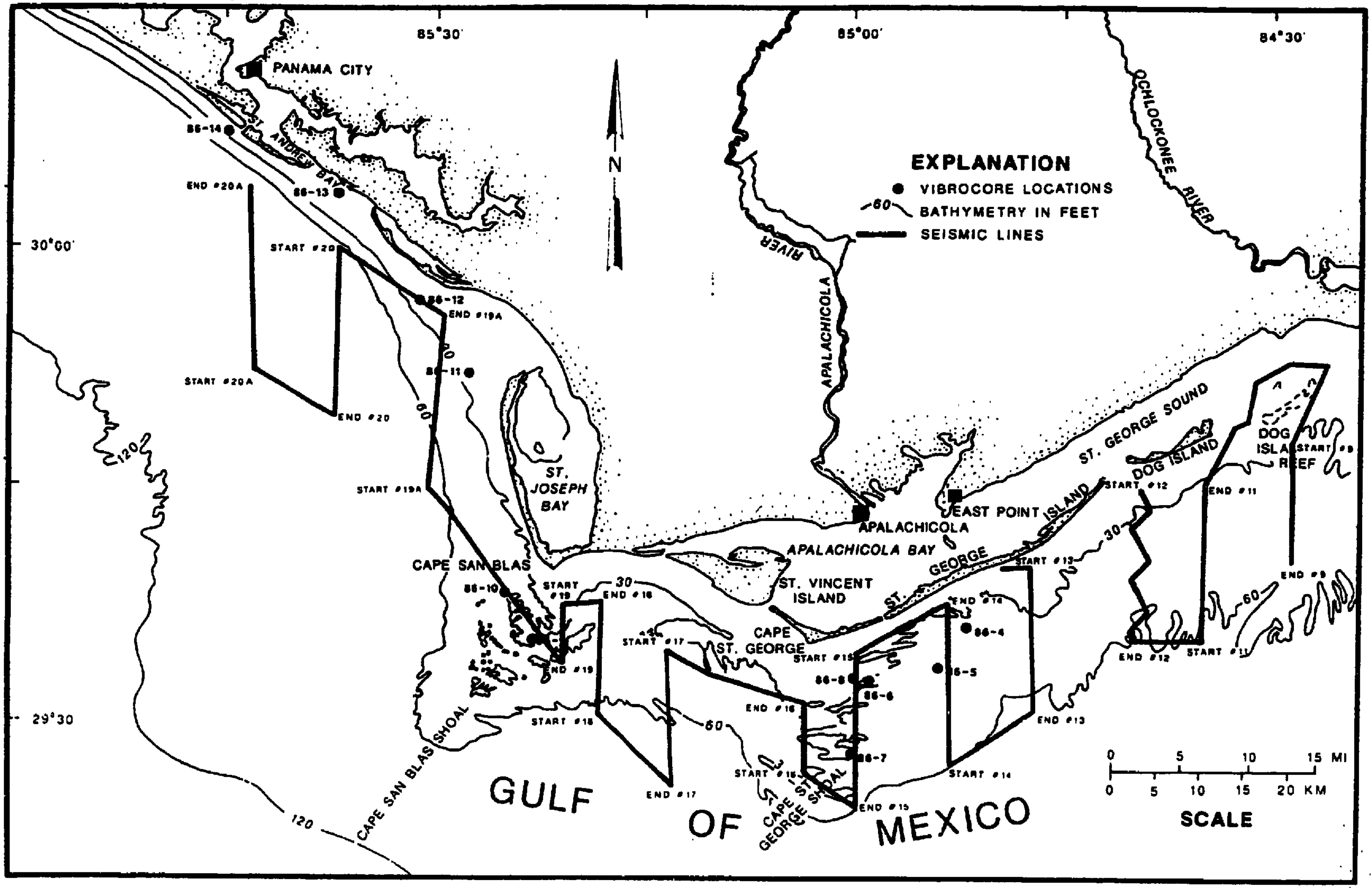

Figure 2 GEOPULSE track lines for seismic survey, showing locations of profiles in figure 3.

Figure 3 Selected GEOPULSE sub-bottom seismic profiles

Figure 3a Portion of seismic line between transects 19 and 19a

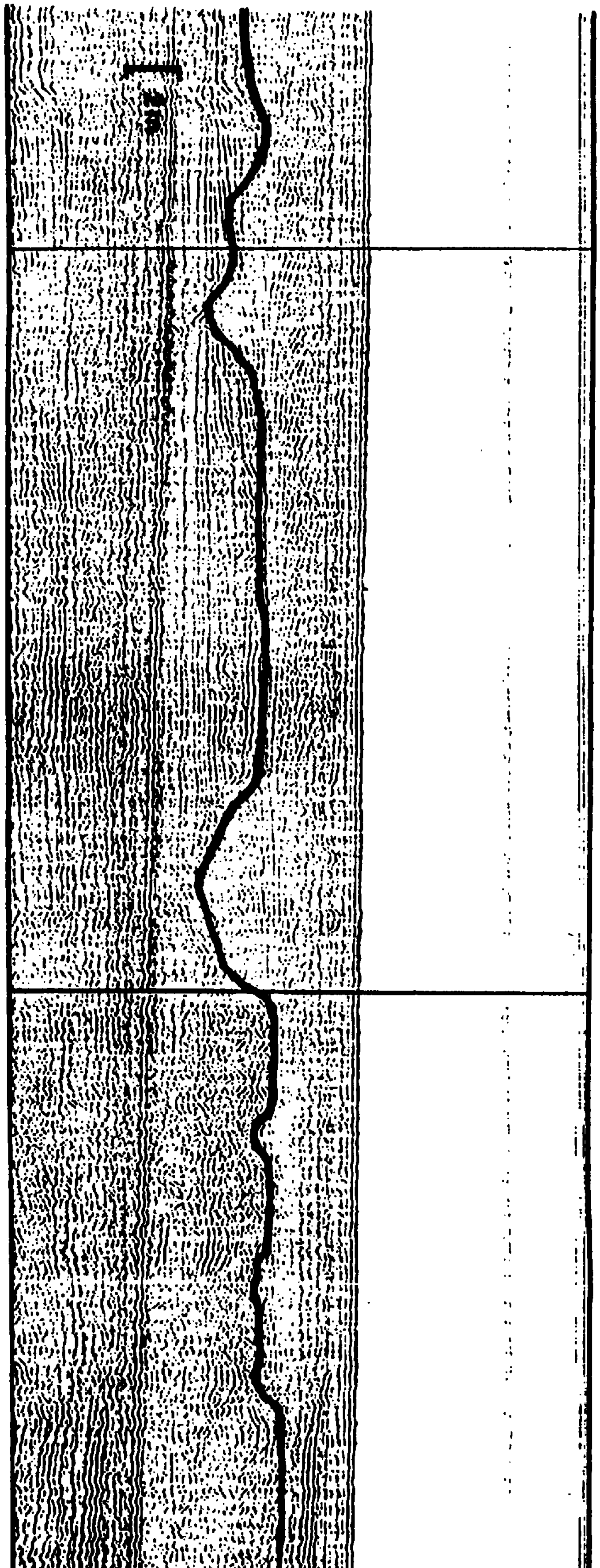

Figure 3b Portion of seismic transect 15

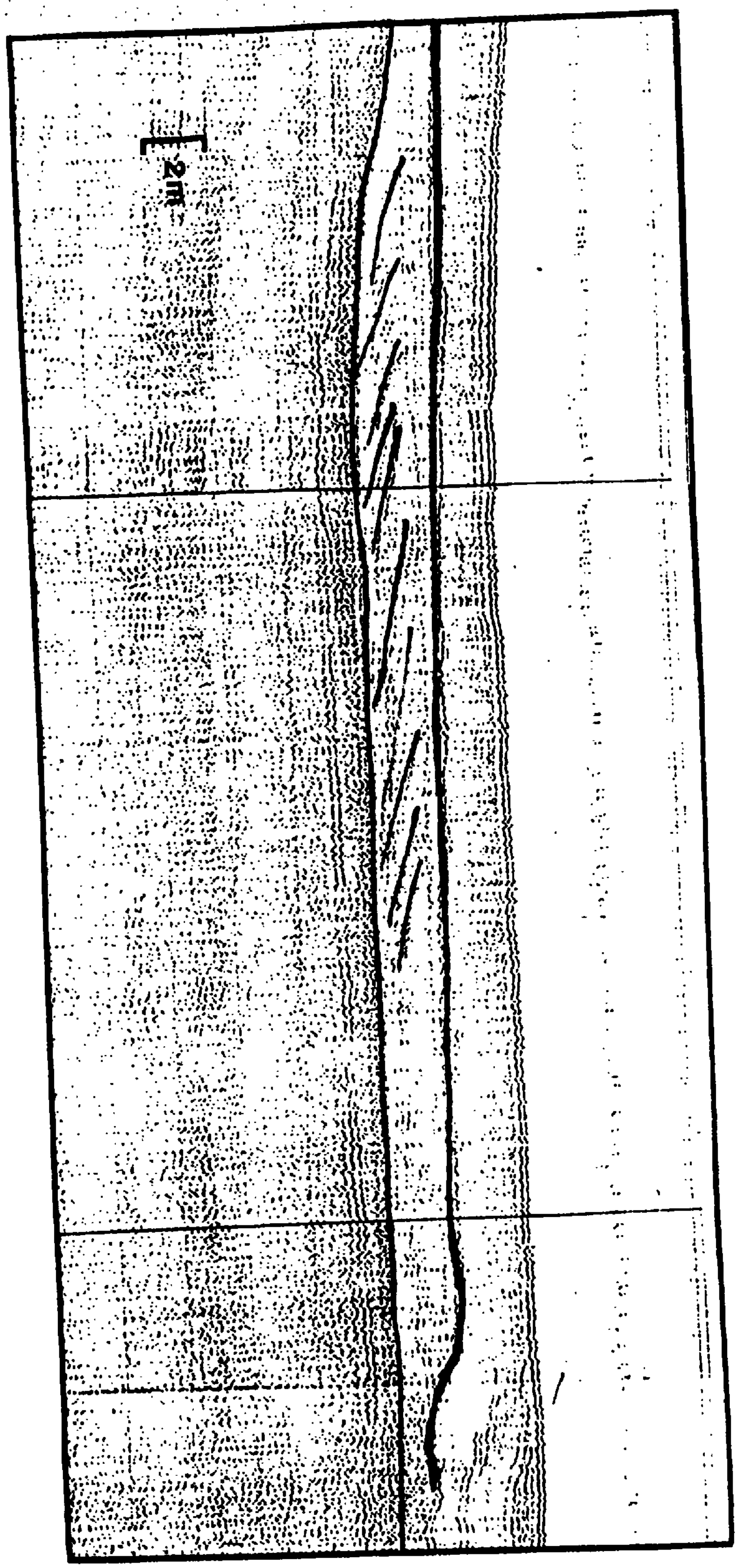
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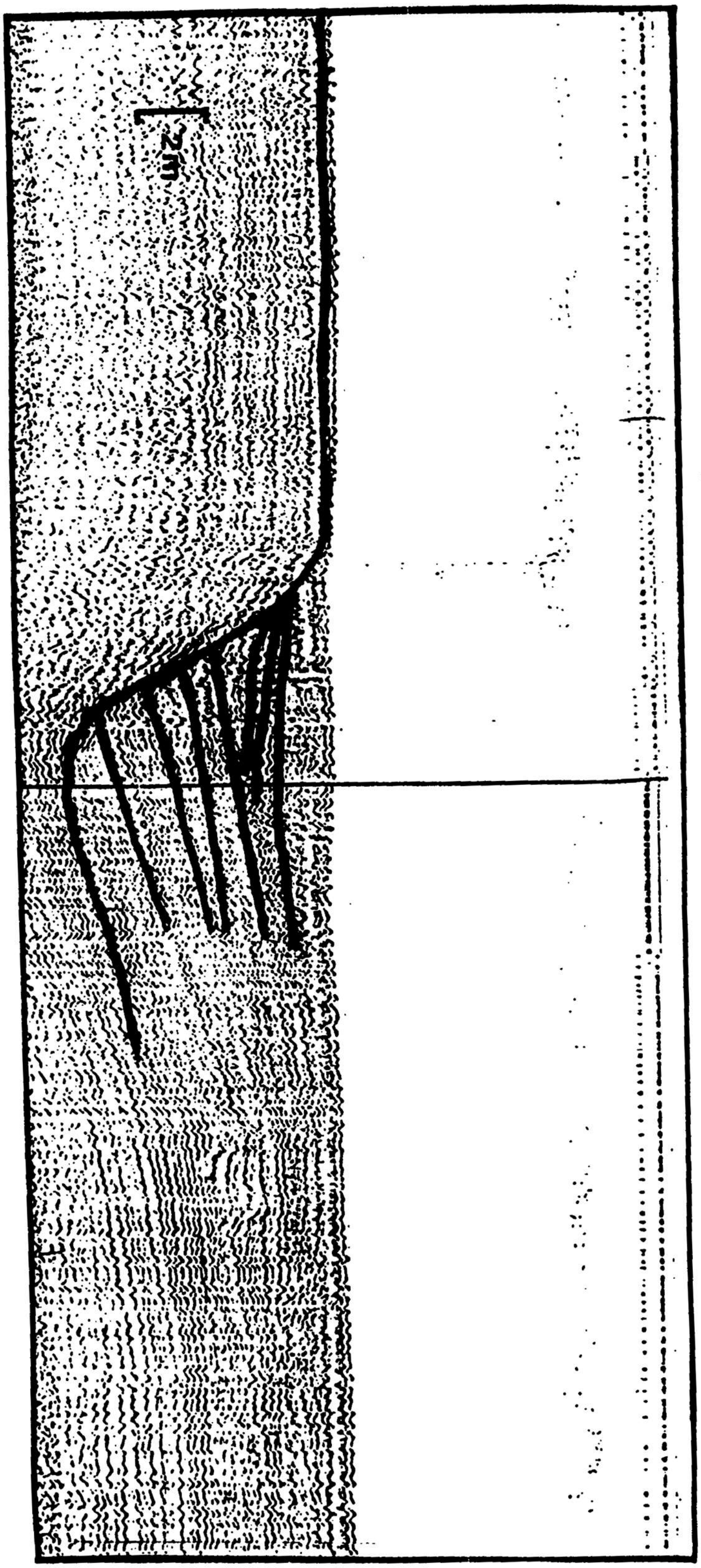
Figure 3c Portion of seismic line between transects 13 and 14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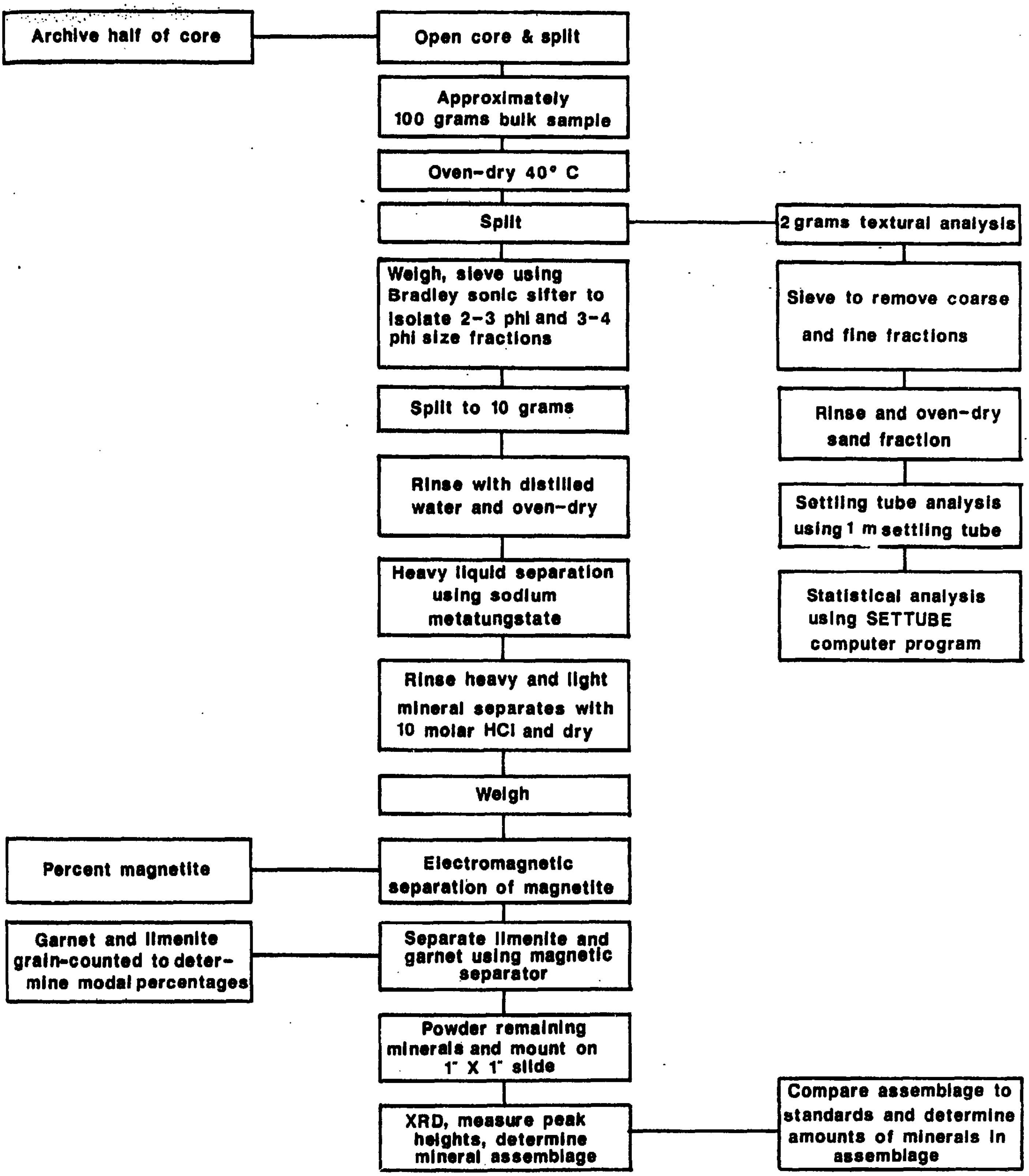


Figure 4 Flowchart of laboratory procedures.

was set aside for textural analysis. A sieving comparison was made using the ro-tap (Mizutani, 1963) method and the Bradley Sonic Sifter. Similar results were generated from each. The material was sieved using the Sonic Sifter at whole-phi intervals to isolate the 2-3 and 3-4 phi fractions. The whole-phi intervals were split down to ten grams, rinsed with distilled water and oven-dried.

<u>Heavy-mineral Separation</u> Heavy-mineral separation was achieved by use of the heavy liquid sodium metatungstate (density 2.90 g/cm^3). Ninety milliliters of heavy liquid were mixed with a sample in a separatory funnel. The funnel was then centrifuged for forty-five minutes at 1500 rpm. The separated heavy minerals were retrieved from the funnel and rinsed with 10 molar hydrochloric acid to avoid deposition of a tungsten precipitate on the grains. The heavy minerals were then rinsed with double-distilled water and dried again. The light minerals remaining in the funnels were treated in the same manner as the heavy minerals. Both fractions of the samples were weighed to obtain relative dry weight percentages in each sample (Appendix C).

The components of the heavy-mineral suite were analyzed by first separating the magnetite using an electromagnet. Ilmenite and garnet were separated from the bulk heavy minerals by a Frantz Isodynamic Magnetic Separator. The separator was set at 0.4 amps, with tilt and side slope angles of 25 and 20 degrees respectively, to separate garnet and ilmenite from the remainder. The garnet and ilmenite mixture was weighed and grain-counted under a binocular microscope to calculate relative modal percentages of each (Appendices D and E).

