AN ABSTRACT OF THE THESIS OF

Rhea Lydia Graham (Name) for the Master of Arts (Degree)

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Title: A PALEOMAGNETIC STUDY OF RECENT SEDIMENTS IN THE SANTA BARBARA BASIN

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Abstract approved:

Jack Dymond, Associate Professor

A five meter long large-diameter core from the Santa Barbara Basin was sampled for paleomagnetic measurements to determine the secular variation for the past 5000 years. The core was dated by counting seasonal rhythmites and by comparing the location of turbidity-current deposits with similar deposits in cores dated by other methods. The core represents 4830 years of depositional history.

The large diameter of the core permitted the taking of samples in two continuous downcore profiles. No secular variation was found in the core. However, differences in paleomagnetic directions measured at the same depth were larger than operator induced errors. From this observation an interesting aspect of detrital remanent magnetization (DRM) was discovered. The magnetic grains which make up the Santa Barbara Basin sediment and deposited within the alignment of seasonal rhythmites show much greater variance in their paleomagnetic components than do recent varved sediments deposited in fresh water. Apparently, deposition of a sediment in seawater creates randomness in the magnetic grains of rhythmically deposited sediments, resulting in large variations in the

measured paleomagnetic directions.

A PALEOMAGNETIC STUDY OF RECENT SEDIMENTS IN THE SANTA BARBARA BASIN

by

Rhea Lydia Graham

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Typed by Cheryl Schurg for Rhea Lydia Graham

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For interesting me in studying paleomagnetism and for in general providing me the opportunity for a good experience in oceanography I owe many thanks to Dr. Jack Dymond, my advisor. Also I want to thank Dr. Rick Blakely, who as a satellite advisor guided me through my research project and arranged for my being able to measure my samples. Dr. Erwin Suess was a very helpful member of my committee who gave me many interesting ideas to consider and Dr. Bradford Arnold also served on my examining committee.

Without the use of the Geophysics Laboratory at Stanford University, there would have been no thesis data. I am grateful to Dr. Allan Cox and his staff and students for allowing me to monopolize their cryogenic magnetometer with my 800 samples. I learned most of what I know about paleomagnetics from this group of people and I enjoyed working with them: Bob Simpson, Ken Kodama, Richard Gordon, and Kai Lance. Also, for providing me a place to stay, for preventing me from missing all of my meals, and for support in general while I worked at Stanford I wish to thank Walt, Diane, Terry, Ralph, Carol, and Mary Lou.

Dr. Joern Theide gave me permission to use the core Y74-1-13K for this study. Dr. Chuck Denham suggested that I take samples in duplicate profiles down the core. Drs. Shaul Levi, Jack Hillhouse, Joe Liddicoat, and Ed Sholkovitz also contributed their ideas to this study.

I would like to thank my many friends at Oregon State who helped me realize that school can be an unforgettable experience because of how great it was. I would like to thank in particular Cliff, whose patience, understanding, and assistance made the whole thing more bearable than I thought it could be.

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A PALEOMAGNETIC STUDY OF RECENT SEDIMENTS IN THE SANTA BARBARA BASIN

INTRODUCTION

Although many paleomagnetic studies of deep-sea sediments (Opdyke, 1968) have provided important stratigraphic and age correlations, there has not been adequate testing of the variability inherent in these measurements. These previous studies have been limited to measuring only one sample per stratigraphic horizon. The reason for this was the narrow diameter (usually 6 cm) of the commonly used sediment coring device. In a study by Amin, _et al._, (1972) susceptibility (the variation in amount of magnetic material present) was measured on both halves of a split core. Their work yielded repeatable results in all cases where the mineralogy was constant.

In this study a large-diameter (15 cm) core from the Santa Barbara Basin was sampled in two downcore profiles to determine the horizontal variability for paleomagnetic measurements of deep-sea sediments and to obtain data on the changes in secular variation recorded in these sediments. In addition this core contains sediment rapidly deposited in seasonal rhythmites (Hülsemann and Emery, 1961) which allow for cross correlation of samples from each profile and an independent age-versus-depth determination. Secular variation is the middle-frequency band of variation in the earth's geomagnetic field which has a time interval of 10 to 10^4 years (Cox, 1975). It is measured as the change in angular dispersion of the non-dipole field with time. Creer (1974), using cores from the Black Sea, has shown that rapidly deposited sediments can provide useful information about the behavior of the geomagnetic field during recent times. The Santa Barbara Basin seemed an ideal site in which to study this variation, especially since a core which was wide enough to be sampled in two downcore profiles was available.

The Santa Barbara Basin

The Santa Barbara Basin is the northernmost major basin of the California Continental Borderland, located southeast of Point Conception and north of Santa Rosa Island, near where the Transverse Range tectonic province joins the Continental Borderland (Figure 1). The basin and ridge topography of the Borderland is due to strike-slip movements and extensive block faulting that probably began in Oligocene times (Emery, 1960). The center of the basin is a filled graben with no structural anomalies.

The Santa Barbara Basin has been receiving sediments since Miocene times. The terrigeneous input is from a drainage area consisting of the Santa Clara River (51%), the Santa Ynez River (27%), coastal drainage (12%), the Ventura River (7%), and the Channel Islands (3%) (Fleischer, 1972). Santa Ynez River input is enhanced due to the southward longshore drift and general surface circulation in the basin. These land-derived sediments are highly reduced, containing hydrogen sulphide at the surface and at all depths (Sholkovitz, 1973), and comprise the winter component of the seasonal rhythmites. They are dark in color because of the increased inorganic runoff from winter rains. The summer part is olive-green and contains a higher percentage of organic matter, mainly diatom frustules, reflecting the increase in organic production in surface waters. Also present in the basin sediments are grey sand layers

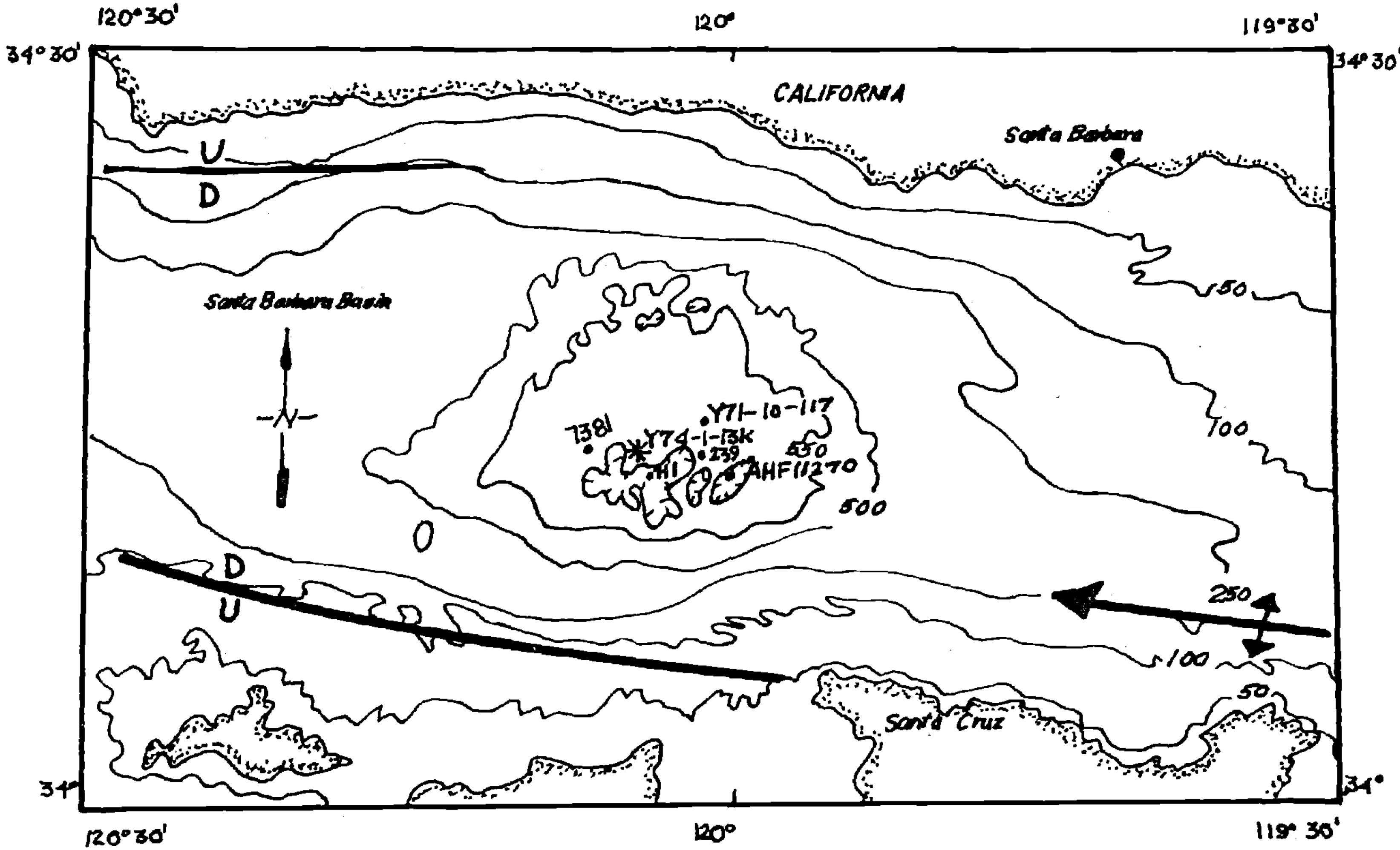


Figure 1. A contour map of the Santa Barbara Basin including core used in this study marked with an asterisk.

which are suspended-load deposits (turbidites) derived from the Santa Clara River during large floods (Fleischer, 1972). Both features of the basin sediments, the seasonal rhythmite couplet and the turbidity-current deposit, can be seen in an X-radiograph of part of the core (Figure 2).

Although the surface waters of the Santa Barbara Basin experience intense biologic upwelling during the summer months, its deepest parts remain anoxic. Rhythmites produced in stagnation basins are composed of very fine-grained silts and clays, and the layers of a couplet differ in color and type of material (Calvert, 1964). Due to lack of oxygen in the overlying waters, there is no benthic fauna and therefore no bioturbation to destroy the rhythmites. Work by Sholkovitz and Gieskes (1971) has shown that water replacement in the Santa Barbara Basin may occur rapidly and quite frequently due to displacement by dense upwelled water from outside the basin, and that some vertical mixing also occurs. Sediment trap observations and chemical anomalies of the basin bottom water suggest turbidity currents are responsible for the transport of sediment, nutrients, and detritus over the sill of the basin creating a region of near bottom transport ranging from 20 meters to 40 meters above the basin floor (Sholkovitz and Soutar, 1974). No submarine canyons exist in the basin (Emery, 1960) and so the turbidity currents which transport suspended matter are more diffuse than in basins with canyons (Sholkovitz and Soutar, 1974), rarely reaching the bottom of the center of the basin with much force. Thus the turbidity-currents are primarily a means of deposition rather than a means of erosion. Moore (1969) feels that the green muds represent particle by particle deposi-

Figure 2. A x-radiograph of a section of core Y74-1-13K with attached centimeter scale. The arrow indicates downward in the core.

tion since they lack graded bedding and contain only deep-water foraminifera.

The core used in this study, Y74-1-13K, is from the Oregon State University core collection and was taken in October of 1974 aboard the R/V Yaquina in 573 m water depth, below the still depth (475 m) of the basin (Kaplan et al., 1963). The core contains seasonal rhythmites ranging in thickness from 1 mm to 5 mm and whole pteropod shells found within it substantiate claims of quiet water deposition. The magnetic mineral is magnetite, which is smaller than the silt and clay grains which have an average grain size of 16 μ (Fleischer, 1972).

Detrital Remanent Magnetization

The fossil magnetism which is initially measured in rocks and sediments is called the natural remanent magnetization (NRM) of that material. In sediments, the manner in which the NRM is acquired is called detrital remanent magnetization (DRM) because it results from the alignment of detrital magnetic particles which occurs in sediments. The alignment of magnetic particles may occur during sedimentation, or it can occur due to particle rotation after deposition but prior to consolidation. The former type of DRM, known as depositional DRM usually is found in freshwater deposits, such as lake sediments and glacial varves. Because of the exchange of sediment and fluids at the seawater-sediment interface, post-depositional DRM is usually found in marine sediments (Irving, 1964).

Research on the mechanical processes of detrital remanent magnetization began thirty years ago with the pioneering work of Johnson, et al. (1948). They showed that the magnetization of the sediment grains making up a sediment are recorders of the ambient field in which they are deposited.

A spherical grain settling in water experiences two opposing rotational torques. The first is a magnetic torque that causes the magnetic amount of the grain to be parallel to the ambient field of the earth. This torque is opposed by viscous drag of the fluid, however, the parameters of viscosity, density, and magnetization are such that alignment occurs very quickly. Systematic errors in the alignment of sediments occasionally occur. Inclination error, for example, is a slight shallowing of the inclination of the sediments produced either by a high proportion of flat grains (King, 1955), by the rolling of grains upon impact (Griffiths, et al., 1960), or by compaction of the grains after deposition (Kodama and Cox, 1976).

In addition to the aligning phenomenon, the magnetic particles also experience randomizing effects and the smaller particles are influenced by Brownian motion (Collinson, 1965). Thus, alignment is only partial for a sediment consisting of a typical grain-size distribution. The net moment is less than the moment of the individual grains but still parallel to the ambient field.

PROCEDURE

Collecting the data for this study consisted of two parts: dating the core and measuring the core samples to determine their magnetic signature. In order to study better the seasonal rhythmites, a slice of the core was shaved off the entire length of the core and X-rayed. The X-rays were developed into photographs and from them the rhythmite couplets could be counted. The part of the core used for this purpose could not be used for sampling for the magnetic measurements. The remainder of the core was sampled for the paleomagnetic measurements.