<u>X-Ray Diffractometry</u> The remaining heavy-mineral assemblage was analyzed using the Philips PW-1710 automated X-ray diffractometer with a copper target. The samples were prepared by powdering for 3 minutes with a ball mill. The powder was spiked with a known weight of the mineral fluorite for use as a calibrating factor in quantitative X-ray diffractometry (XRD). The mixture was mounted on a 2.6 cm x2.6 cm glass microscope slide using a Duco cement and acetone slurry. The slides were X-rayed within a range of 10 to 70 degrees 2Θ at generator settings of 20 milliamps and 40 kilovolts.

The diffraction peaks and their heights from the X-ray spectra were compared to standards prepared for this project using a variety of heavy-mineral compositions and proportions. Peak height was used for ease of measurement and because preliminary tests showed that peak height is a reliable index of weight percent. To ascertain the reproducibility of the peak-height measurements, replicates were made for a number of the sample XRD slides. Ten of them were chosen at random and scanned. Peak heights were compared to the corresponding peaks on the sample slides. Average percent deviation for all of the measured peaks for each of the minerals identified in the replicate samples was 12 percent. This was a good level of repoducibility, based on extensive previous experimentation with powder diffraction. This was also based on the fact that all of the factors identified by Pryor and Hester (1969) and Van Andel (1959) as having a measurable effect on reproducibility were minimized.

The peaks and their d-spacing shown below were used for quantifying the XRD data for the nine heavy minerals found in the powdered samples. For each mineral in every sample, one of the peaks in the list below was located and its height above background was measured. Confirmatory peaks were then searched in order conclusively to identify the mineral. The peak height was then converted to a dimensionless ratio by dividing it by the height of one of the peaks attributable to the fluorite spike, whose weight percentage in each sample was known. This normalization enabled the quantitative determination of the percentage of that mineral in the sample. For a few samples, an additional peak was used for sillimanite, sphene and zircon, as shown below.

Mineral Name	Peak Label	d -spacing (Angstroms)
Epidote	(Ep1)	2.90
Hornblende	(Ho1)	3.14
Kyanite	(Ky1)	3.18
Rutile	(Ru1)	3.25
Sillimanite	(Si1)	3.42
	(Si2)	3.37
Sphene	(Sp2)	3.00
	(Sp3)	2.61
Staurolite	(St1)	2.69
Tourmaline	(To2)	2.56
Zircon	(Zi1)	3.30
	(Zi2)	4.43
Fluorite	(Fl1)	1.93
(Spike)	(Fl2)	3.15

The Florida Geological Survey holds some reservations concerning the use of the XRD for quantification and identification of heavy minerals. However, considering the non-economic quantities of the heavy minerals found within the study area as determined by heavy liquid separation, XRD and optical methods, we believe that these concerns are not critical to the resource evaluation. We also feel that XRD may provide a rapid, first approximation of the mineral suite and mineral abundances and is a valuable tool for resource investigations.

Textural Analysis   Textural analysis was carried out on the settling tube in the FSU Sedimentology Laboratory. The tube is modeled after Gibbs' (1974) device, which had a settling distance of 140 cm and a diameter of 12 cm. The Florida State University settling tube has a settling distance of 100 cm and a diameter of 13 cm. A Cahn digital electrobalance is connected to the settling tube system.

One hundred and twenty six samples from the cores underwent grain size analysis. The individual samples weighed between 0.5 and 2 grams. Each sample was first sieved using the Bradley Sonic Sifter to remove sizes coarser than -1 phi and finer than 4 phi. These two fractions were weighed on the Mettler balance and the percentages of the original sample weight were calculated. The remainder of the sample was rinsed with distilled water and oven-dried.

Statistical analysis of the settling tube data was achieved by use of the SETTUBE computer program, written by A. Kaharoeddin of Florida State University. The program is designed to calculate moment measures and histograms from points defining the slope of the settling tube printout of cumulative weight versus setting time. Textural data is presented in Appendix C.

RESULTS

Seismic Profiling

The seismic lines shown in Figure 3, totaling approximately 320 km, provided high resolution profiles of the upper 50 meters of the seafloor of the northeastern Gulf of Mexico inner shelf. These data in conjunction with the existing bathymetric maps were utilized in the selection of the vibrocoring sites. Numerous subsurface features were recognized on the profiles (Figure 3a-c).

The most commonly encountered subsurface structure was buried channels, representing ancient positions of the Apalachicola River, with its tributaries and distributaries. Other structures observed included subsurface lenticular sand bodies, and buried scarps. The first two probably represent nearshore or barrier island features while the third may be the result of dissolution of the Tertiary limestones that approach the surface in the easternmost part of the study area. Examples are shown in Figure 3.

Textural Analysis

The sample suite consists of a moderately sorted, finely-skewed fine sand. The percentage of fines is negligible in all samples except for two from Core 5. Mean percent of fines is less than 0.1 wt.%. Percentage of gravel (coarser than -1 phi or 2 mm) was zero in all samples. The gross textural data indicate that the depositional environment of the samples studied was one of moderate energy, with deposition dominated by fine to medium sand, and virtually no mud or gravel. Further analysis of the depositional environments of these sediments is obtained through the use of scatter plots of various parameters against each other (Figures 5-7). The results of these plots are compared to the results obtained from previous investigations that utilized measured grain size parameters from known environments.

Figure 5 is a plot of sample mean vs. standard deviation showing two fields labeled R (River) and B (Beach) as taken from Friedman (1967). It can be seen that most of the samples fall in the River field, although a significant number lie within the Beach field. The result underscores the interplay that has taken place on a continual basis throughout the study area, with the Apalachicola River and its distributaries migrating across the area during low-stands, and beaches developing during high-stands.

Figure 6 plots skewness vs. kurtosis, with another set of environmental fields from Friedman (1961). The fields represent Beach (B) and River (R) sand samples. Again, most of the samples cluster close to the line, with the scatter approximately equal on either side, indicating further that the environment was influenced by both beach and river hydrodynamic processes.

In order to determine if there were any east to west differences among the cores, the core mean grain size was plotted versus the core standard deviation. Results are shown in Figure 7. Once again Friedman's (1979) River (R) and Beach (B) fields are superimposed. It can be seen that the three easternmost cores and the three westernmost cores fall in the River field. The western cores may have been more influenced by ancient deltas to the west of the present one, located just east of the town of Apalachicola (Figure 1). The data, however, are still mixed - five cores plot in the Beach field.

Textural characteristics and heavy-mineral concentrations of the surface sediments in the study area were also checked for the presence of trends by analyzing both the surface vibracore samples from this study and the samples from transects 14 through 21 of the Arthur, et al. (1986) investigation. No regional trends were found.

For the five longest cores (cores 4, 6, 12, 13, and 14) depth profiles were plotted for mean grain size (Figures 8-12), standard deviation (Figures 13-17). A general coarsening upward trend can be detected in most of the cores in the study area. This trend is most prominant in cores 13 and 14 (Figures 11 and 12).

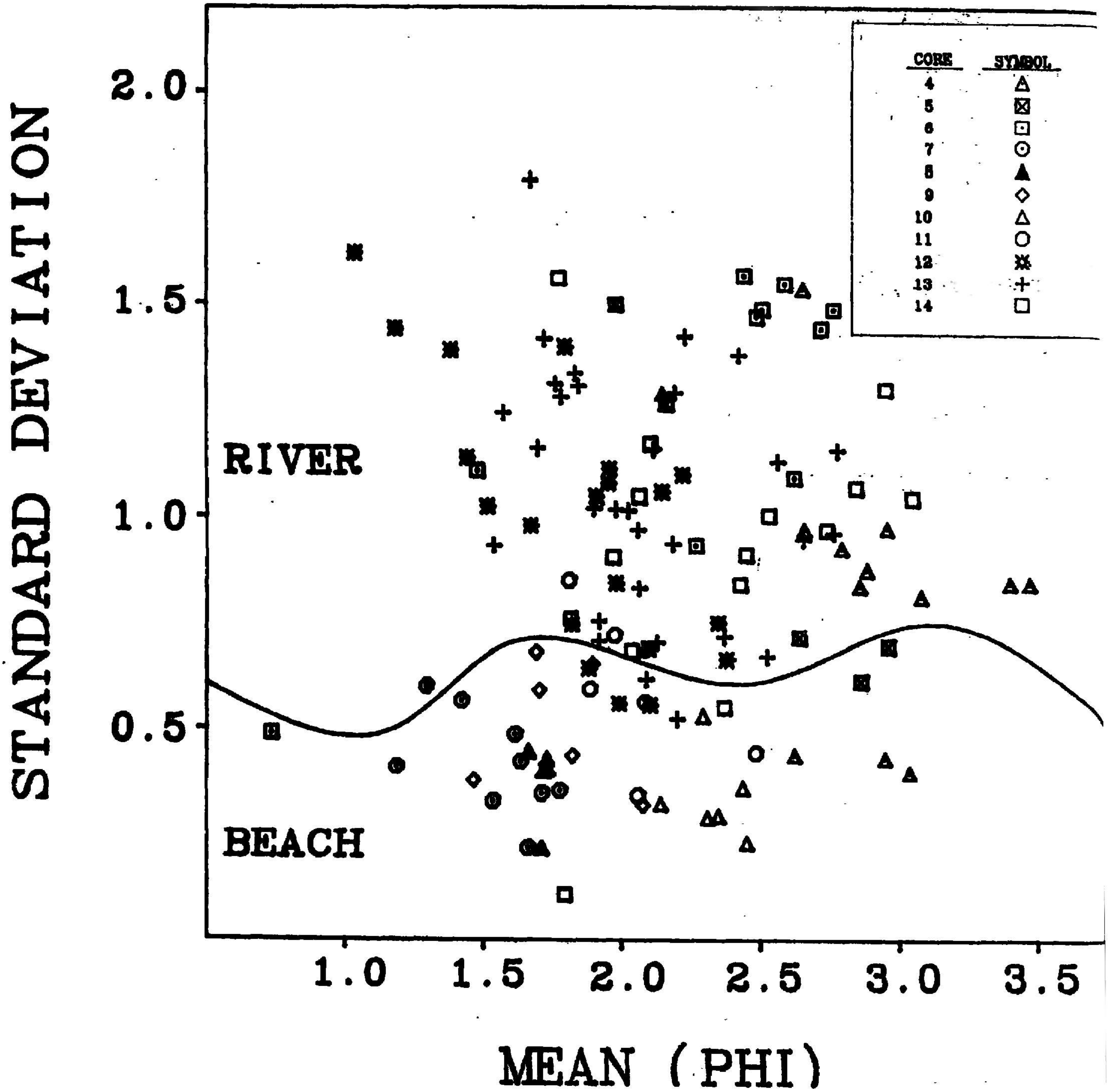


Figure 5 Textural data: mean versus standard deviation (environmental data from Friedman, 1967).

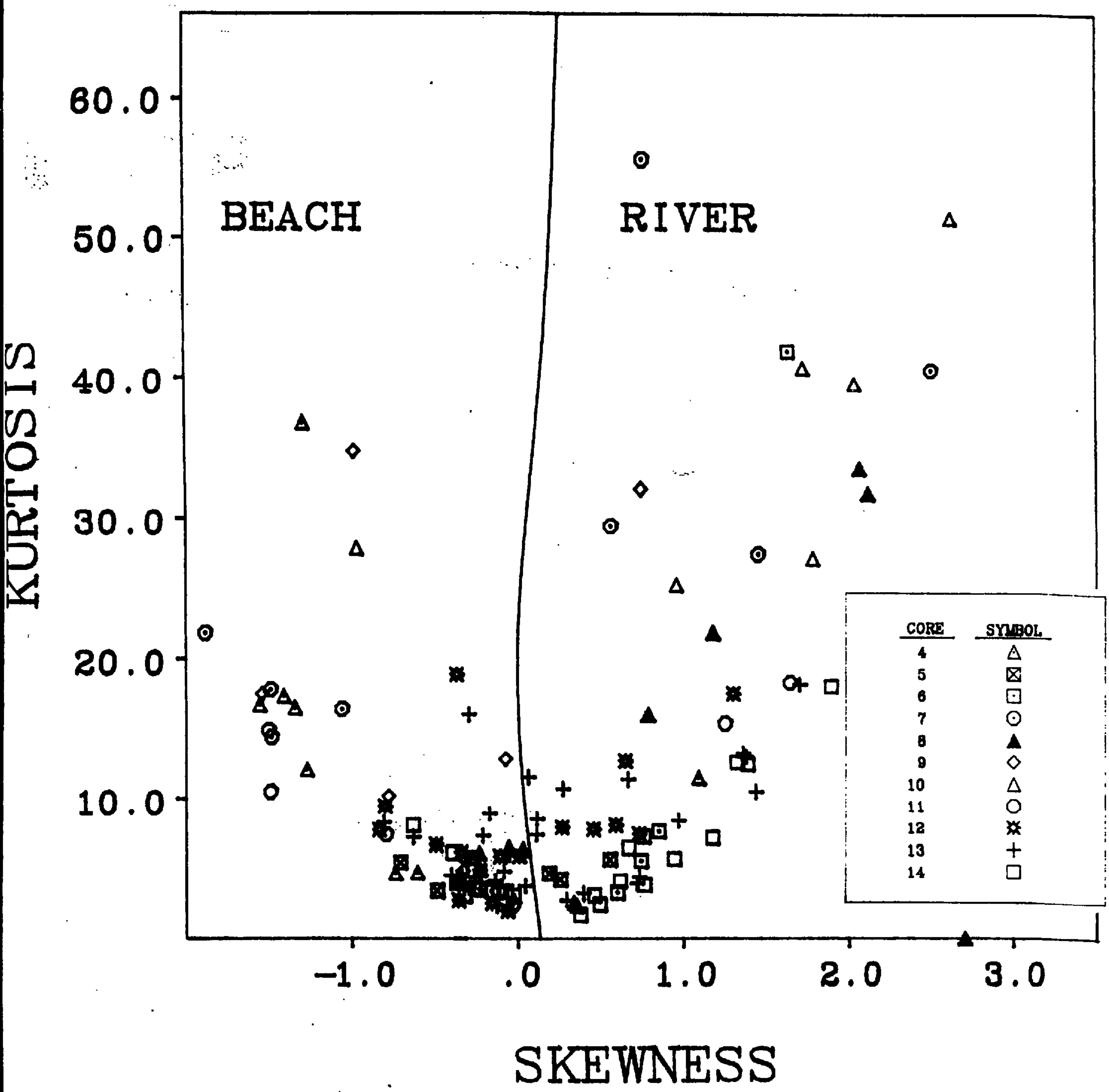


Figure 6 Textural data: skewness versus kurtosis (environmental data from Friedman, 1961).

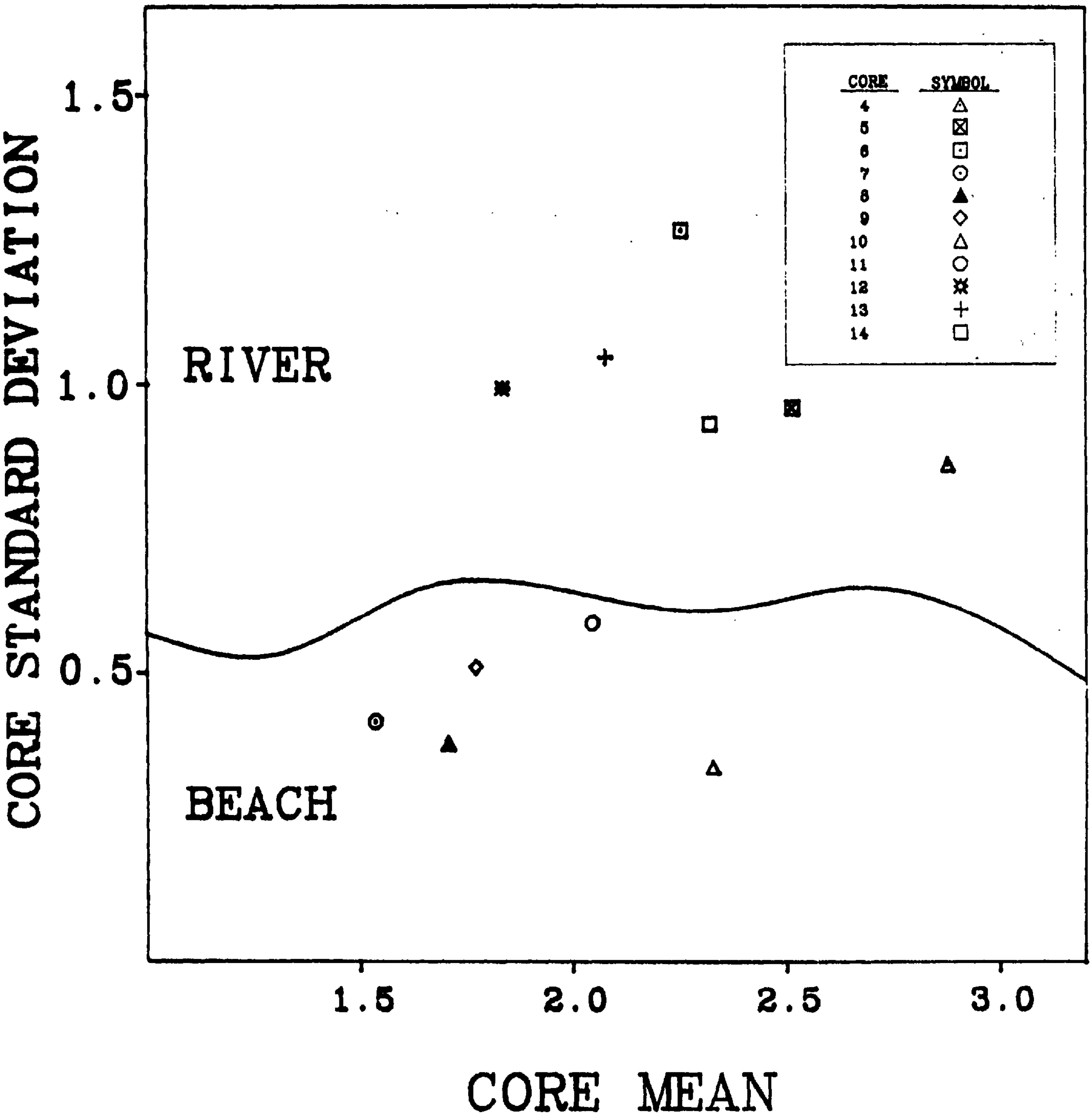


Figure 7 Textural data: core mean versus core standard deviation (environmental data from Friedman, 1979)