Chronology of the Core

I found that the core Y74-1-13K contained three types of sedimentation patterns indicative of three different modes and rates of deposition. The fastest rate of sedimentation is associated with the turbidity current deposits. The seasonal rhythmites are deposited at either a fast or a slow rate of deposition. Figure 3 is a schematic diagram of the core which shows the different segments of varying sedimentation rates. The blank areas represent "homogeneous" intervals, in that they lack seasonal rhythmites or turbidity current deposits. These "homogeneous" intervals represent very fine, slow deposition of sediment. After counting the couplets within each sedimentation rate grouping, an estimate was made for the number of years represented by each interval. Since the turbidity current deposits are likely to be contemporaneously deposited throughout the basin, the positions of the gray sand layers in Y74-1-13K were compared with two other cores for which similar information existed.

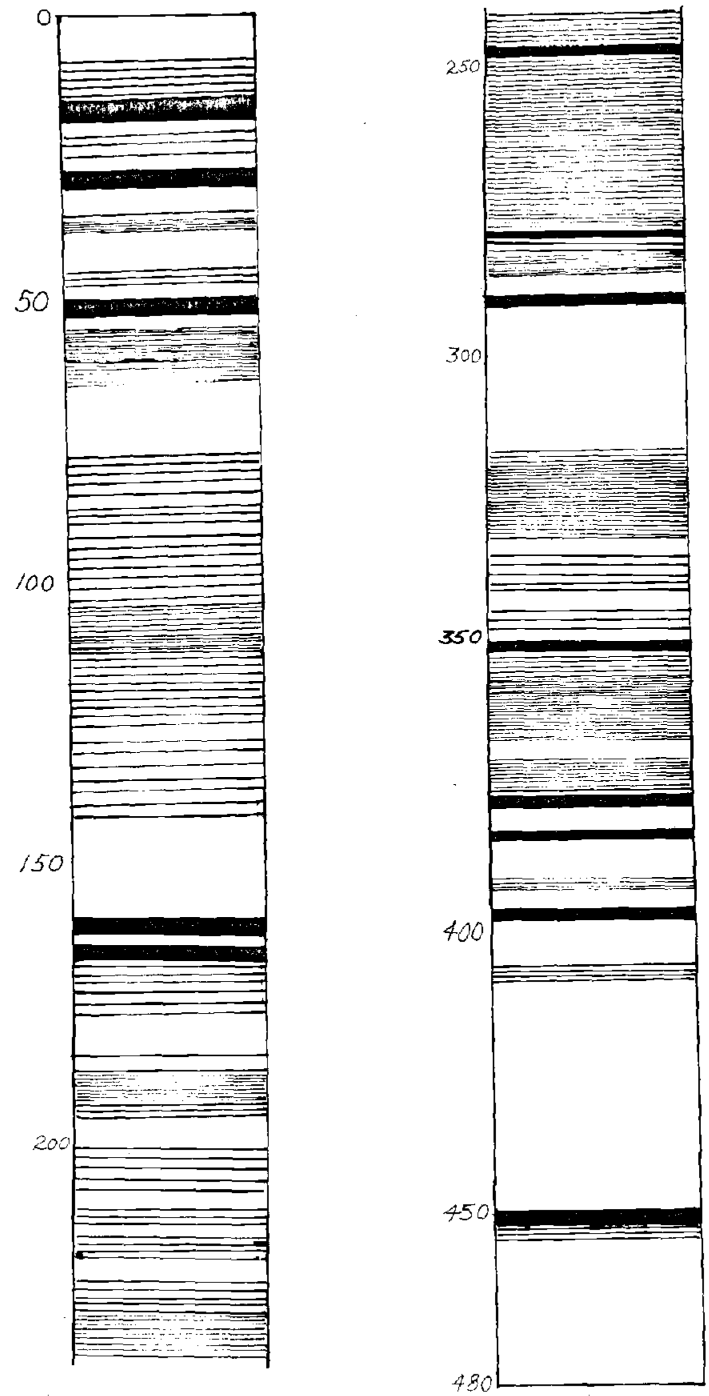


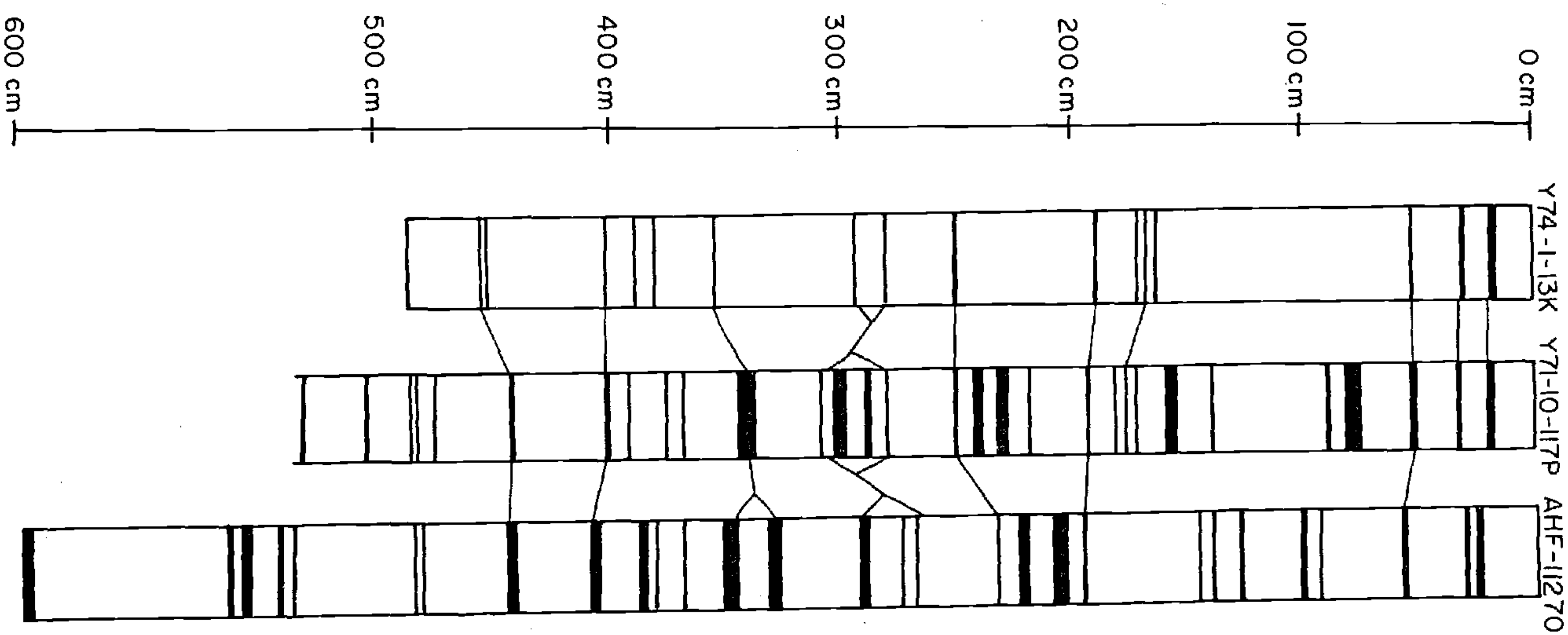
Figure 3. A schematic diagram of depositional intervals in Y74-1-13K. The dark areas represent turbidity current deposits and the alternating light and dark regions are rhythmites. The blank areas represent slow deposition periods.