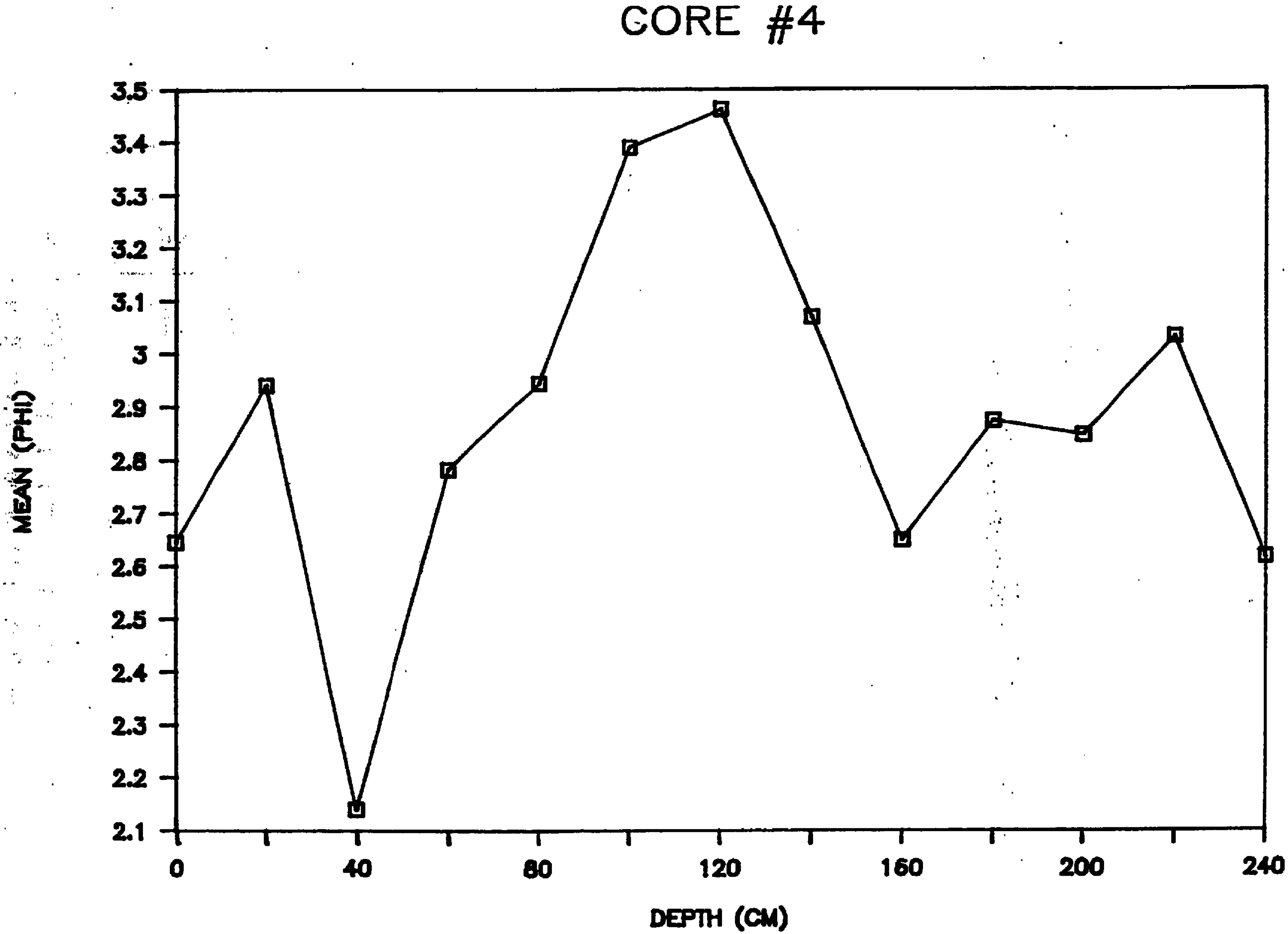


Figure 8   Core #4: mean vs. depth.

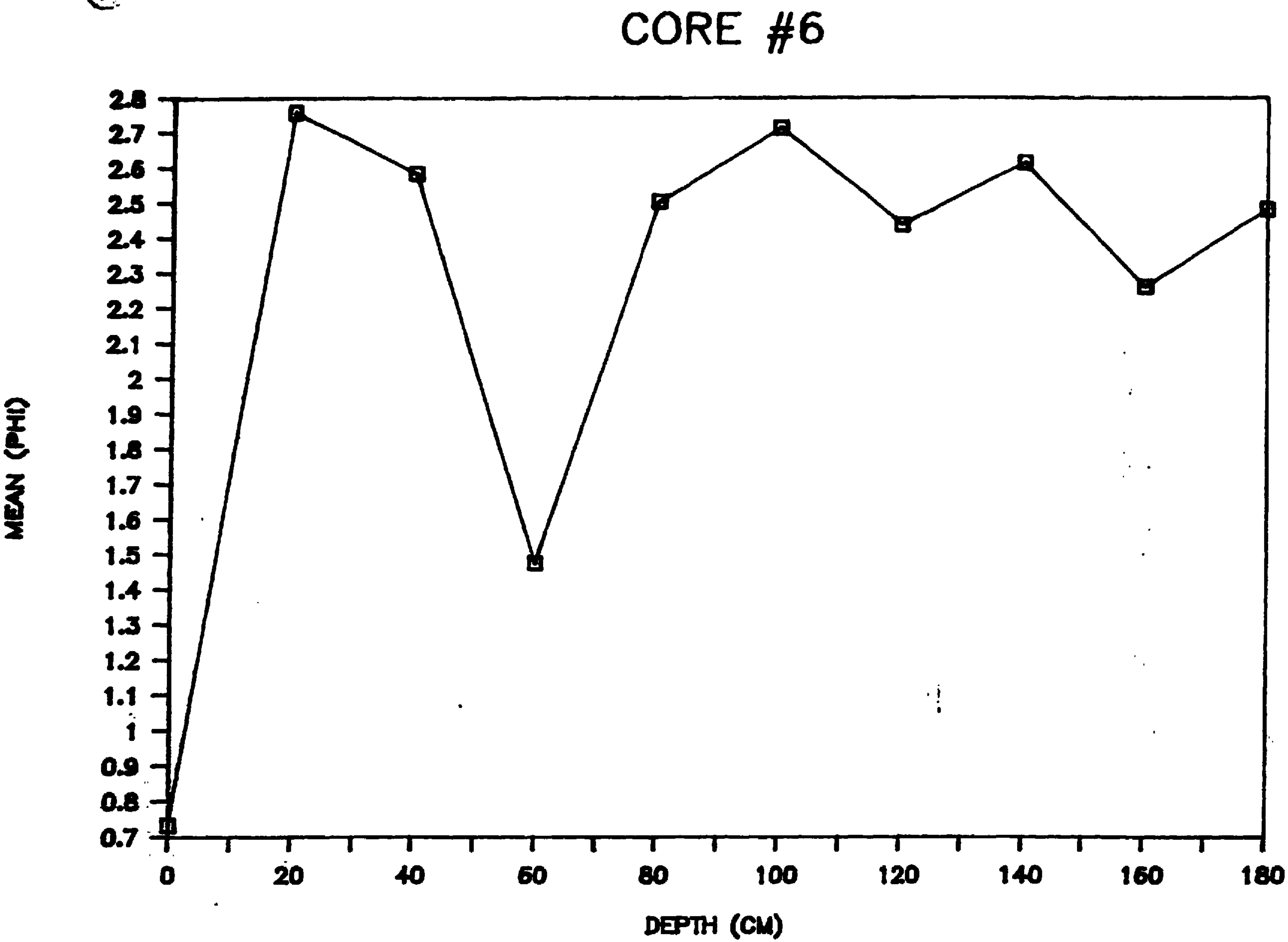


Figure 9 Core #6: mean vs. depth.

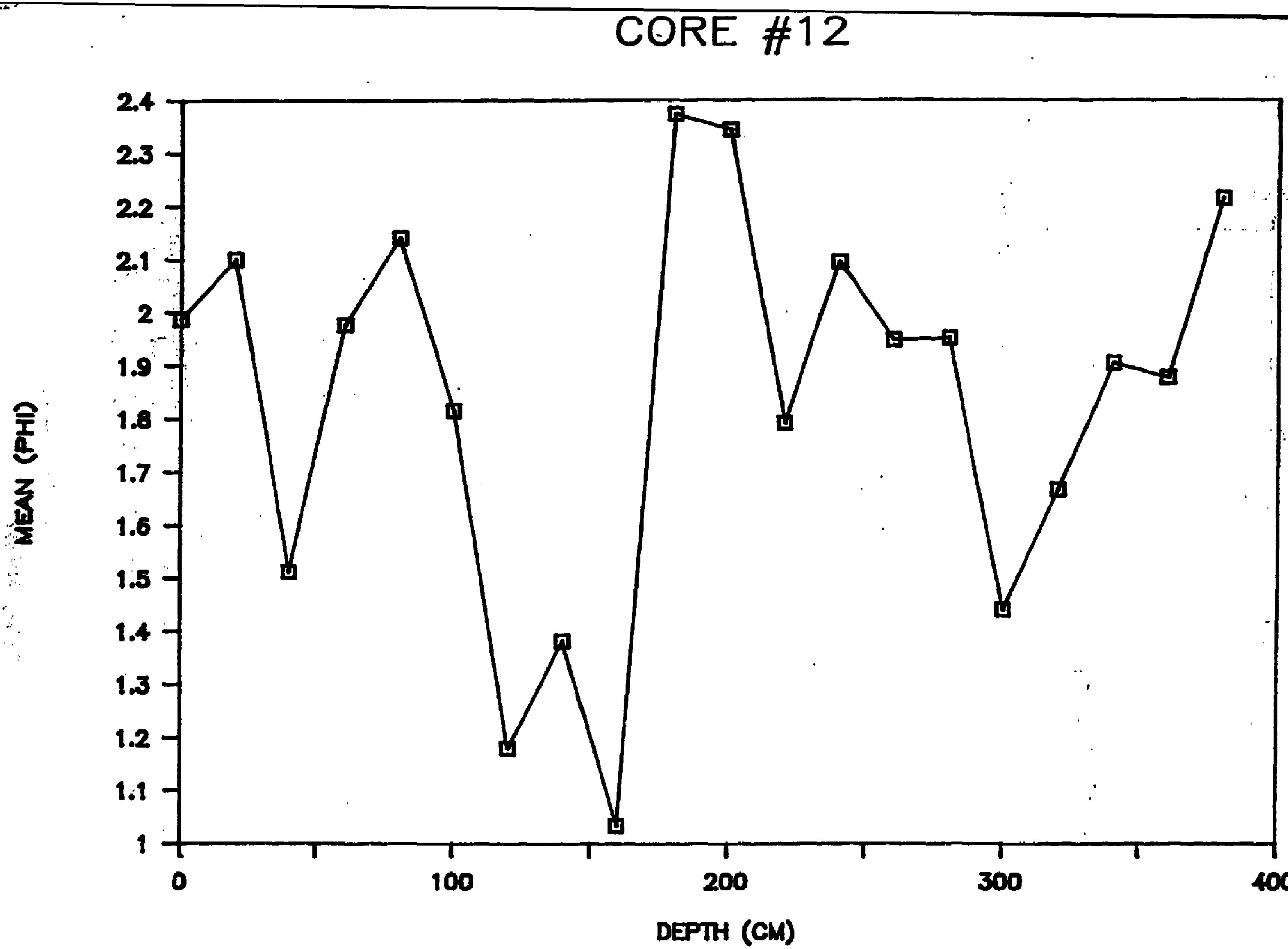


Figure 10 Core #12: mean vs. depth.

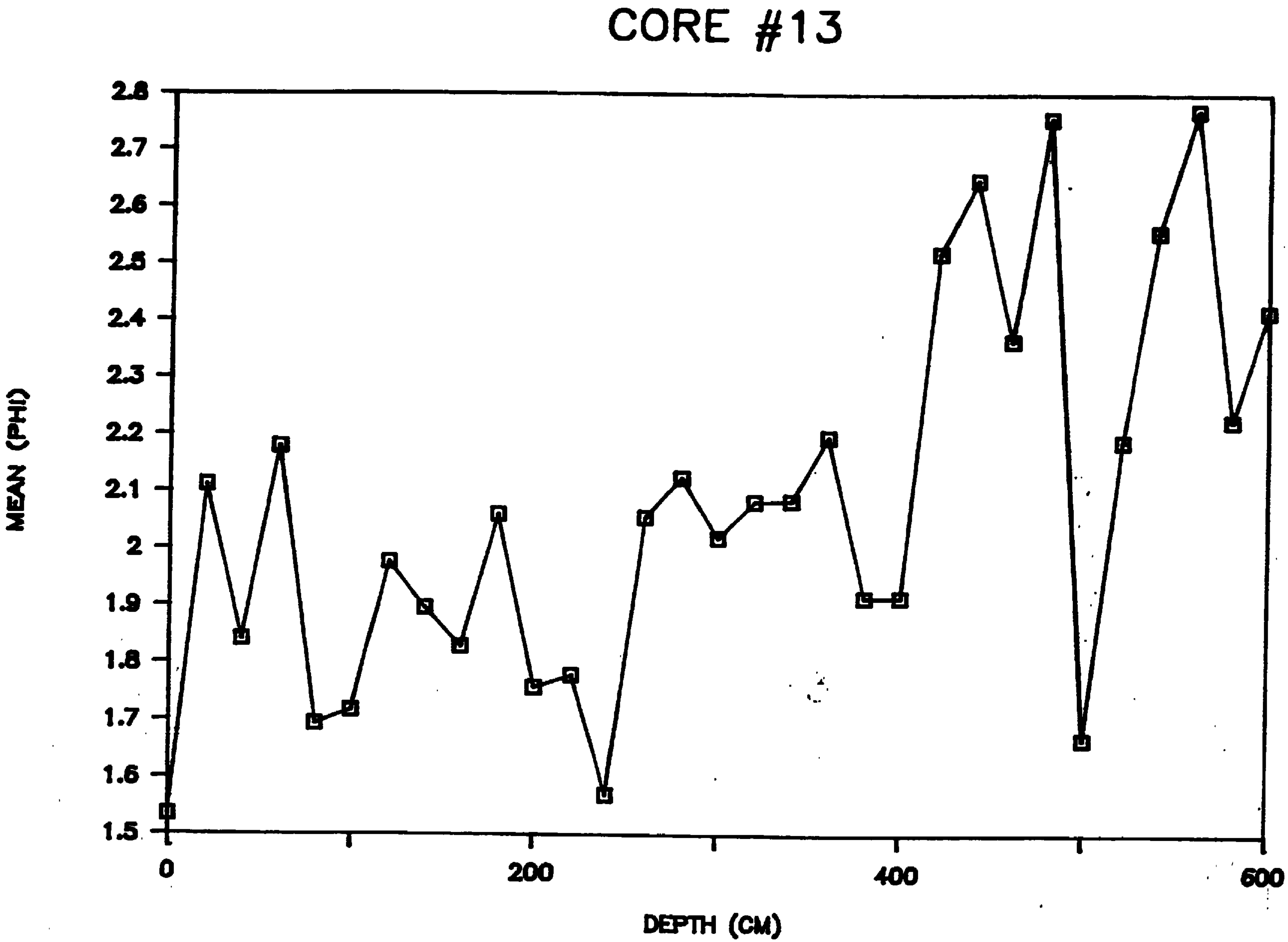


Figure 11 Core #13: mean vs. depth.

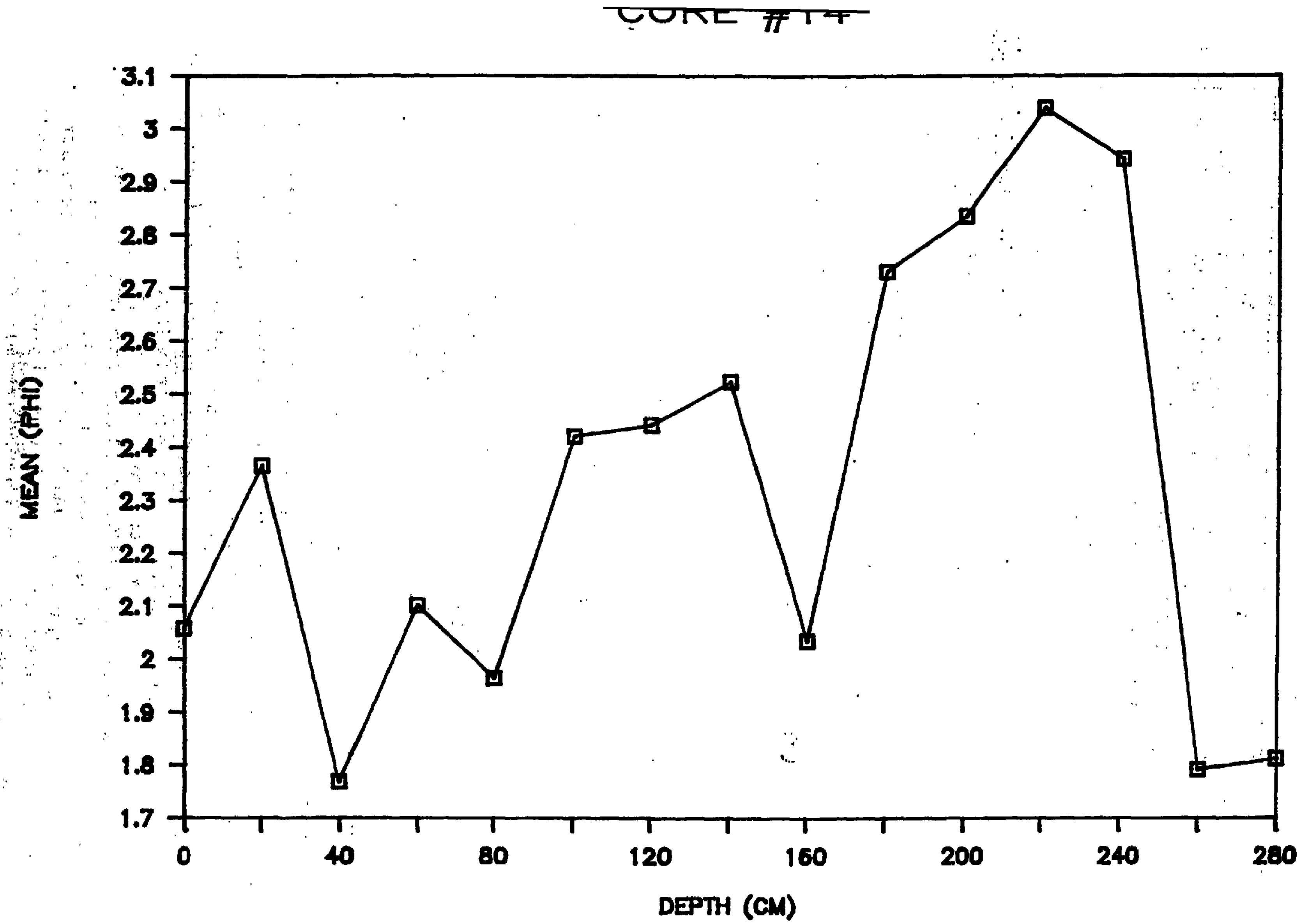


Figure 12 Core #14: mean vs. depth.

The sorting profiles (Figures 13-17) indicate moderate sorting, with a tendency for poorer sorting towards the top evident in some cores (e.g.,cores 4, 14 and the upper half of 13; Figures 13, 17 and 16, respectively). On the contrary, sorting worsens with depth in core 6 (Figure 14).

Heavy-mineral Analysis

Heavy minerals, as a percentage of the bulk weight, varied from 0.03% to 1.4% with a mean of 0.3%. Figures 18-22 show the percentage of heavy minerals vs. depth in each of the plotted cores. The samples were divided into two fractions within the sand size range, 2-3 phi and 3-4 phi. On average there was slightly more sample in the finer 3-4 phi fraction. Forty-three percent of the sample weight fell within the 3-4 phi fraction, while 40% occurred within the 2-3 phi range. There was also a larger percentage of heavy minerals in the finer range, an average of 0.5% in the 3-4 phi fraction versus 0.2% in the 2-3 phi fraction.

Magnetite averaged 5.6% by weight in the 2-3 phi fraction and 3.5% in the 3-4 phi fraction. Garnet + Ilmenite averaged 9.7% by weight in the 2-3 phi fraction and 6.4% in the 3-4 phi fraction. It can be seen that, on the average, the garnet + ilmenite weight is nearly twice the weight of the magnetite for both size fractions.

Nine heavy minerals were detected by XRD in the sample suite. Kyanite, sillimanite and zircon were found to be the most abundant of the low-susceptibility minerals in both size fractions. Kyanite favors the coarser fraction, while zircon slightly favors the finer. The percentages obtained from the XRD analyses are relative, the sum of the peak heights on the X-ray diffractogram being recalculated to 100%. In order to compare these percentages with the weight percentages of magnetite, ilmenite and garnet, the XRD results have been renormalized. This normalization involved subtracting the magnetite + ilmenite + garnet percentage from 100% and then taking the sum of the percentages obtained from the XRD data and adjusting it to equal the difference. The results are shown in Appendices D and E for the 2-3 phi and 3-4 phi fractions, respectively.

It can be seen that kyanite, sillimanite and zircon remain the predominant heavy minerals, even in comparison with magnetite, ilmenite and garnet, particularly in the coarser 2-3 phi fraction. In both size fractions, kyanite, sillimanite and zircon comprise about 70% of the heavy-mineral suite. Staurolite, rutile and hornblende are concentrated in the fine fraction. Magnetite and tourmaline favor the coarse fraction. Ilmenite shows no preference. Sphene, epidote and

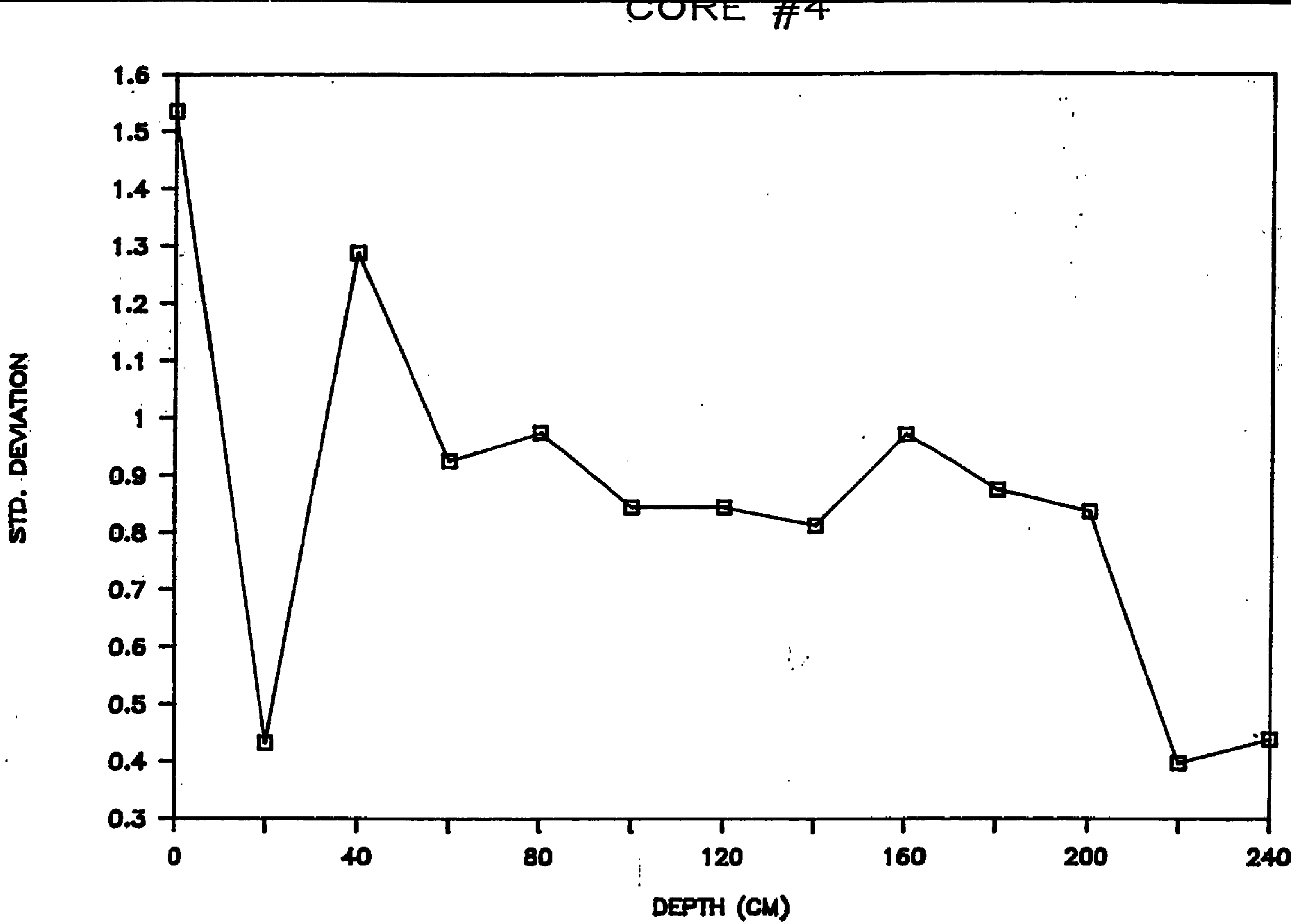


Figure 13   Core #4: standard deviation vs. depth.

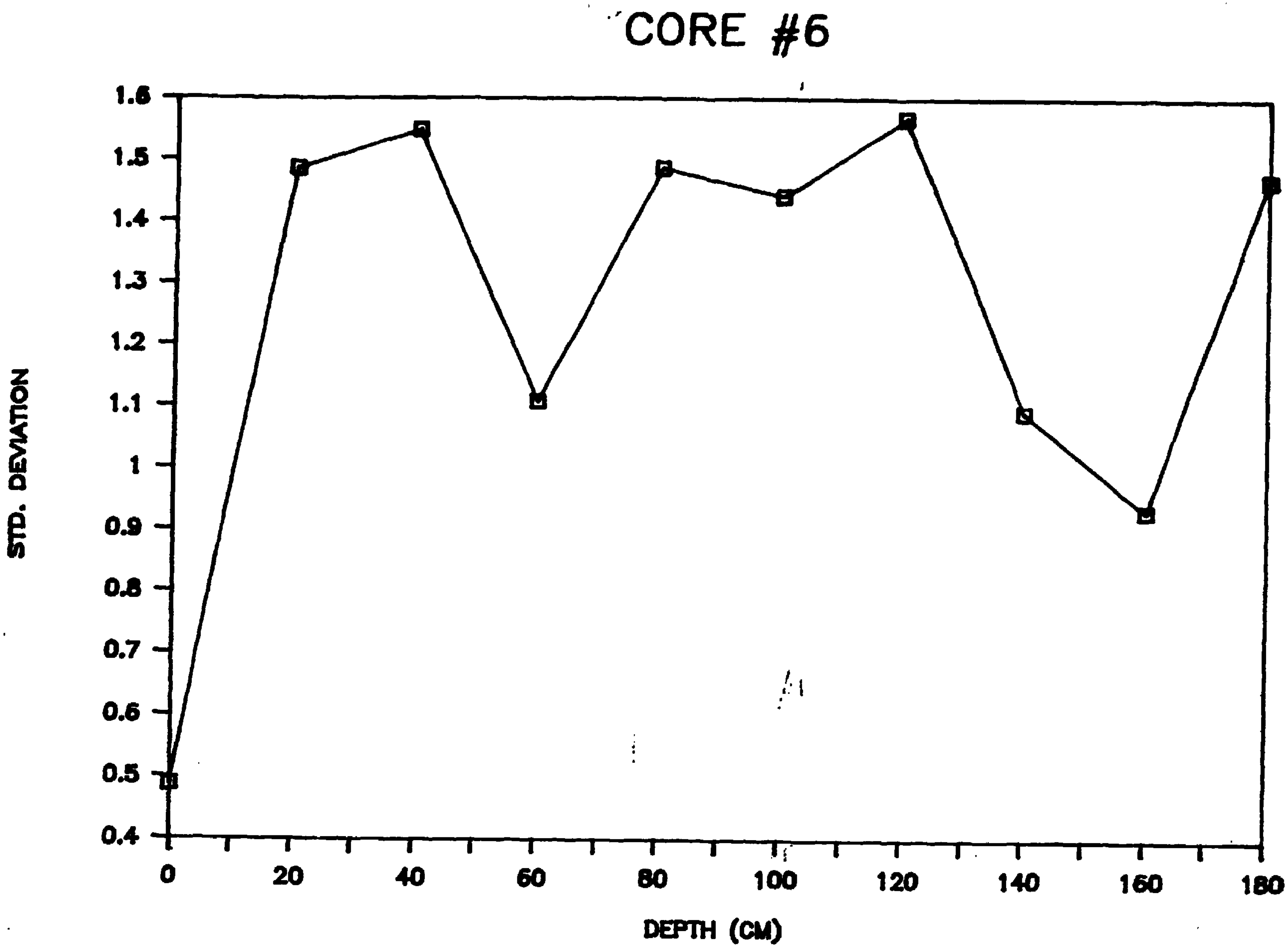


Figure 14 Core #6: standard deviation vs. depth.

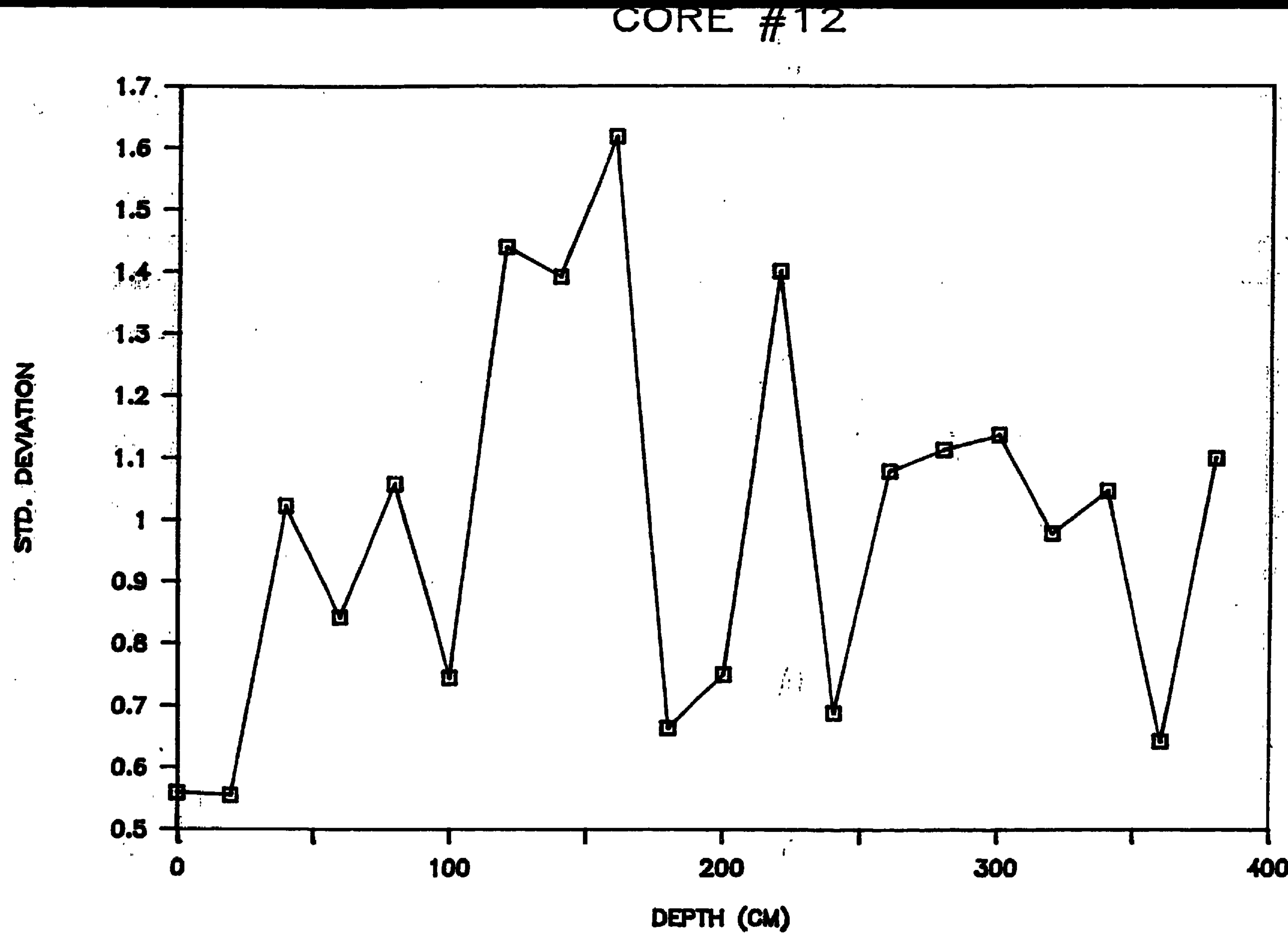


Figure 15 Core #12: standard deviation vs. depth.

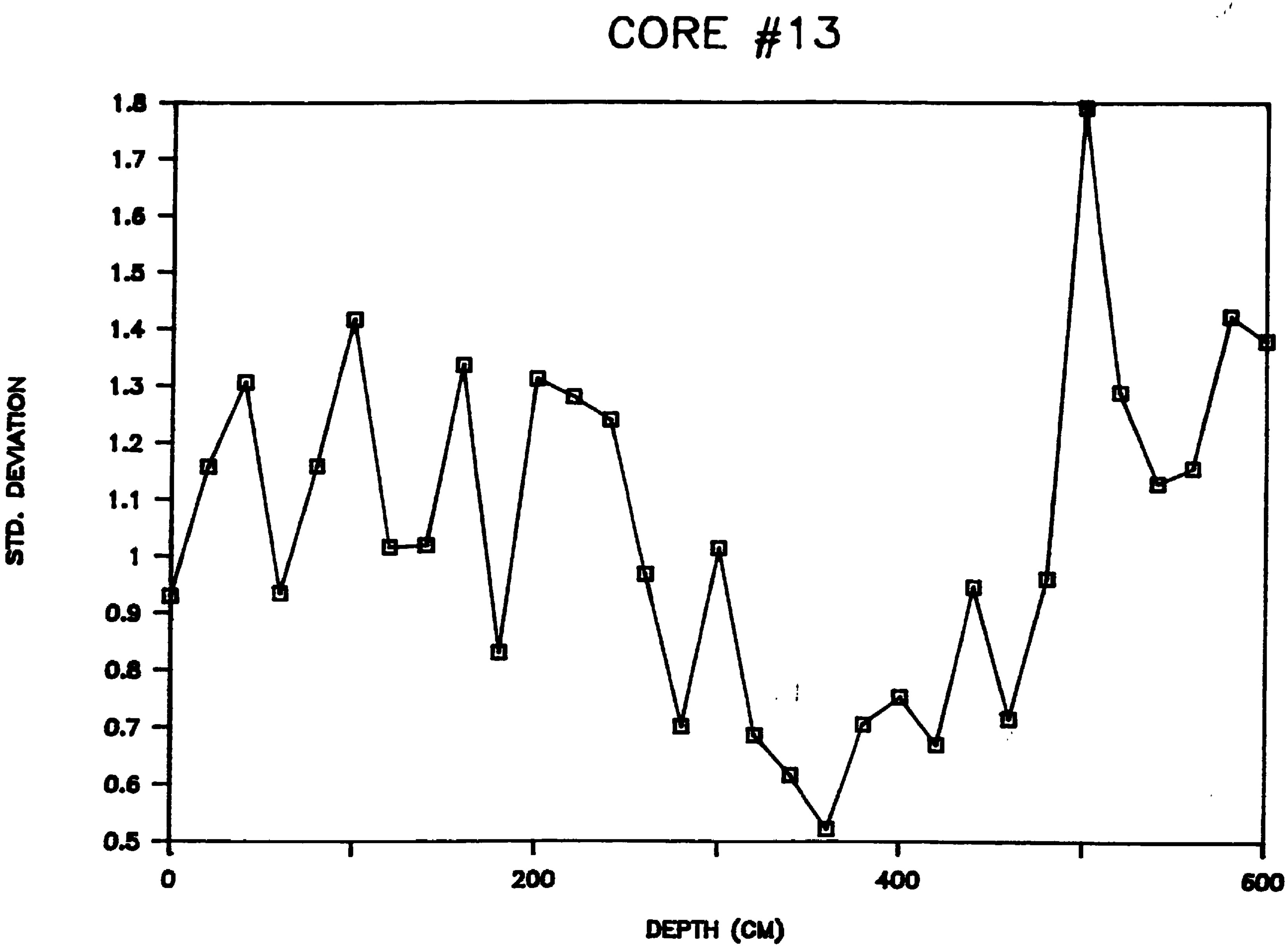


Figure 16 Core #13: standard deviation vs. depth.

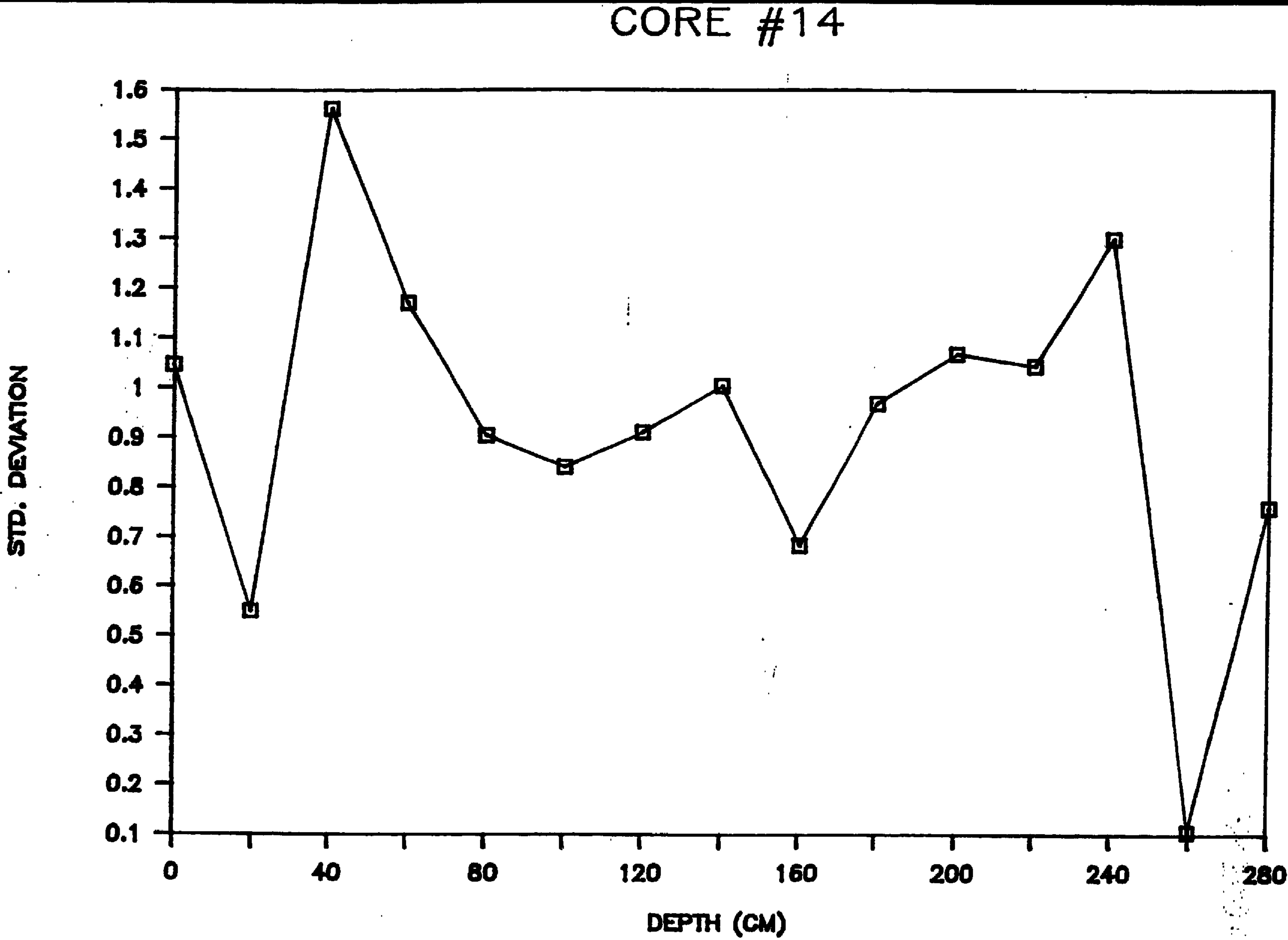


Figure 17 Core #14: standard deviation vs. depth.

garnet are present in small amounts in only a few samples. The titanium heavy minerals (ilmenite, rutile and sphene) comprise on average, 11.1% and 13.6% of the total, for the 2-3 phi and 3-4 phi fraction, respectively. The profiles of heavy-mineral weight percentage (Figures 18-22) show little variation (a range of 0.3 weight percent) or trend with depth. In general, however, the heavy fraction increases upward in cores 5 and 13 and decreases upward in core 14 (Figure 22). For all cores except 7 and 14, the heavy-mineral concentrations of the surface sample exceed those of the sampled interval immediately below.