The result of this comparison is shown in Figure 4.

In Figure 4a schematic diagrams of all three cores are shown. It can be expected that some of the gray layers (dark lines) were contemporaneously deposited. However, the absence of these layers in some of the cores requires an explanation. Figure 4b shows a sketch of the basin bottom near the area of the three cores. The core AHF11270, which has the highest sedimentation rate of the three (at 120 cm/thousand years) (Fleischer, 1972), is located within a more deeply channelled area and closer to the source of the turbidity currents than the other two cores. The core Y74-1-13K is separated from Y71-10-117 by a more deeply channelled area (70 cm/thousand years) (Moore et al., unpubl. data), as well as being farther from the source of the grey sand input. For these reasons, nearness to source and intervening topography, I feel that it is reasonable to assume that Y74-1-13K has a slower sedimentation rate than AHF11270 and fewer turbidity-current deposits than the Y71-10-117.

Sedimentation rates computed for other cores in the Basin include 90 cm/thousand years (Emery, 1964) for core 7381; 114 cm/thousand years (Emery and Bray, 1962 for core H1; and 390 cm/thousand years (Koide, et al., 1972) for core 239. The first two rates are from radiocarbon dating methods. The last one is from ^{210}Pb dating techniques, and has been extrapolated backwards for 1000 years as the core used was only 55 cm long. From all of this information as well as from my counting of discreet intervals of seasonal rhythmites, I have computed an average sedimentation rate of 100 cm/thousand years for Y74-1-13K.

Figure 4a. Comparison of the locations of turbidity current deposits in three cores from the Santa Barbara Basin.



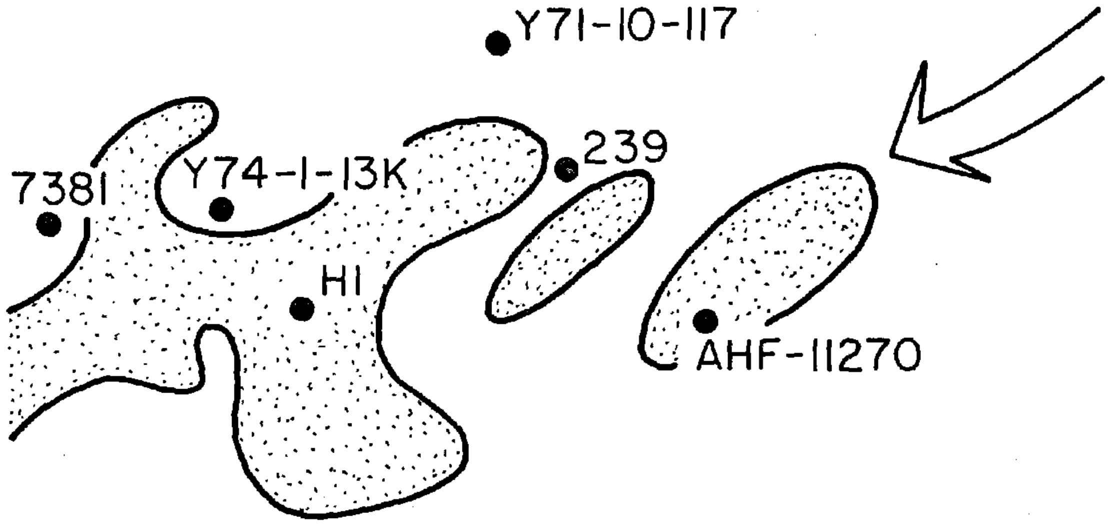


Figure 4b. An enlargement of the basin area in Figure 1 showing the location of the cores used for comparison.

The Paleomagnetic Measurements

The continuous sampling and the fact that more than one sample per stratigraphic horizon was measured make this study unique. Figure 5 shows the brass non-magnetic sampling device, which cuts a trough of samples down the core. The samples were sealed in plastic boxes with non-magnetic Duco® cement to preserve their moisture content. The average sample volume was six cubic centimeters. The thickness of the sampling device and of the sides of the plastic box limit the volume to this value. Alignment of the sample within the plastic box is accurate to within 6°. Samples in which the sediment had rotated more than 6° as judged by the lack of concordance between layering and the edge of the box were not used in this study.

In addition to the two sets of downcore samples, samples were taken continuously across the core at 15 cm depth intervals to measure the lateral variations within the same stratigraphic horizon more closely, and to see if edge effects related to drag of the sediment along the side of the core barrel could be statistically predicted. These samples were taken in the same manner as the previous samples.

A new type of highly sensitive magnetometer called a cryogenic magnetometer was used to measure the NRM of the samples. The cryogenic magnetometer has a precision three orders of magnitude greater than the conventional magnetometers, permitting the measurement of weakly magnetized sediments. The cryogenic magnetometer used in this study is part of the Geophysics Laboratory at Stanford University and accurately measures intensities of 10^{-7} emu/cm^3 with less than 1% error in the

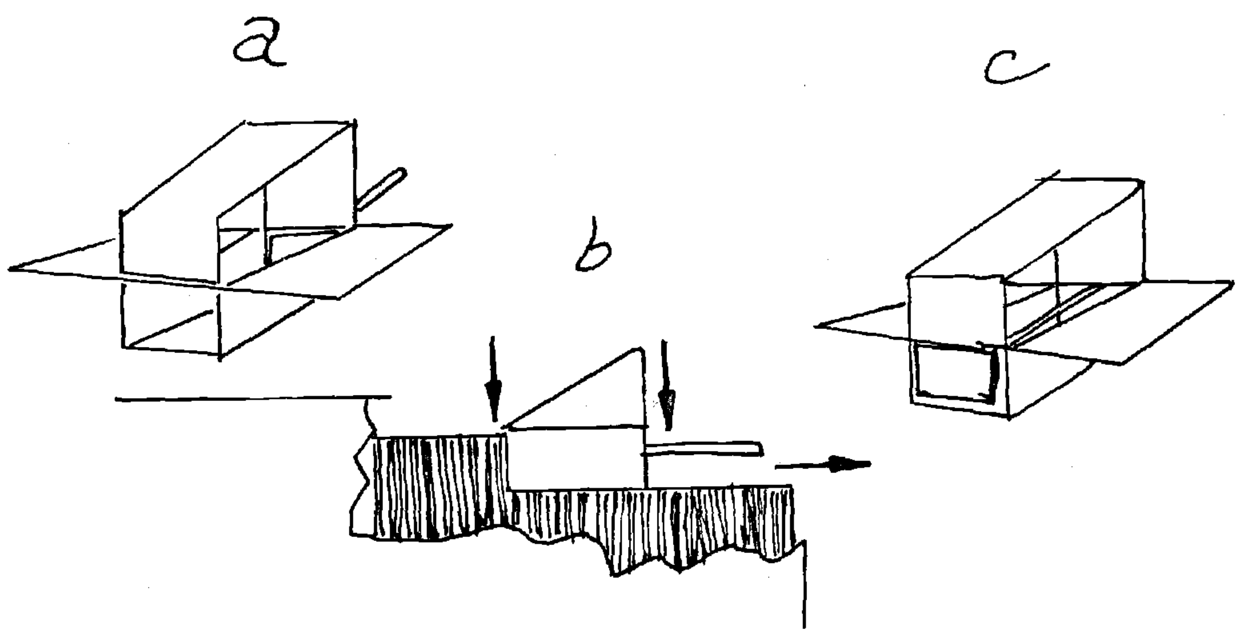


Figure 5. The brass non-magnetic sampling device used for obtaining samples from the core.

direction of magnetization.