Results of the heavy-mineral analysis are tabulated in Appendices C through G. Point count data for selected intervals containing the highest percentages of heavy minerals are shown in Appendix F. A comparison of the data from the year one study (Arthur et al.,1986) can be found in Appendix G.

CONCLUSION

This investigation has provided an in-depth look at heavy-mineral occurrence on the inner shelf of the northeast Gulf of Mexico. Heavy minerals constitute, on the average, 0.1 weight percent of the 2-3 phi fraction (Appendix D). This fraction constitutes 39.7% of the bulk weight. The 2-3 phi heavy minerals therefore constitute 0.04% of the bulk weight of the sediments. Likewise, heavy minerals make up, on average, 0.6 weight percent of the 3-4 phi fraction (Appendix E). This fraction comprises 43.3% of the bulk weight. The 3-4 phi heavy minerals therefore make up 0.26% of the bulk weight of the sample. Total weight of heavy minerals is approximately 0.3% of the bulk sediment. The titanium minerals (rutile, ilmenite, sphene) comprise an estimated 0.04% of the bulk sediment weight.

None of the samples analyzed contained heavy minerals in amounts greater than 1.4% of the total sediment. The heavy minerals were found to be more than four times as abundant in the finer sand than in the coarser sand fraction. Kyanite dominates both fractions, followed by sillimanite and zircon. Ilmenite, rutile and hornblende are also significant, especially in the finer sand fraction.

Some previous investigations suggested the possibility of economically important heavy-mineral deposits in the area investigated (Tanner et al.,1961). This study did not locate any heavy-mineral deposits of sufficient grade to be considered of potential economic importance. To be of economic importance, a deposit would have to be greater than ten times more concentrated than the overall average found in this area. Data from this investigation suggest that sands from this area may be a potential glass sand resource.

Continually shifting depositional environments, from river to beach to nearshore, appear to have heavily reworked the sand

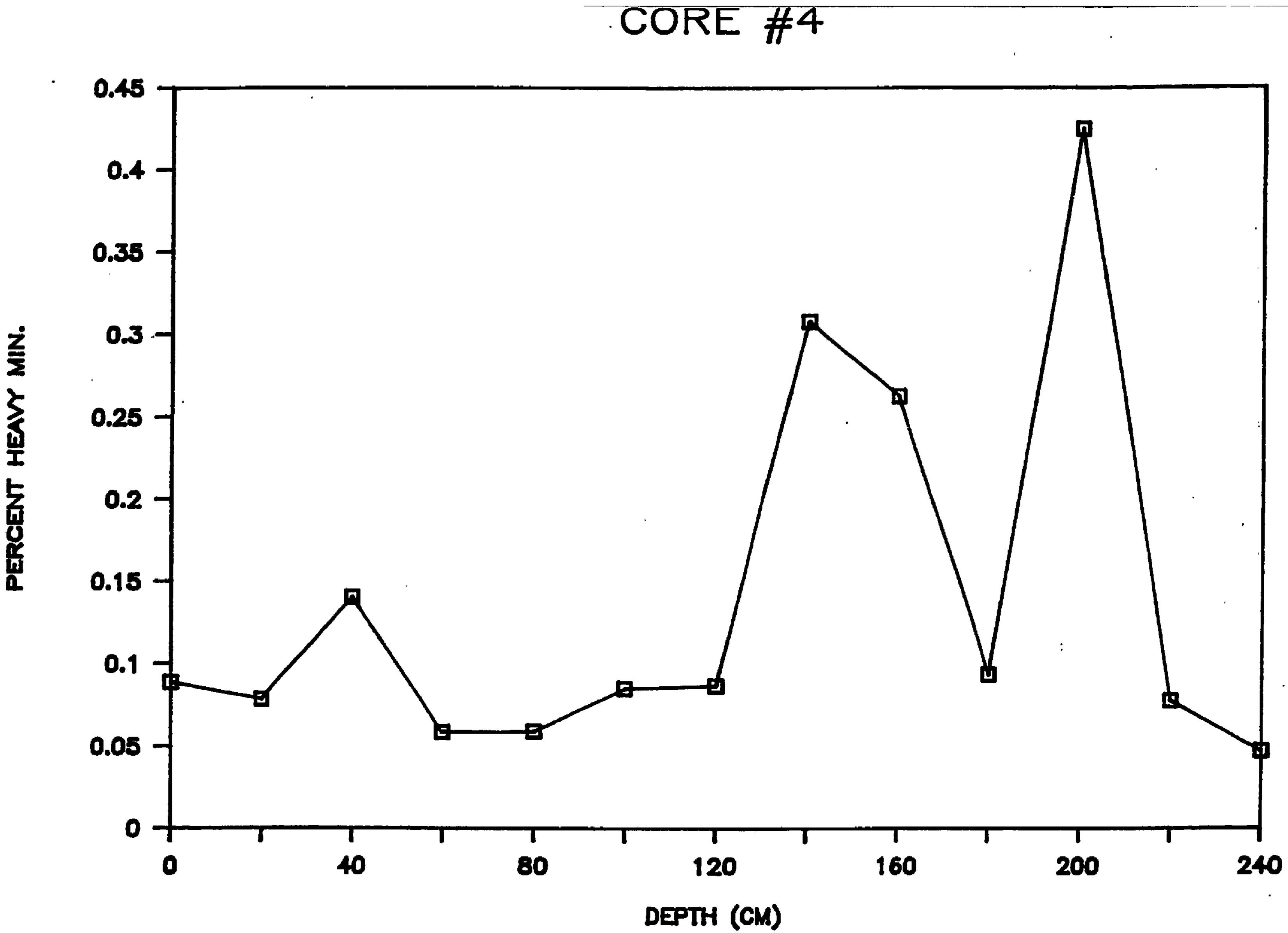


Figure 18 Core #4: percent heavy minerals vs. depth.

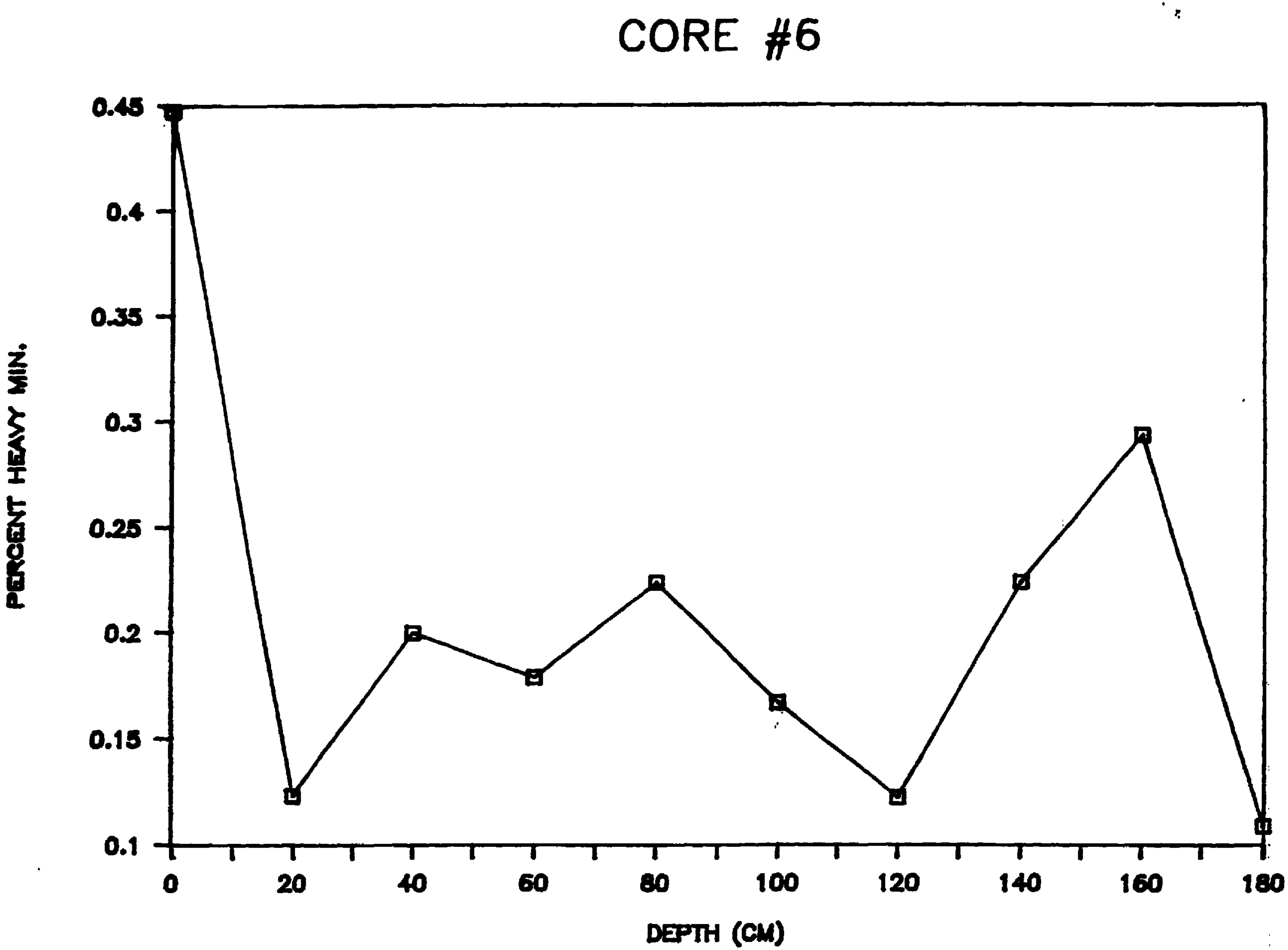


Figure 19   Core #6: percent heavy minerals vs. depth.

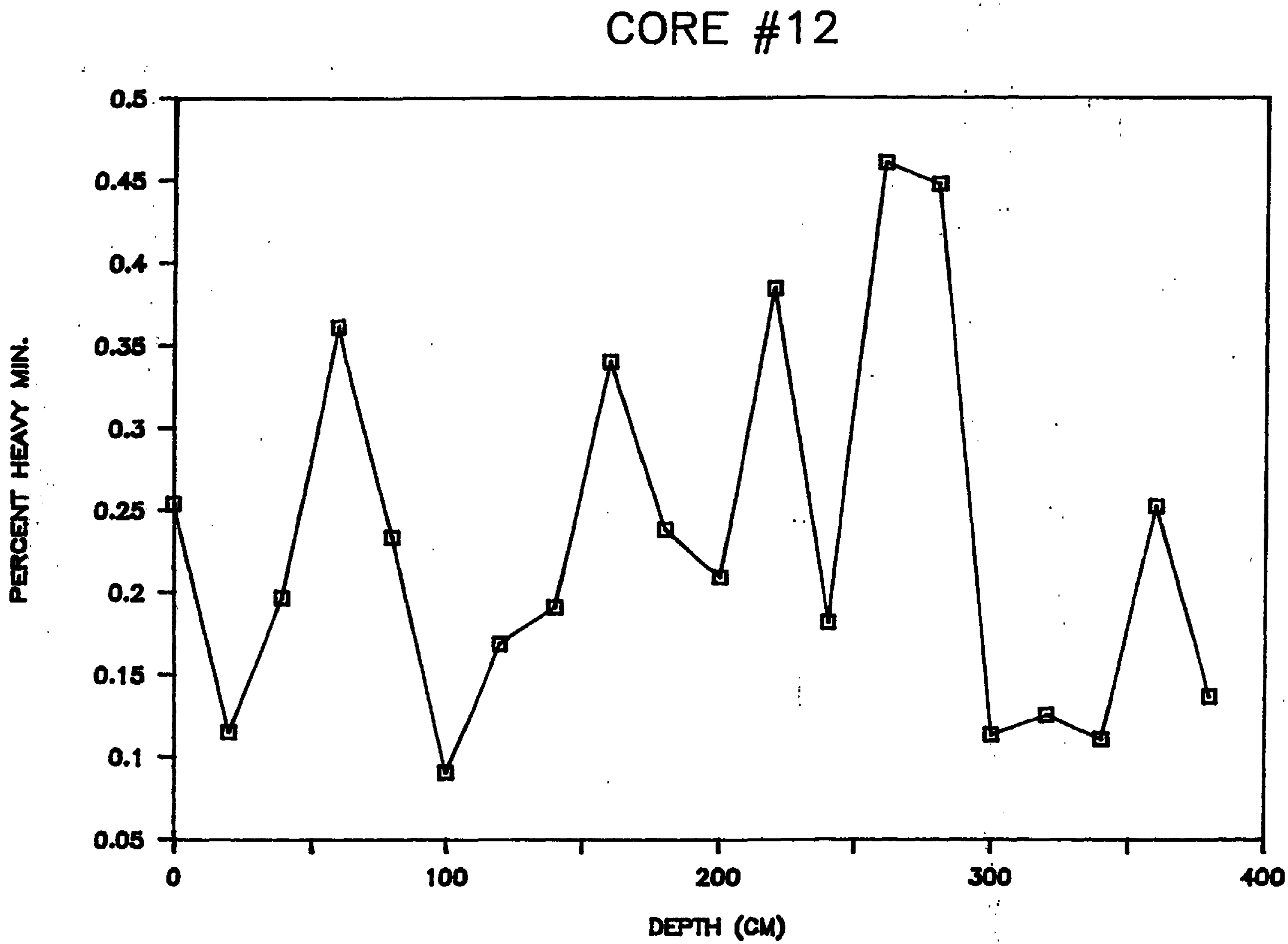


Figure 20 Core #12: percent heavy minerals vs. depth.

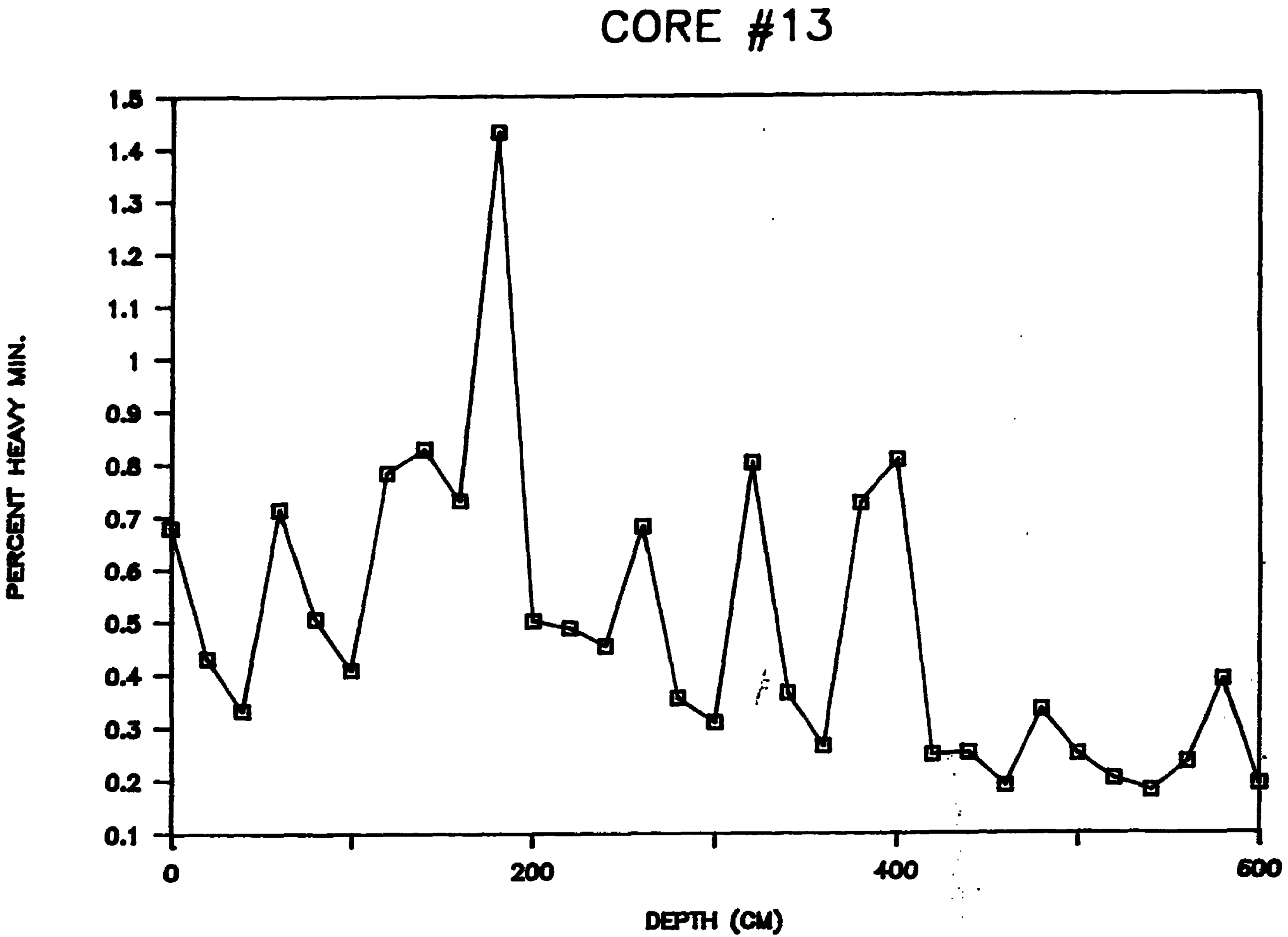


Figure 21   Core #13: percent heavy minerals vs. depth.