Stability tests were conducted on the samples to determine if the measured NRM was the moment of magnetization acquired by the sediment at the time of deposition (or consolidation) or if it was due to other factors. Test samples were subjected to alternating field demagnetization in successive peak fields of 25, 50, 100 and 150 oe. The cryogenic magnetometer at Stanford has an alternating field demagnetization unit which is attached to the magnetometer. Therefore, it is not necessary to expose the sample to the earth's field at any time during the demagnetization process.

The stepwise demagnetization of the test samples is shown in Figure 6. Two factors were used to determine the optimum cleaning field for these sediments. One factor was the sharpness of change in slope of the line plotted in Figure 6. The other factor was the limits of the cryogenic magnetometer to accurately measure the remaining magnetic moment of the sample. It was found that a field in excess of 100 oe very sharply reduced the intensity of most samples, thus 100 oe was chosen as the optimum peak field for demagnetization. It was assumed that the mineralogy was constant enough, the age span short enough, and the NRM intensities constant enough to demagnetize all samples in the same field. Most sediments cleaned by this process are optimally cleaned in fields ranging from 100 oe to 200 oe.

Several plotting techniques were used to display the results of the paleomagnetic measurements. The traditional method of showing the inclination, declination, and intensity for each depth in the core for both

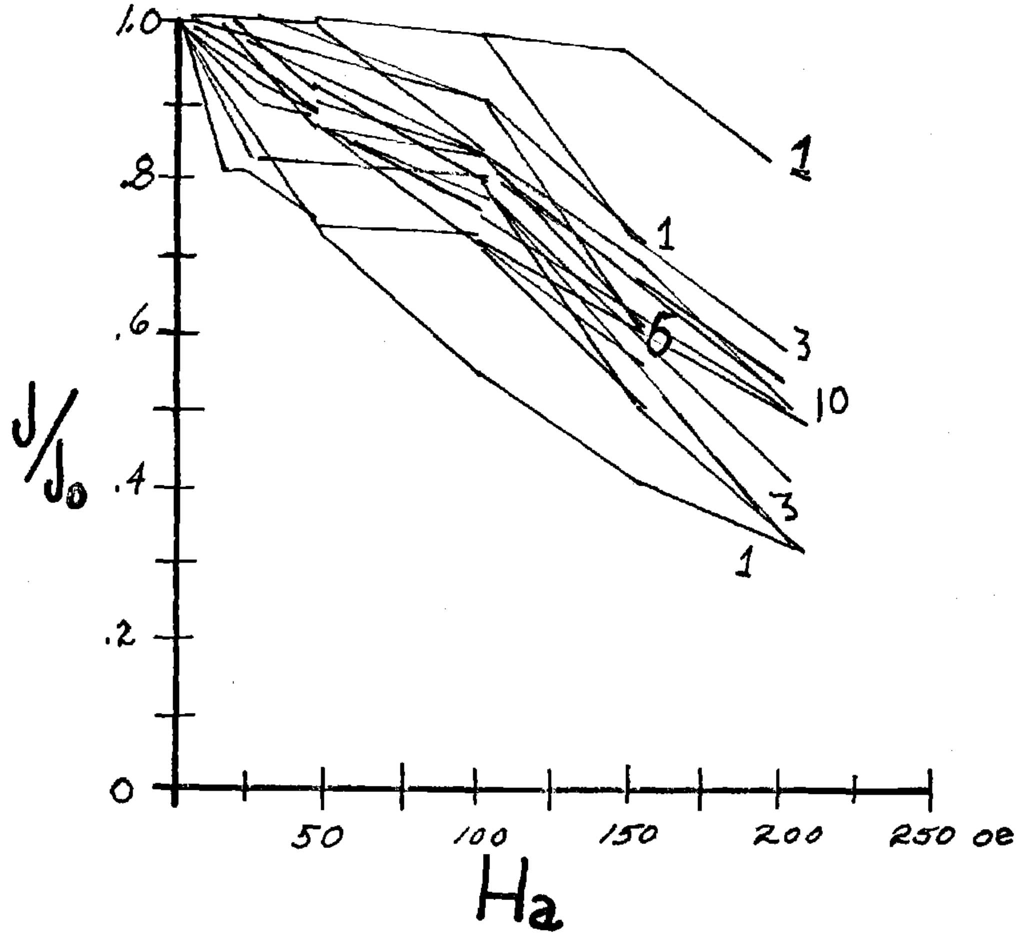


Figure 6. The results of the stepwise demagnetization of test samples. The abscissa is the applied field in oersteds. The ordinate is the ratio of the measured intensity over the intensity before a cleaning field was applied.

the NRM measurements and the 100 oe cleaning are shown for both profiles in Figure 7. Figure 8 shows the inclination with five-point running means computed for both the NRM and cleaned samples. In order to show the changes in declination, the northward and eastward components of the declination were computed for each sample for the NRM measurements and for after cleaning (Figure 9). This figure clearly illustrates the lateral variations of magnetic direction in the core. The plots of the three geomagnetic components for the across-core samples shows that the alternating field demagnetization does not cause the values to coincide more closely (Figure 10).