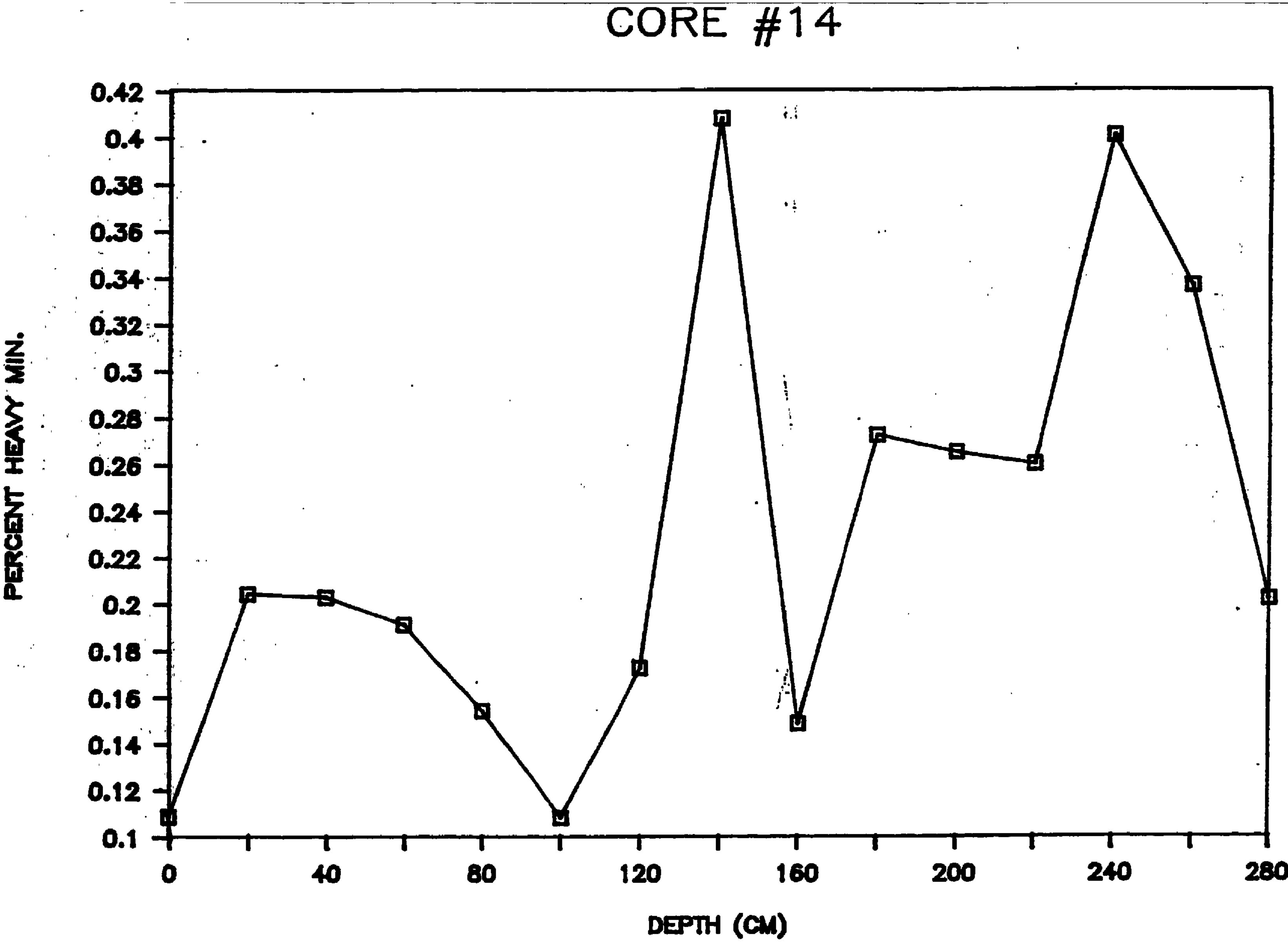


Figure 22 Core #14: percent heavy minerals vs. depth.

deposits of the inner shelf of the northeastern Gulf of Mexico off northwestern Florida. The resulting sediment is a moderately sorted, finely-skewed, fine sand with virtually no gravel or mud fraction present. Although ample heavy-mineral material appears to be available for concentration, as evidenced by concentrates of 50% and higher on some of the present-day beaches, it would appear that such concentrations do not survive unless they are rapidly drowned and buried. This has not been the case in the inner shelf, where the sea level has risen relatively slowly and the Apalachicola River has periodically changed its course over the past 10,000 years (Schnable, 1966; Schnable and Goodell, 1968). The slow rise of sea level during the Holocene, and the consequent re-working of inner shelf sediments may have been the reason for the low heavy-mineral concentrations in the inner shelf of the northeastern Gulf. If this is the case, heavy-mineral concentrates may be found further out on the shelf and upper slope, where low-stand beach and river channel deposits underwent in-situ drowning during the rapid sea-level rise associated with the waning of the late Wisconsin glaciers.

REFERENCES

Arthur, J.D., Melkote, S., Applegate, J., and Scott, T.M., 1986, Heavy-mineral reconnaissance off the coast of the Apalachicola River delta, northwest Florida: Florida Bureau of Geology Report of Investigation No. 95, 51p.

Bedosky, S.J., 1987, Recent sediment history of Apalachicola Bay, Florida: unpublished M.S. Thesis, Fla. State Univ., Tallahassee, Florida, 235 p.

Brenneman, L., 1957, Preliminary sedimentary study of certain sand bodies in the Apalachicola Delta: unpublished M.S. Thesis, Fla. State Univ.,Tallahassee, Florida, 151p.

Doyle, L.J. and Sparks, T.N., 1980, Sediments of the Mississippi, Alabama, and Florida (MAFLA) continental shelf: Jour. Sed. Petrology, v.50, n.3, p.905-916.

Drummond, S.E., and Stow, S.H., 1979, Hydraulic differentiation of heavy minerals, offshore Alabama and Mississippi, Summary: Geol. Soc. Amer. Bull., v.90, p.806-807.

Flores, R.M., and Shideler, G.L., 1978, Factors controlling heavy-mineral variations on the south Texas outer continental shelf, Gulf of Mexico: Jour. Sed. Petrology v.48, n.1. p.269-280.

Foxworth, R.D., Priddy, R.R., Wendell, B.J., and Moore, W.S., 1962, Heavy minerals of sand from recent beaches of the Gulf Coast of Mississippi and associated islands: Miss. Geol. Surv. Bull. 93, p.1-92.

Friedman, G.M., 1961, Distinction between dune, beach, and river sands from their textural characteristics: Jour. Sed. Petrology, vol.31, n.4, p.514-529.

Friedman, G.M., 1967, Dynamic processes and statistical parameters compared for size and frequency distribution of beach and river sands: Jour. Sed. Petrology, v.37, p.327-354.

Friedman, G.M., 1979, Address of the retiring president of the International Association of Sedimentologists: Differences in size distributions of populations of particles among sands of various origins: Sedimentology, v.26, p.3-32.

Gibbs, R.J., 1974, A settling tube system for sand size analysis, Jour. of Sed. Petrology, v.44, p.583-588.

Goldstein, A., 1942, Sedimentary petrologic provinces of the northern Gulf of Mexico: Jour. Sed. Petrology v.12, n.2, p.77- 84.

Grosz, A.E., and Escowitz, E.E., 1983, Placer heavy minerals of the United States Atlantic continental shelf: Southeastern Section Geol. Soc. Amer., Abstracts with Programs, 1983, p.103.

Hsu, K.J., 1960, Texture and mineralogy of the Recent sands of the Gulf Coast: Jour. of Sed. Petrology vol.30, no. 3, p.380-403.

Isphording,W.C., 1985, Sedimentological investigation of Apalachicola Bay,Florida,estuarine system, prepared for the Mobile District, Corps of Engineers, University of Alabama, BER Report no. 343-260. 99p.

Kofoed, J.W., and Gorsline, D.S., 1963, Sedimentary environments in Apalachicola Bay and vicinity, Florida, Jour. of Sed. Petrology, v.33, n.1, p.205-223.

Lader, G., 1974, A sedimentological investigation of coastal cells from Cape San Blas to Indian Pass, Florida: unpublished M.S. thesis, Florida State University, 96p.

Mizutani, S., 1963, A theoretical and experimental consideration on the accuracy of sieving analysis, Journal of Earth Science, Nagoya, Japan, v.11, p.1-27.

Murray, G.E., 1960, Geologic framework of Gulf Coastal Province of United States: in Shepard, F.P., Phelger, F.B., and Van Andel, T.H., _eds._, Recent Sediments, Northwest Gulf of Mexico: Am. Assoc. Petroleum Geol., Tulsa, Oklahoma, 349p.

Pryor, W., and Hester, N., 1969, X-ray diffraction analysis of heavy minerals: Jour. Sed. Petrology, v.39, p.1384-89.

Saffer P.E.,1955, A preliminary investigation of river and beach samples collected in the states of Florida, Georgia, and Alabama: unpublished M.S. Thesis, Fla. State Univ., Tallahassee, Florida, 59p.

Schnable, J.E., 1966, The evolution and development of the part of the northwest Florida coast: unpubl. PhD dissertation, Florida State University, Tallahassee, Florida, 231 p.

Schnable, J.E., and Goodell, H.G., 1968, Pleistocene-Recent stratigraphy, evolution and development of the Apalachicola coast, Florida: Geol. Soc. Amer. Spec. Paper n.112, 72p.

Stapor, F.W., 1973a, Heavy-mineral concentrating processes and density/shape/size equilibria in the marine and coastal dune sands of the Apalachicola, Florida, region: Jour. Sed. Petrology, v.43, n.2, p.396-407.

Stapor, F.W., 1973b, Coastal sand budgets and Holocene beach ridge plain development, northwest Florida: unpubl. PhD dissertation, Fla. State Univ., Tallahassee, 219p.

Stewart, R.A., 1962, Recent sedimentary history of St. Joseph Bay, Florida: unpublished M.S. thesis, Fla. State Univ., Tallahassee, Florida, 70p.

Tanner, W.F., Mullins, A., and Bates, J.D., 1961, Possible masked heavy-mineral deposit, Florida Panhandle: Economic Geology, v.56, p.1079-1087.

Van Andel, T., 1959, Reflections on the interpretation of heavy-mineral analysis: Jour. Sed. Petrology, v.29, p.153-163.

Van Andel, T.H., and Poole, D.M., 1960, Sources of recent sediments in the Northern Gulf of Mexico, Jour. of Sed. Petrology, v.30, n.1., p.91-122.

Ware, P.W., and Kirkpatrick, 1981, Preliminary geologic evaluation of portions of Cape St. George Shoal on state drilling lease 224-A, in the Gulf of Mexico, Franklin County, Florida:unpublished Coastal Petroleum Company report 59p.

APPENDIX A

DETAILED CORE LOCATION

CORE #	CORE LENGTH (cm)	LORAN-C COORDINATES		W. Latitude	N. Longitude
4	250	14247.22	46511.17	29 36.81	84 52.78
5	89	14223.94	46484.00	29 33.01	84 54.13
6	200	14198.96	46505.35	29 32.43	84 59.08
7	174	14156.16	46473.46	29 26.81	85 02.73
8	93	14169.58	46530.27	29 31.96	85 04.78
9	103	14084.64	46639.05	29 34.96	85 22.98
10	100	14088.17	46666.20	29 37.44	85 24.28
11	117	14137.37	46800.32	29 51.30	85 26.78
12	388	14140.67	46870.28	29 57.55	35 30.81
13	610	14002.00	46935.53	30 02.90	85 37.07
14	280	14084.21	46993.89	30 07.70	85 44.86

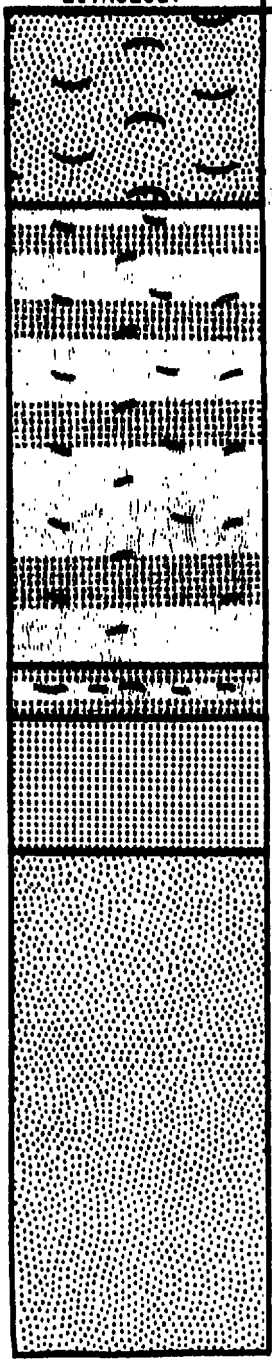
Appendix B Core Logs

CORE NUMBER: CA-86-STA4

Latitude: 29.36.81 Corr. Depth: 35 ft.

Longitude: 84.52.78 Core Length: 250 cm

LITHOLOGY	LITHOLOGIC DESCRIPTION



0-35cm Dark yellowish-brown, medium fine, subrounded, well-sorted sand, a few broken Pelecypod shells, uniform lithology. Gradational contact.

35-120cm Greenish-gray, silty sand intermixed with coarse sand, poorly sorted. Scattered shell fragments. Gradational contact.

120-130cm Light olive-gray silty sand mixed with coarse sand, poorly sorted very small shell chips. Gradational contact.

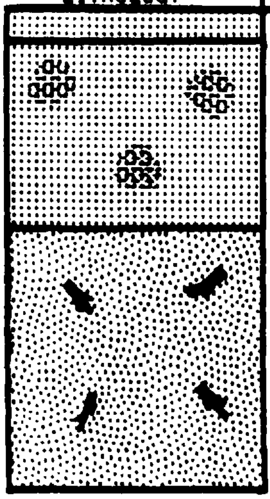
130-155cm Dark greenish-gray, coarse and angular sand, slightly clayey, poorly sorted. Large shell fragments present, random orientation.

155-250cm Very light gray-white medium-fine, subrounded sand. Dark gray clumps randomly scattered sand is well-sorted, uniform lithology.

CORE NUMBER: CA-86-STA5

Latitude: 29.33.01 Corr. Depth: 45 ft.

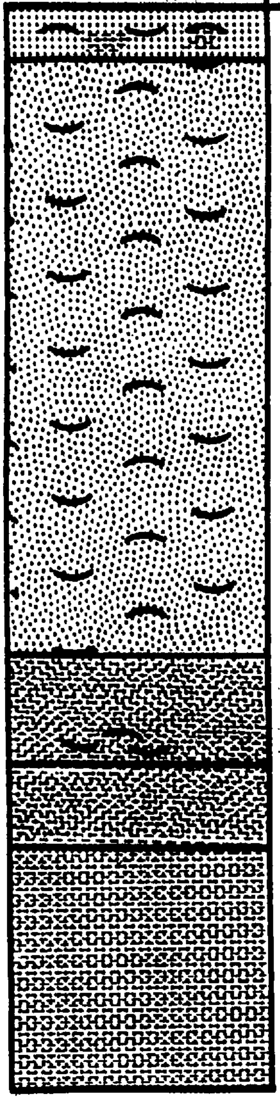
Longitude: 84.54.13 Core Length: 89 cm

LITHOLOGY	LITHOLOGIC DESCRIPTION
	0-5cm Olive-gray, coarse subangular sand and shell hash abundant organics. Shell hash consists of small fragments. Sharp contact. 5-40cm Olive-gray, medium coarse, subangular and in medium gray clay matrix. Minor amount of shell hash. Large clay spheres scattered randomly, gradational contact. 40-89cm Grayish-black, medium-fine grained sand and mud. Large black organic chunks scattered randomly. At 68cm a large, black tree fragment is present.

CORE NUMBER: CA-86-STA6

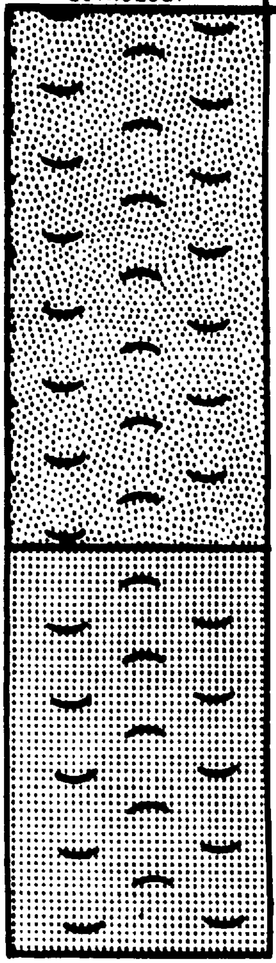
Latitude: 29.32.43 Corr. Depth: 36 ft.

Longitude: 84.59.08 Core Length: 200 cm

LITHOLOGY	LITHOLOGIC DESCRIPTION
	0-10cm Olive gray, coarse, angular sand with minor clay. Large amount of randomly oriented shell hash, closely packed. One noticeable burrow 5cm in length. Gradational contact. 10-120cm Dark-gray, fine-grained, clayey sand with minor scattered shell fragments. One large overturned inarticulated mollusk shell, bioturbation noticeable. Gradational contact. 120-140cm Grayish-black, organic-rich sandy clay. Large tree knob near base, below which shell hash is present. Gradational contact. 140-155cm Bluish-gray organic-rich sandy clay. No shells are present. Uniform lithology. Gradational contact. 155-200cm Medium bluish-gray clay, medium reddish-brown to dark yellowish-orange, medium-coarse sand. The sand and clays mix with no specific pattern. Clay sections are rounded, possibly burrow in-fills. No shell present.

CORE NUMBER: CA-86-STA7

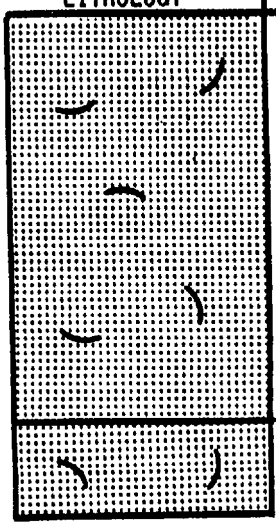
Latitude: 29.26.81	Corr. Depth: 20 ft.
Longitude: 85.02.73	Core Length: 174 cm.

LITHOLOGY	LITHOLOGIC DESCRIPTION
	0-100cm Yellowish-gray, medium-fine, subrounded sand. Small shell fragments randomly scattered, no evidence of bioturbation, minor amounts of mica. Uniform lithology. Gradational contact. 100-174cm Medium light-gray, medium-coarse, angular sand. Shell fragments present. Small, intact, inarticulated coquina pelecypods. Uniform lithology.

CORE NUMBER: CA-86-STA8

Latitude: 29.31.96 Corr. Depth: 21 ft.

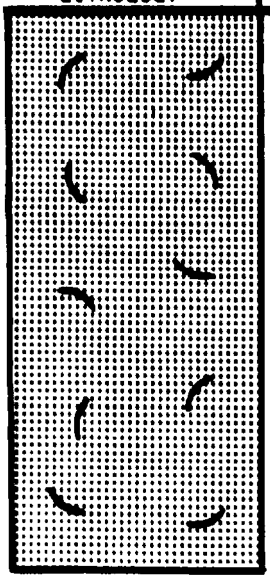
Longitude: 85.04.78 Core Length: 93 cm.

LITHOLOGY	LITHOLOGIC DESCRIPTION
	0-75cm Yellowish-gray, coarse, subangular sand. Small, black, shell fragments randomly scattered. One long, thin burrow 12 cm in length. Uniform lithology. Gradational contact.
	75-93cm Pale-olive, coarse, fossiliferous sand. Forams, and inarticulated mollusks present. Small shell fragments. Some bioturbation at 80 cm.

CORE NUMBER: CA-86-STA9

Latitude: 29.34.96 | Corr. Depth: 30 ft.

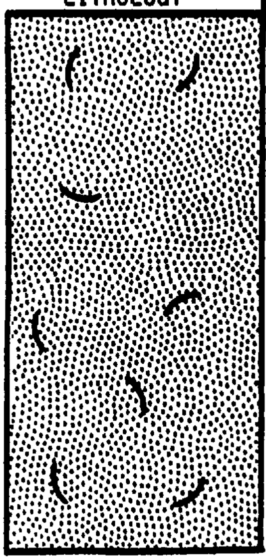
Longitude: 85.22.98 | Core Length: 103 cm.