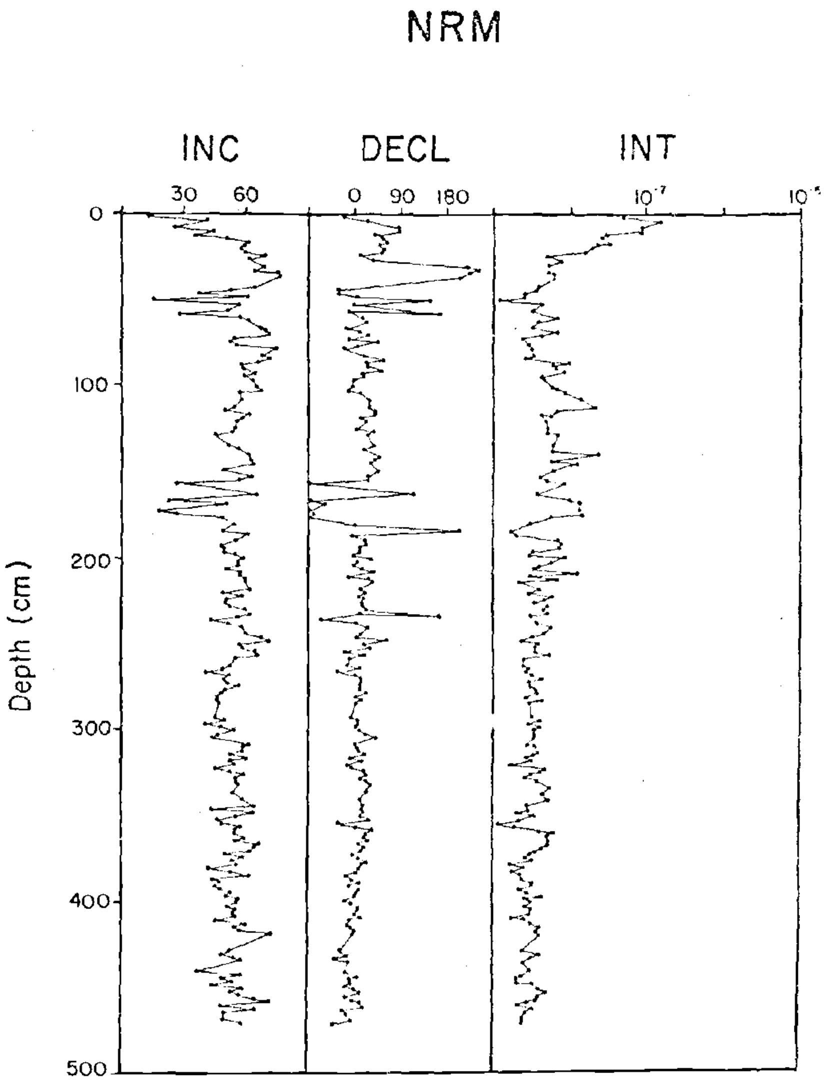


Figure 7a. Results of NRM measurements for the first profile of continuous samples taken from the core. Inclination, declination, and intensity are plotted as a function of depth before treatment in the optimum cleaning field.

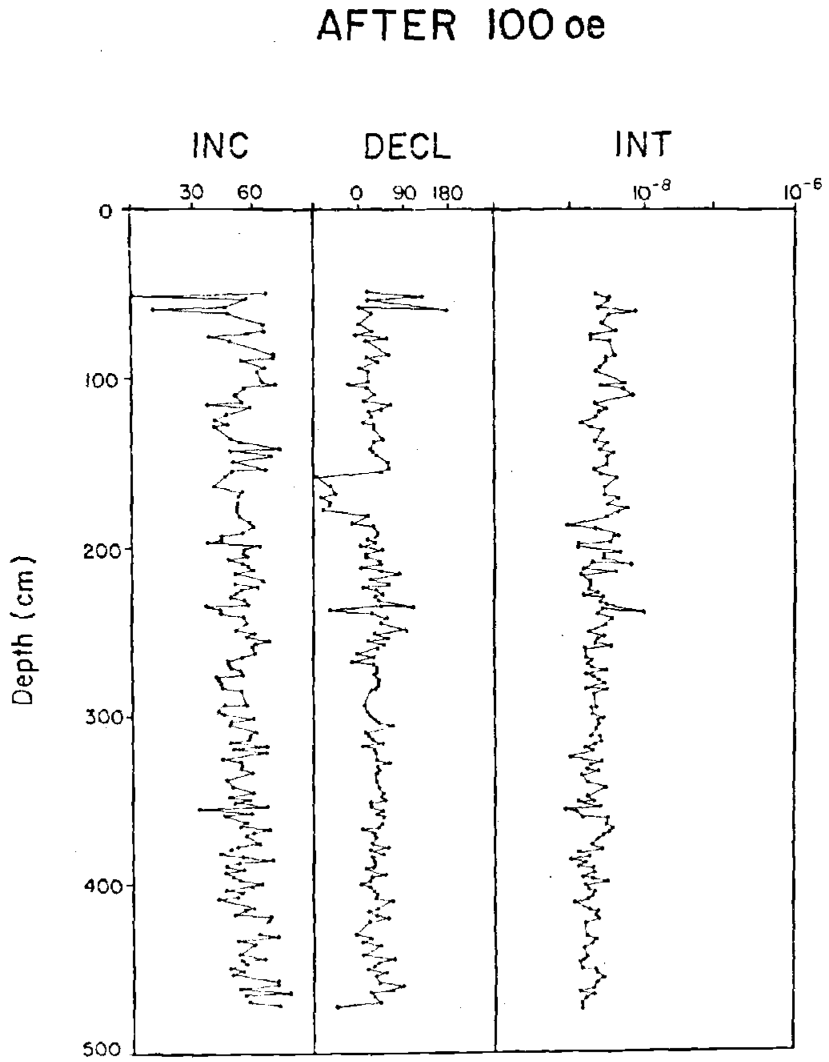


Figure 7b. Results of NRM measurements for the first profile of continuous samples taken from the core. Inclination, declination, and intensity are plotted as a function of depth after treatment in the optimum cleaning field.

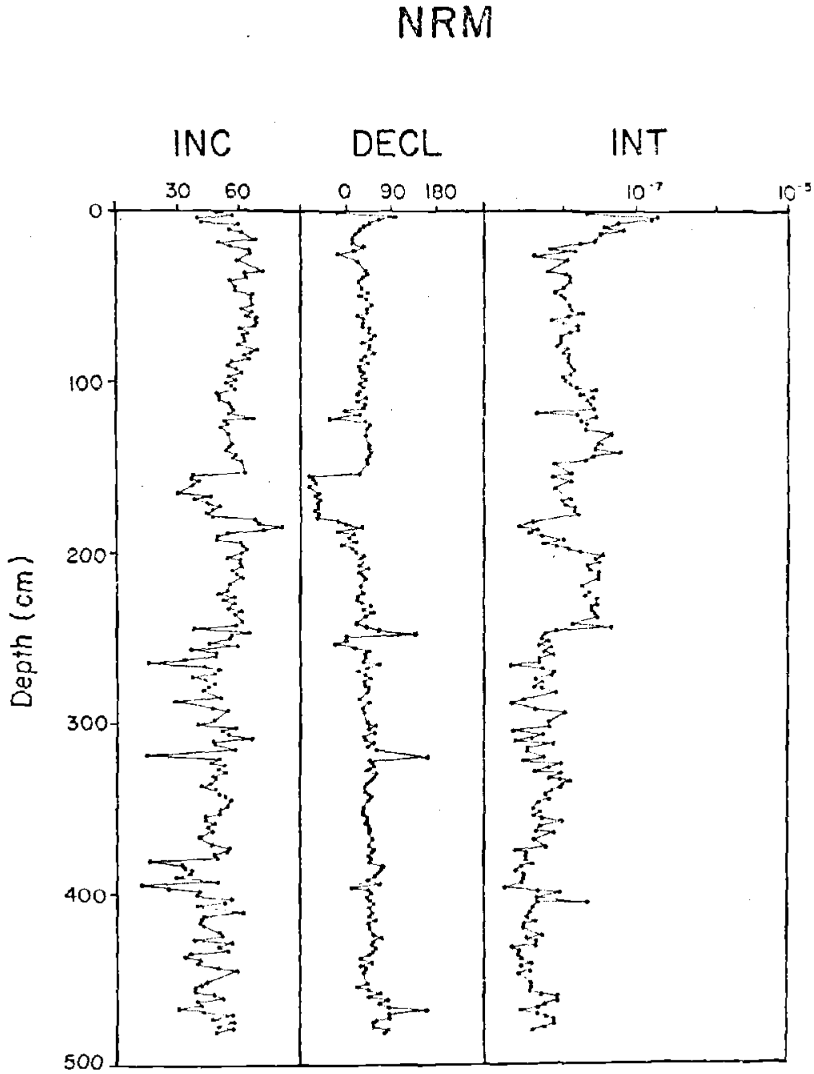


Figure 7c. Results of NRM measurements for the second profile of continuous samples taken from the core. Inclination, declination, and intensity are plotted as a function of depth before treatment in the optimum cleaning field.