LITHOLOGY	LITHOLOGIC DESCRIPTION
	0-103cm Yellowish-gray, medium-coarse, subangular sand, minor biotite randomly scattered. Bioturbation around 18 cm. Small shell fragments randomly oriented. Lithology constant, moderate sorting.

CORE NUMBER: CA-86-STA10

Latitude: 29.37.44 Corr. Depth: 30 ft.

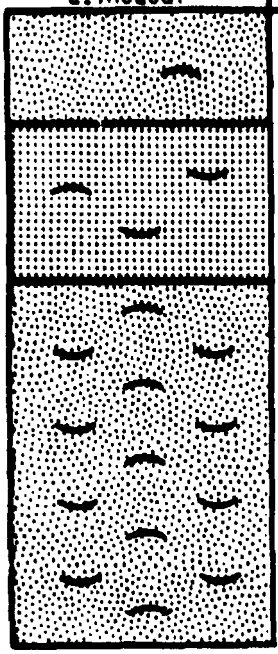
Longitude: 85.24.28 Core Length: 100 cm.

LITHOLOGY	LITHOLOGIC DESCRIPTION
	0-100cm Very light-gray, subangular, fine-grained sand, medium, sorted, scattered shell fragments. Inarticulated mollusk shells. Burrows present 10-20 cm in length.

CORE NUMBER: CA-86-STA11

Latitude: 29.51.30 Corr. Depth: 27 ft.

Longitude: 85.26.78 Core Length: 117 cm.

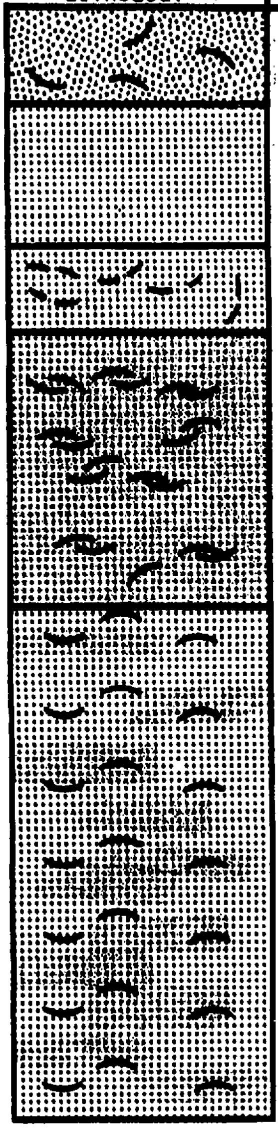
LITHOLOGY	LITHOLOGIC DESCRIPTION
	0-21cm Grayish-orange, medium-fine grained, subrounded, well-sorted sand. One inarticulated mollusk. Burrow fill at 14 cm. Uniform lithology. Gradational contact. 21-45cm Yellowish-gray, medium-coarse, subrounded sand, minor, unevenly distributed shell fragments, minor organics. 45-117cm White, moderately-sorted, medium-fine sand. Scattered heavy minerals, shell fragments.

CORE NUMBER: CA-86-STA12

Latitude: 29.57.55 Corr. Depth: 22 ft.

Longitude: 85.30.81 Core Length: 388 cm.

LITHOLOGY	LITHOLOGIC DESCRIPTION



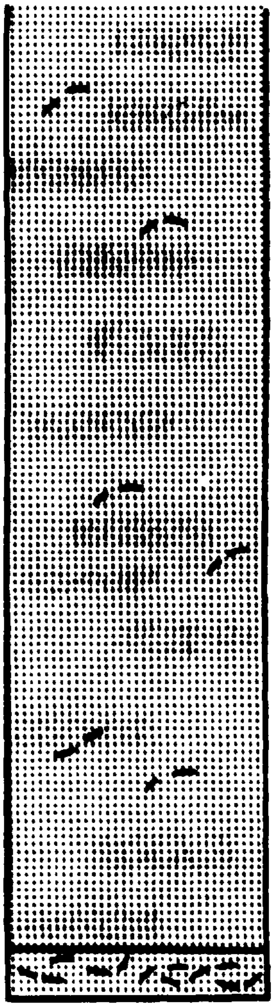
0-17cm Light olive-gray, well-rounded, fine sand. Mionr amount of shell fragments. Well sorted, gradational contact.

17-43cm Yellowish-gray, well-rounded, medium-coarse sand, minor inarticulated, unoriented pelecypods. Gradational contact.

43-59cm Very light-gray, subangular, medium-coarse sand, minor small shell fragments, unevenly distributed, moderate sorting. Gradational contact.

59-110cm Olive-gray, subrounded, medium-coarse silty sand. Grades to darker color with depth. Large amount of shell hash. Minor intact pelecypods, no orientation. Gradational contact.

110-205cm Dark greenish-gray. subrounded, coarse, silty sand, shell present, mollusks in live position, and articulated, pelecypods, gastropods. Gradational contact.



205-380cm Medium dark-gray, subangular, coarse, silty sand, minor broken fossils randomly scattered. Semi-uniformed lithology. Gradational contact.

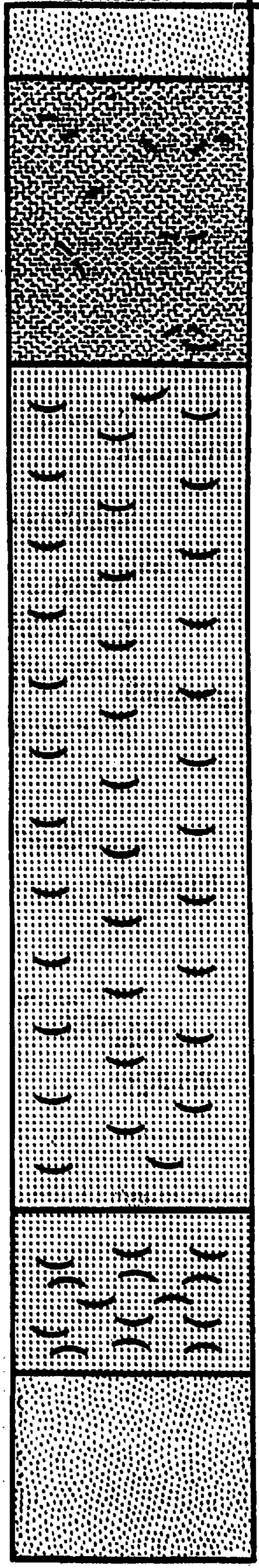
380-388cm Medium dark-gray, subangular, medium-coarse sand. Large shell fragments, pelecypod shells, moderate sorting.

CORE NUMBER: CA-86-STA13

Latitude: 30.02.90 Corr. Depth: 23 ft.

Longitude: 85.37.07 Core Length: 610cm

LITHOLOGY	LITHOLOGIC DESCRIPTION



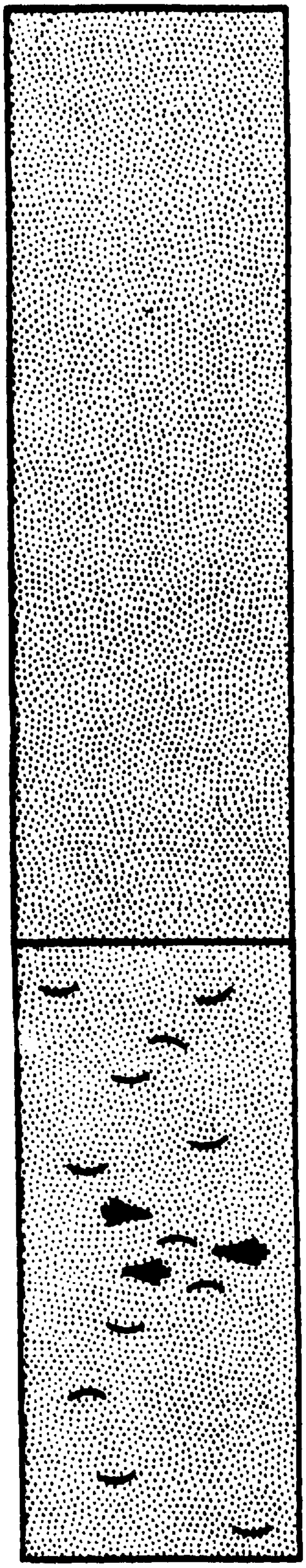
0-13cm Yellowish-gray, subrounded, medium-fine sand, no fossils, no structure. Very sharp contact.

13-66cm Dark greenish-gray, subrounded, fine-clayey sand. Small shell fragments, unoriented. Bioturbation, burrows oriented vertically. Gradational contact.

66-240cm Olive-gray, subangular, medium-coarse silty sand. Large shell fragments present. Whole inarticulated valves. Shells oriented concave up. Gradational contact.

240-273cm Dark gray, medium-coarse, muddy sand. Abundant shell fragments, concave upward, minor broken pelecypod shells. Gradational contact.

273-310cm Black, subrounded, medium-fine muddy sand. Uniform lithology. Organic matter present. Minor amount of small fossil fragments.



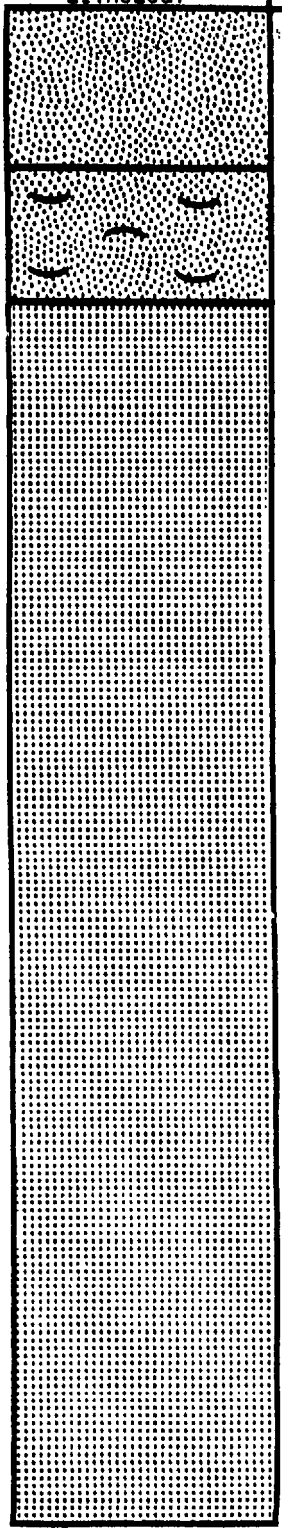
310-490cm Olive-gray to olive-black, subrounded, muddy fine sand. Uniform lithology, no fossils, no bioturbation, high organic content. Gradational contact.

490-610cm Olive black, subrounded, medium fine muddy sand. Large round mud balls. Sand contains large amounts of fine shell hash. Wood fragments present at 520 cm.

CORE NUMBER: CA-86-STA14

Latitude: 30.07.70 | Corr. Depth: 42 ft.

Longitude: 85.44.86 | Core Length: 280 cm.

LITHOLOGY	LITHOLOGIC DESCRIPTION
	0-30cm Yellowish-gray, subangular, medium-fine sand. Well sorted, no fossils, minor bioturbation. Gradational contact. 30-54cm Light olive-gray at top - yellowish gray at base. Subangular, medium-fine sand. Minor mud clumps, fossil fragments, mollusk shells. Gradational contact. 54-280cm Dark yellowish-brown, grading to dark-medium gray at base. Subangular, medium-fine sand. Lacks fossils. One mud infilled burrow.

Appendix C: Textural Data

Sample Wt.	= Total sample weight, including fines.
HM. Tot. Wt. %	= Heavy-mineral weight as a percent of total sample weight.
Percent Fines	= Weight percent of total sample finer than 62 microns.
Mean	= Mean grain size (phi units).
Std. Dev.	= Standard deviation.

CORE NO.	DEPTH (CM.)	SAMPLE WT. (GM.)	HM. TOT WT%	PERCENT FINES	MEAN	STD. DEV.	SKEW-NESS	KUR-TOSIS
4	0	98.072	0.099	0.071	2.646	1.535	-0.743	4.659
4	20	103.576	0.079	0.010	2.941	0.432	0.025	6.364
4	40	67.879	0.140	0.026	2.141	1.208	-0.612	4.697
4	60	108.020	0.059	0.066	2.783	0.925	-0.237	6.091
4	80	94.006	0.059	0.135	2.945	0.974	-0.059	6.513
4	100	110.240	0.065	0.203	3.390	0.044	0.320	2.561
4	120	107.737	0.087	0.233	3.462	0.844	0.348	2.360
4	140	82.728	0.308	0.036	3.069	0.812	-1.351	16.526
4	160	101.176	0.263	0.028	2.649	0.971	-1.276	12.089
4	180	99.728	0.093	0.028	2.874	0.874	-1.563	16.722
4	200	95.357	0.425	0.038	2.847	0.836	-1.416	17.350
4	220	97.657	0.078	0.023	3.032	0.397	1.085	11.513
4	240	128.170	0.047	0.009	2.617	0.439	-1.296	36.811
5	0	49.290	0.266	0.025	2.157	1.262	-0.710	5.432
5	20	100.935	0.183	0.050	2.635	0.715	0.551	5.640
5	40	55.231	0.107	2.050	1.976	1.497	-0.490	3.402
5	60	81.450	0.138	0.050	2.953	0.695	0.251	4.212
5	80	96.876	0.047	3.250	2.855	0.613	0.183	4.647
6	0	73.272	0.447	0.007	0.733	0.488	1.636	41.947
6	20	46.019	0.123	0.206	2.758	1.486	-0.267	3.600
6	40	47.778	0.200	0.215	2.583	1.548	-0.165	3.354
6	60	51.441	0.179	0.075	1.476	1.107	0.847	7.651
6	80	71.757	0.224	0.191	2.503	1.487	-0.077	3.335
6	100	94.520	0.167	0.224	2.714	1.441	-0.031	3.055
6	120	90.721	0.122	0.174	2.437	1.568	-0.234	3.518
6	140	99.798	0.224	0.164	2.615	1.091	0.597	3.309
6	160	83.910	0.293	0.081	2.262	0.931	0.739	5.574
6	180	52.237	0.109	0.114	2.483	1.469	-0.376	3.984
7	0	93.210	0.231	0.000	1.710	0.345	-0.118	3.348
7	20	106.916	0.280	0.003	1.534	0.327	0.764	55.563
7	40	118.300	0.231	0.000	1.660	0.215	0.560	29.418
7	60	120.652	0.394	0.004	1.775	0.353	1.448	27.411
7	80	108.251	0.232	0.012	1.633	0.423	2.505	40.571
7	100	116.947	0.211	0.004	1.293	0.599	-1.064	16.415
7	120	72.425	0.342	0.000	1.185	0.409	-1.885	21.794
7	140	109.541	0.158	0.000	1.612	0.407	-1.493	17.783
7	160	106.299	0.132	0.000	1.420	0.565	-1.488	14.453
8	40	97.938	0.098	0.002	1.709	0.215	2.699	0.000
8	60	107.287	0.363	0.012	1.659	0.447	2.112	31.823
8	80	108.774	0.108	0.011	1.726	0.430	2.061	33.575
9	0	96.663	0.145	0.003	1.698	0.680	-0.782	10.192
9	20	109.506	0.325	0.007	1.700	0.591	-0.075	12.878
9	40	112.773	0.123	0.004	1.465	0.377	0.742	32.119
9	60	95.541	0.163	0.000	2.076	0.320	-0.335	4.835
9	80	107.905	0.238	0.005	1.819	0.438	-0.987	34.841
9	100	89.096	0.230	0.003	1.891	0.653	-1.545	17.499
10	0	110.648	0.254	0.012	2.288	0.531	-0.975	27.874
10	20	100.490	0.098	0.007	2.138	0.322	1.724	40.734
10	40	104.484	0.131	0.008	2.307	0.289	2.625	51.421
10	60	103.602	0.281	0.007	2.346	0.294	2.033	39.559
10	80	91.611	0.219	0.012	2.433	0.360	1.776	27.121
10	100	110.699	0.133	0.002	2.448	0.228	0.952	25.218
11	0	89.771	0.401	0.028	1.883	0.594	1.640	18.313
11	20	95.576	0.123	0.000	2.480	0.444	-0.035	2.403
11	40	117.416	0.032	0.024	2.081	0.563	1.247	15.418
11	60	108.745	0.230	0.000	2.057	0.341	-0.797	7.400
11	80	122.677	0.276	0.000	1.806	0.849	-1.494	10.500
11	100	105.720	0.130	0.003	1.972	0.719	-1.507	14.941
12	0	110.150	0.254	0.023	1.989	0.559	1.297	17.516
12	20	76.750	0.116	0.011	2.100	0.555	-0.371	18.903
12	40	52.008	0.197	0.015	1.512	1.023	-0.234	4.863
12	60	81.765	0.361	0.013	1.977	0.842	-0.804	9.471
12	120	51.974	0.169	0.019	1.180	1.439	-0.160	2.552
12	140	39.024	0.191	0.013	1.381	1.391	-0.362	2.733
12	160	48.045	0.340	0.024	1.034	1.618	-0.067	2.003
12	180	73.066	0.238	0.030	2.373	0.664	0.452	7.736
12	200	88.448	0.209	0.050	2.343	0.750	0.728	7.451
12	220	80.840	0.385	0.052	1.792	1.400	-0.366	4.013
12	240	105.927	0.182	0.026	2.094	0.688	0.588	8.104
12	260	84.405	0.461	0.048	1.948	1.078	-0.111	5.651
12	280	89.978	0.447	0.043	1.952	1.113	-0.265	5.716
12	300	80.120	0.114	0.040	1.440	1.137	0.007	5.909

CORE NO.	DEPTH (CM.)	SAMPLE WT. (GM.)	HM. TOT WT%	PERCENT FINES	MEAN	STD. DEV.	SKEW-NESS	KUR-TOSIS
12	323	86.236	0.126	0.044	1.667	0.970	0.263	7.943
12	340	88.601	0.111	0.033	1.905	1.047	-0.346	6.131
12	360	94.011	0.252	0.030	1.878	0.642	-0.839	7.749
13	20	78.664	0.431	0.082	2.112	1.159	-0.055	5.905
13	40	65.503	0.333	0.076	1.841	1.307	-0.089	4.792
13	60	85.671	0.714	0.052	2.100	0.935	0.113	8.554
13	80	101.601	0.506	0.036	1.694	1.160	-0.312	5.479
13	100	112.854	0.409	0.050	1.718	1.418	-0.327	3.826
13	120	67.710	0.782	0.044	1.976	1.017	-0.213	7.342
13	140	87.215	0.828	0.056	1.895	1.020	0.110	7.420
13	160	88.280	0.731	0.053	1.828	1.337	-0.343	4.483
13	180	63.279	1.431	0.043	2.060	0.831	0.063	11.568
13	200	71.041	0.501	0.050	1.757	1.312	-0.265	4.381
13	220	78.919	0.488	0.022	1.778	1.280	-0.355	
13	240	87.394	0.453	0.028	1.570	1.240	-0.407	4.521
13	260	90.249	0.681	0.052	2.055	0.959	-0.172	8.953
13	280	86.505	0.356	0.027	2.125	0.702	0.269	10.739
13	300	86.348	0.310	0.024	2.019	1.015	-0.813	8.301
13	320	91.354	0.802	0.023	2.003	0.687	-0.296	16.057
13	340	93.790	0.365	0.031	2.085	0.617	1.356	13.285
13	360	97.825	0.266	0.026	2.197	0.523	1.699	18.196
13	380	101.853	0.725	0.041	1.915	0.706	1.372	13.019
13	400	86.714	0.807	0.036	1.915	0.754	0.662	11.379
13	420	87.637	0.249	0.052	2.520	0.671	0.965	8.425
13	440	90.106	0.253	0.133	2.648	0.947	0.727	4.408
13	460	76.735	0.189	0.069	2.365	0.716	1.433	10.524
13	480	75.045	0.334	0.155	2.756	0.962	0.714	3.929
13	500	64.037	0.250	0.093	1.667	1.791	-0.133	2.370
13	520	58.965	0.203	0.082	2.109	1.290	-0.231	4.549
13	540	79.795	0.180	0.145	2.557	1.130	0.392	3.255
13	560	80.985	0.235	0.181	2.771	1.157	0.288	2.765
13	580	66.651	0.391	0.150	2.225	1.424	0.040	3.770
13	600	47.113	0.194	0.142	2.418	1.381	-0.142	4.126
14	0	101.697	0.109	0.038	2.059	1.047	-0.634	8.094
14	20	117.962	0.205	0.041	2.366	0.550	1.889	18.059
14	40	91.479	0.204	0.058	1.769	1.562	-0.324	3.092
14	60	91.021	0.192	0.058	2.102	1.170	-0.397	6.114
14	80	90.398	0.155	0.060	1.965	0.903	0.755	7.292
14	100	109.310	0.109	0.075	2.422	0.840	0.665	6.492
14	120	107.443	0.174	0.108	2.443	0.910	0.939	5.702
14	140	102.210	0.409	0.122	2.525	1.004	0.612	4.109
14	160	93.802	0.150	0.041	2.035	0.682	1.384	12.495
14	180	99.406	0.274	0.155	2.732	0.969	0.758	3.822
14	200	92.411	0.266	0.188	2.836	1.068	0.455	3.112
14	220	94.475	0.261	0.228	3.039	1.044	0.490	2.452
14	240	106.238	0.402	0.304	2.943	1.300	0.370	1.703
14	260	102.253	0.338	0.098	1.793	0.106	1.171	7.197
14	280	118.677	0.204	0.045	1.813	0.759	1.318	12.630
MEAN			0.275	0.101	2.139	0.869	0.174	11.562

Appendix D: Combined Heavy-Mineral Data from Magnetic Separation, Point-Counting and X-Ray Diffractometry, 2-3 Phi Fraction.

Depth (cm)	= Depths or intervals in core.
Hmin % 2-3 phi	= Weight percent of heavy minerals in 2-3 phi fraction.
% Magnetite, Ilmenite, Garnet	= Percentages of each mineral, from magnetic separation and point-counting.
% Epidote, etc.	= Percentages of each mineral as determined by x-ray diffractometry.

CORE #	DEPTH (CM.)	HMIN % 2-3 PHI	% MAGNETITE	% ILMENITE	% GARNET	% EPI-DOTE	% HORN-BLENDE	% KYAN-ITE	% RU-TILE	% SILLI-MANITE	% SPHENE	% STAUR-OLITE	% TOUR-MALINE	% ZIR-CON	% TOTAL
4	0-40	0.1	2.3	3.3	0.2	0.7	0.0	51.2	5.6	28.7	0.0	0.0	0.0	0.0	100.0
4	60	0.1	0.0	6.0	0.7	0.0	0.0	73.7	0.0	19.6	0.0	0.0	0.0	0.0	100.0
4	80-120	0.1	0.0	6.4	0.5	0.0	0.0	93.2	0.0	0.0	0.0	0.0	0.0	0.0	100.0
4	140-200	0.1	0.9	3.3	0.3	0.0	0.0	47.7	0.0	47.7	0.0	0.0	0.0	0.0	100.0
4	220-240	0.0	3.0	6.0	0.1	21.9	0.0	50.5	0.0	18.5	0.0	0.0	0.0	0.0	100.0
5	0-80	0.1	0.0	3.0	0.1	0.0	0.0	37.9	0.6	50.5	0.0	0.0	0.0	0.0	100.0
6	0	0.1	3.0	3.0	0.0	0.0	0.0	39.9	0.0	6.3	0.0	0.0	32.5	15.4	100.0
6	20-80	0.1	1.5	5.4	0.4	0.0	0.0	0.0	9.2	0.0	0.0	0.0	83.5	0.0	100.0
6	100-180	0.2	6.5	6.0	0.5	0.0	0.0	0.0	0.0	87.1	0.0	0.0	0.0	0.0	100.0
7	0	0.1	0.0	2.4	0.0	0.0	0.0	0.0	15.6	46.0	0.0	0.0	0.0	35.9	100.0
7	20-40	0.0	3.6	3.5	0.1	0.0	0.0	35.9	0.0	20.8	0.0	0.0	0.0	35.9	100.0
7	60	0.1	1.3	1.3	0.0	0.0	0.0	83.9	0.0	0.0	0.0	0.0	0.0	13.4	100.0
7	80	0.0	0.0	2.9	0.0	0.0	0.0	0.0	0.0	97.1	0.0	0.0	0.0	0.0	100.0
7	100-160	0.1	0.5	1.7	0.1	0.0	0.0	59.9	0.0	19.2	0.0	0.0	0.0	18.6	100.0
8	0-40	0.0	1.8	4.4	0.8	0.0	0.0	42.8	0.0	39.8	0.0	0.0	0.0	10.4	100.0
8	60-80	0.1	2.9	1.7	1.1	0.0	0.0	49.4	0.0	26.7	0.0	0.0	18.3	0.0	100.0
9	0-40	0.1	2.1	4.9	1.3	0.0	0.0	72.2	0.0	19.5	0.0	0.0	0.0	0.0	100.0
9	60-100	0.2	2.1	3.9	0.3	0.0	0.0	73.1	0.0	12.4	0.0	0.0	0.0	0.0	100.0
10	0-60	0.1	5.7	5.7	1.8	0.0	0.0	59.9	10.2	0.0	16.8	0.0	0.0	0.0	100.0
10	80-100	0.3	0.0	5.6	2.4	0.0	0.0	0.0	0.0	68.3	0.0	0.0	0.0	15.7	100.0
11	0-60	0.1	3.4	4.0	0.5	0.0	0.0	32.7	0.4	0.0	0.0	9.9	38.0	3.0	100.0
11	80-100	0.1	0.0	15.4	0.0	0.0	0.0	79.1	5.5	0.0	0.0	0.0	0.0	0.0	100.0
12	0-80	0.2	6.5	6.1	0.4	0.0	0.0	57.0	0.0	14.5	0.0	0.0	13.5	2.1	100.0
12	100-180	0.2	8.7	18.9	2.8	7.4	0.0	57.0	0.0	5.1	0.0	0.0	0.0	0.0	100.0
12	200-260	0.3	3.6	8.3	0.8	0.0	0.0	81.6	0.0	0.0	0.0	0.0	0.0	5.7	100.0
12	280-320	0.3	5.6	14.4	2.2	0.0	0.0	0.0	19.4	51.2	0.0	0.0	3.6	3.6	100.0
12	320-380	0.1	14.3	14.3	0.4	0.0	0.0	61.8	0.0	9.3	0.0	0.0	0.0	0.0	100.0
13	0-40	0.2	9.4	9.4	0.0	0.0	0.0	21.9	0.0	30.9	0.0	26.0	0.0	2.4	100.0
13	60-120	0.1	12.5	16.5	0.1	0.0	0.0	68.1	0.0	0.0	0.0	0.0	0.0	2.7	100.0
13	140-160	0.4	3.8	3.8	0.1	0.0	0.0	0.0	0.0	0.0	43.2	0.0	0.0	43.1	100.0
13	180-240	0.1	3.2	12.6	0.3	0.0	49.3	34.5	0.0	0.0	0.0	0.0	0.0	0.0	100.0
13	260-320	0.2	0.9	6.0	0.7	0.0	0.0	0.0	0.0	58.3	0.0	0.0	0.0	34.2	100.0
13	340-400	0.2	0.0	7.4	0.6	0.0	0.0	0.0	0.0	67.0	0.0	0.0	0.0	17.0	100.0
13	420-460	0.1	0.6	12.9	1.4	0.0	0.0	35.2	4.6	33.5	0.0	0.0	0.0	3.9	100.0
13	480-540	0.2	9.5	13.4	0.9	0.0	0.0	64.6	0.0	11.6	0.0	0.0	0.0	0.0	100.0
13	560-600	0.3	4.0	6.2	1.0	0.0	0.0	74.3	0.0	13.8	0.0	0.0	0.0	0.0	100.0
14	0	0.1	12.5	11.3	1.3	0.0	0.0	37.5	0.0	10.1	0.0	0.0	0.0	27.4	100.0
14	20-60	0.2	2.0	5.3	0.9	0.0	0.0	0.0	0.0	91.8	0.0	0.0	0.0	0.0	100.0
14	80-160	0.2	5.9	4.0	0.4	0.0	0.0	32.8	0.0	57.7	0.0	0.0	0.0	0.0	100.0
14	180	0.3	0.0	4.9	0.1	0.0	0.0	0.0	0.0	87.2	0.0	0.0	0.0	7.8	100.0
14	200-280	0.2	7.4	8.9	0.3	0.0	0.0	0.0	12.7	57.9	0.0	0.0	12.7	0.0	100.0

Appendix E: Combined Heavy-Mineral Data from Magnetic Separation, Point-Counting and X-Ray Diffractometry, 3-4 Phi Fraction.

Depth (cm)	= Depths or intervals in core.
Hmin % 3-4 phi	= Weight percent of heavy minerals in 3-4 phi fraction.
% Magnetite, Ilmenite, Garnet	= Percentages of each mineral, from magnetic separation and point-counting.
% Epidote, etc.	= Percentages of each mineral as determined by x-ray diffractometry.

CORE NO.	DEPTH (CM.)	HMIN % 3-4 PHI	% MAGNE-TITE	% ILMEN-ITE	% GARNET	% EPI-DOTE	% HORN-BLENDE	% KYAN-ITE	% RU-TILE	% SILLI-MANITE	% SPHENE	% STAUR-OLITE	% TOUR-MALINE	% ZIR-CON	% TOTAL
4	0-40	0.1	1.5	3.0	1.4	0.0	0.0	53.3	0.0	0.0	0.0	0.0	0.0	0.0	100.0
4	60	0.1	5.9	5.0	0.9	0.0	0.0	0.0	0.0	70.2	0.0	0.0	0.0	18.0	100.0
4	80-100	0.1	0.0	2.4	0.2	0.0	0.0	0.0	4.7	26.4	7.6	0.0	0.0	58.7	100.0
4	120	0.1	0.0	9.7	0.3	0.0	59.5	0.0	17.4	0.0	0.0	0.0	0.0	13.1	100.0
4	140-160	0.3	0.0	0.0	0.0	0.0	0.0	0.0	62.0	0.0	0.0	0.0	0.0	37.2	100.0
4	180-220	0.4	0.4	1.3	0.2	0.0	0.0	0.0	0.0	98.0	0.0	0.0	0.0	0.0	100.0
4	240	0.1	2.5	6.0	1.5	0.0	0.0	0.0	0.0	68.6	21.4	0.0	0.0	0.0	100.0
5	0-80	0.2	2.3	2.6	0.3	0.0	0.0	65.3	0.0	29.5	0.0	0.0	0.0	0.0	100.0
6	0	1.8	0.6	0.6	0.0	0.0	0.0	31.6	0.0	22.7	0.0	36.6	0.0	7.9	100.0
6	20-80	0.1	3.2	3.8	0.4	0.0	0.0	55.8	0.0	30.7	0.0	0.0	0.0	6.1	100.0
6	100-120	0.1	3.6	24.2	4.4	19.4	0.0	48.5	0.0	0.0	0.0	0.0	0.0	0.0	100.0
6	140-180	0.2	1.7	5.9	1.8	0.0	0.0	86.2	0.0	0.0	0.0	0.0	0.0	4.3	100.0
7	0	1.6	0.7	0.7	0.0	0.0	0.0	19.3	8.0	32.1	0.0	28.9	0.0	10.3	100.0
7	20-40	1.9	0.9	6.9	0.4	17.4	0.0	32.5	11.1	24.5	0.0	0.0	0.0	6.3	100.0
7	60	2.6	0.0	0.3	0.0	0.0	44.1	0.0	0.0	16.8	16.8	0.0	0.0	22.1	100.0
7	80	1.6	0.5	0.5	0.0	0.0	28.7	18.6	0.0	28.7	22.9	0.0	0.0	0.0	100.0
7	100-120	1.8	0.8	4.7	1.6	0.0	0.0	0.0	50.0	0.0	0.0	0.0	0.0	42.9	100.0
7	140-160	2.9	0.5	7.0	4.4	0.0	0.0	78.8	9.2	0.0	0.0	0.0	0.0	0.0	100.0
8	0-20	0.7	0.5	4.7	0.8	0.0	0.0	0.0	0.0	74.6	0.0	0.0	0.0	19.4	100.0
8	40-80	0.6	1.2	1.1	0.1	0.0	0.0	0.0	0.0	97.6	0.0	0.0	0.0	0.0	100.0
9	0-40	0.2	2.3	3.0	0.1	0.0	45.5	45.5	0.0	3.6	0.0	0.0	0.0	0.0	100.0
9	60-100	0.2	2.9	2.6	0.3	0.0	0.0	55.8	28.5	0.0	0.0	0.0	0.0	10.0	100.0
10	0-60	0.2	1.7	6.0	0.7	0.0	0.0	91.7	0.0	0.0	0.0	0.0	0.0	0.0	100.0
10	80-100	0.0	6.5	6.5	0.0	0.0	0.0	73.8	0.0	0.0	0.0	0.0	0.0	13.3	100.0
11	0-60	0.1	3.0	3.5	0.5	0.0	0.0	65.6	0.0	27.4	0.0	0.0	0.0	0.0	100.0
11	80-100	0.3	2.9	4.3	1.6	12.9	0.0	64.4	0.0	13.9	0.0	0.0	0.0	0.0	100.0
12	0-80	0.2	4.5	7.8	1.2	0.0	0.0	49.3	0.0	35.2	0.0	0.0	0.0	2.1	100.0
12	100-120	0.1	8.3	16.7	0.0	0.0	0.0	46.9	15.5	0.0	0.0	0.0	0.0	12.7	100.0
12	140-200	0.3	4.1	4.9	0.5	0.0	0.0	0.0	0.0	45.2	0.0	0.0	36.2	9.0	100.0
12	220-240	0.2	4.5	8.6	0.5	0.0	26.1	26.1	0.0	8.1	0.0	0.0	0.0	26.1	100.0
12	260-320	0.2	4.5	5.0	0.3	0.0	0.0	0.0	0.0	89.4	0.0	0.0	0.0	0.0	100.0
12	340-380	0.2	10.7	10.4	0.4	0.0	0.0	67.0	0.0	11.6	0.0	0.0	0.0	0.0	100.0
13	0-40	1.0	1.6	4.5	0.2	0.0	26.2	18.3	0.0	0.0	0.0	23.6	23.6	2.1	100.0
13	60-80	1.0	1.0	3.4	0.7	0.0	0.0	0.0	0.0	80.1	0.0	0.0	0.0	14.8	100.0
13	100	0.7	2.0	5.5	0.6	0.0	0.0	0.0	0.0	91.8	0.0	0.0	0.0	0.0	100.0
13	120	1.6	0.0	0.6	0.1	0.0	0.0	0.0	15.6	39.2	0.0	0.0	44.6	0.0	100.0
13	140-160	1.3	0.9	3.9	0.4	0.0	0.0	0.0	0.0	0.0	0.0	76.7	0.0	18.1	100.0
13	180-200	1.4	1.1	3.2	1.2	0.0	31.3	17.2	3.4	0.0	0.0	11.3	31.3	0.0	100.0
13	220-240	1.0	2.3	5.3	0.5	0.0	0.0	46.3	0.0	0.0	0.0	34.4	0.0	11.2	100.0
13	260-280	1.1	1.9	1.9	0.0	0.0	0.0	0.0	0.0	30.2	0.0	30.2	30.2	5.7	100.0
13	300-380	0.8	2.0	1.9	0.0	0.0	0.0	0.0	0.0	80.8	0.0	0.0	0.0	15.3	100.0
13	400-420	0.9	1.9	8.3	5.2	0.0	0.0	45.0	0.0	36.0	0.0	0.0	0.0	3.6	100.0
13	440-460	0.3	5.1	5.6	2.1	0.0	0.0	67.6	0.0	13.5	0.0	0.0	0.0	6.1	100.0
13	480-500	0.3	2.1	4.0	0.2	0.0	0.0	0.0	93.8	0.0	0.0	0.0	0.0	0.0	100.0
13	520-600	0.2	6.3	7.7	0.2	0.0	0.0	0.0	0.0	53.7	32.2	0.0	0.0	0.0	100.0
14	0-60	0.2	4.4	4.3	0.2	0.0	0.0	0.0	0.0	72.4	0.0	0.0	0.0	18.7	100.0
14	80-140	0.2	6.6	6.5	0.1	0.0	0.0	71.0	0.0	15.1	0.0	0.0	0.0	0.0	100.0
14	160-180	0.2	0.0	6.7	0.7	0.0	32.1	0.0	11.1	43.4	0.0	0.0	0.0	0.0	100.0
14	200-220	0.3	4.5	4.4	0.1	0.0	0.0	50.9	0.0	12.4	0.0	0.0	0.0	27.6	100.0
14	240-260	0.5	4.4	6.4	0.2	0.0	36.3	36.3	0.0	14.5	0.0	0.0	0.0	1.9	100.0

Appendix F. Point Count Data For Selected Samples of 3-4 Phi Heavy Mineral Fraction.

SAMPLE #	OPAQUES	KYANITE	SILLIMANITE	ZIRCON	TOURMALINE	GARNET	STAUROLITE	SPHENE	EPIDOTE	HORNEBLENDE	OTHER
6-0	55	18	4	3	5	1	4	2	2	3	3
6-0 *	56	18	7	1	6	1	4	2	2	2	4
7-0	48	21	7	3	4	0	7	2	1	3	3
7-40	44	23	11	1	1	0	8	1	1	3	6
7-60	44	24	8	3	4	2	2	1	1	2	7
7-80	49	24	6	3	2	1	8	3	0	3	2
8-0	34	33	11	2	4	1	5	1	1	2	7
13-120	45	22	10	3	3	0	8	2	1	2	6
MEAN **	46	21	8	3	3	2	6	2	1	3	5

*Duplicate
**Does not include duplicate analysis.

Appendix G. Comparison of Average Mineral Percentages in the Heavy Mineral Fraction For Surface (Arthur, et al., 1985) and Vibracore Samples.

	Arthur, et al., 1985 Transects 14 through 21		Present Study	
	2-3 Phi	3-4 Phi	2-3 Phi	3-4 Phi
OPAQUES*	37.1	50.1	14.0	14.4
KYANITE	24.5	18.7	39.2	28.8
STAUROLITE	11.8	7.9	0.9	4.7
TOURMALINE	10.4	4.9	4.9	3.3
ZIRCON	2.0	7.3	7.3	9.1
EPIDOTE	4.9	2.3	0.9	1.0
SPHENE	1.3	0.4	1.6	2.0
AMPHIBOLE	5.5	1.6	1.2	6.5
SILLIMANITE	1.9	8.3	29.3	29.6
GARNET	0.6	0.1	0.6	0.7

*Includes Magnetite, Ilmenite, Leucoxene and Rutile.