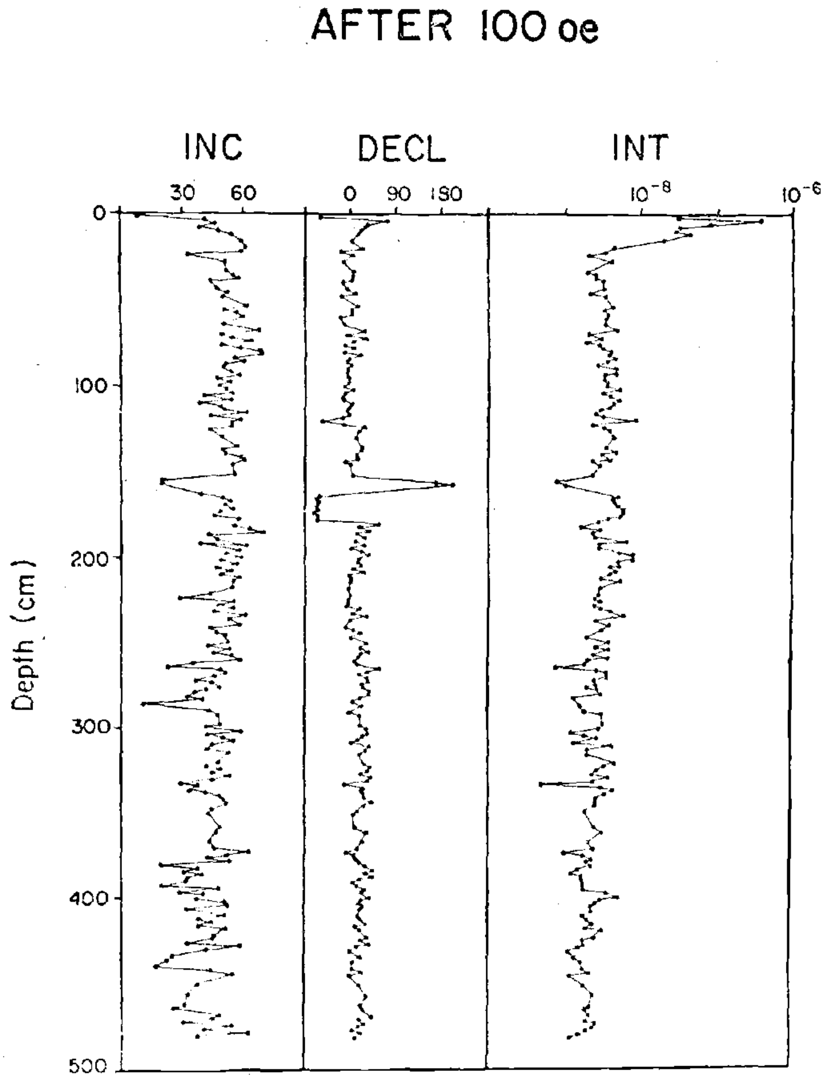


Figure 7d. Results of NRM measurements for the second profile of continuous samples taken from the core. Inclination, declination, and intensity are plotted as a function of depth after treatment in the optimum cleaning field.

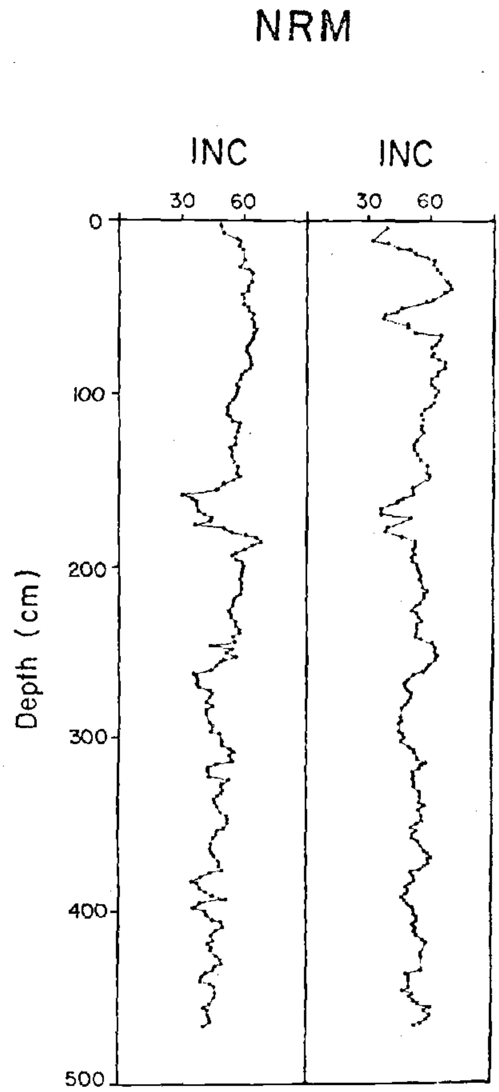


Figure 8a. Five-point running means computed for inclination values before cleaning. The left side of the figure corresponds to the left continuous profile in the core.

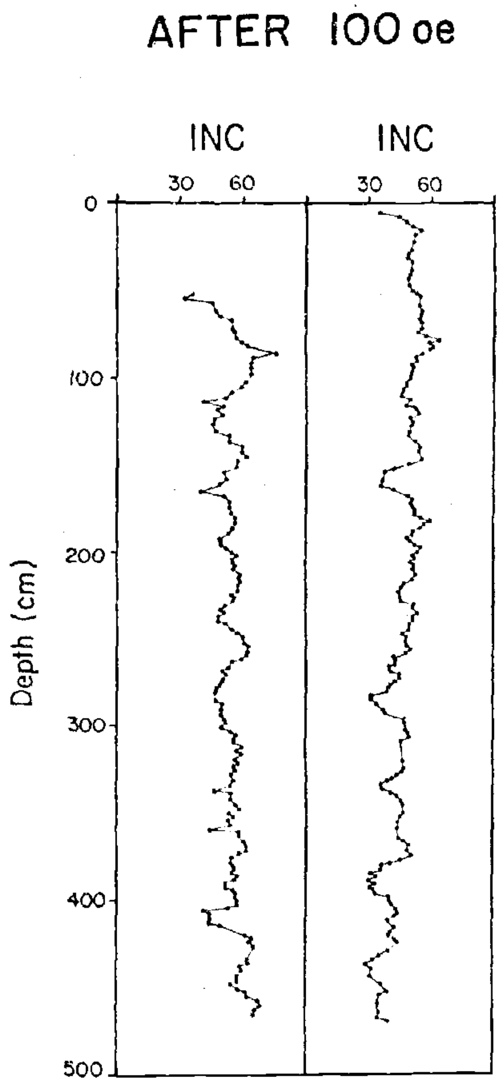


Figure 8b. Five-point running means computed for inclination values after cleaning. The left side of the figure corresponds to the left continuous profile in the core.

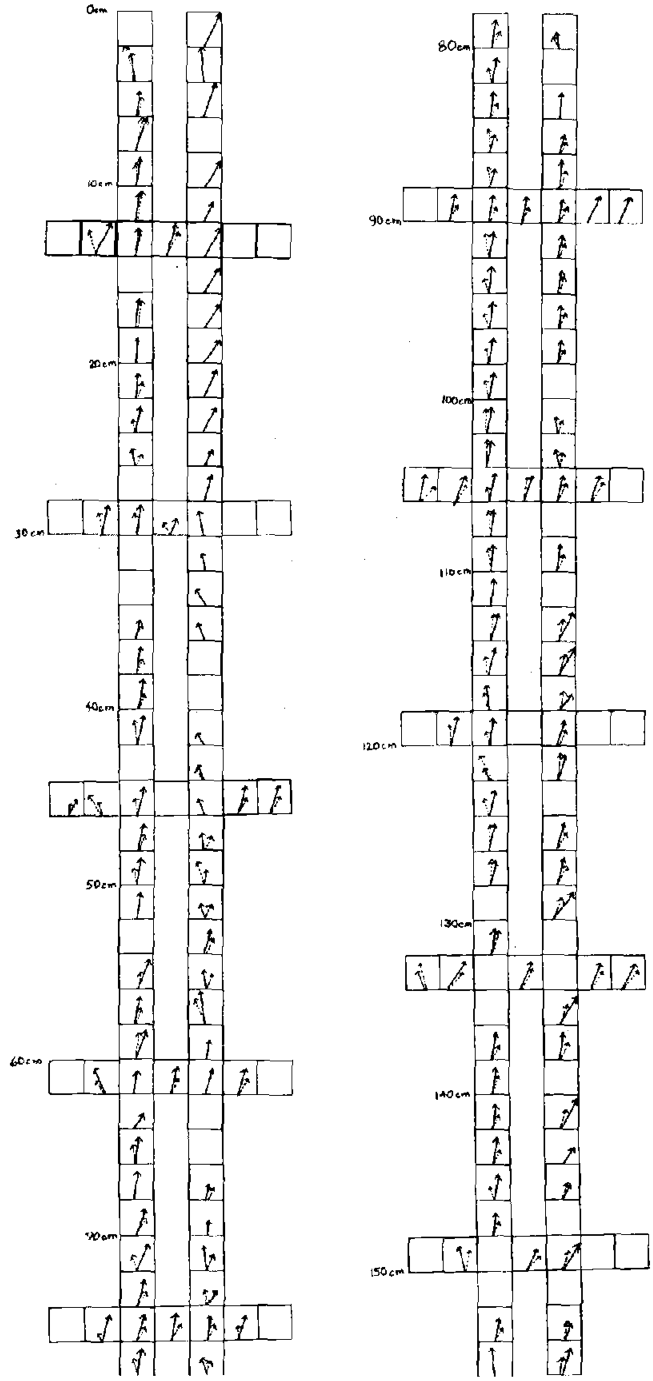


Figure 9. Map of declination for all samples taken on core Y74-1-13K. The solid arrows are before cleaning and the dashed arrows are after the 100 oe field was applied. Depth in the core is indicated to the left of the boxes.

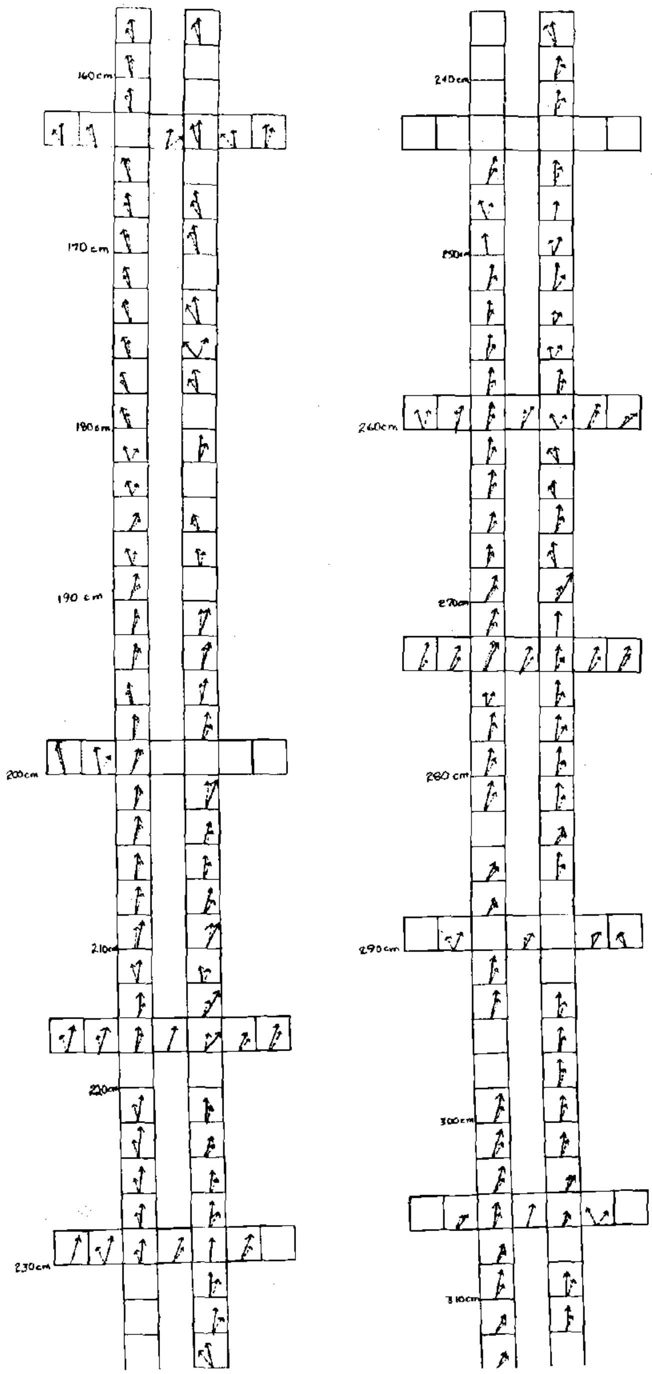


Figure 9. Continued.

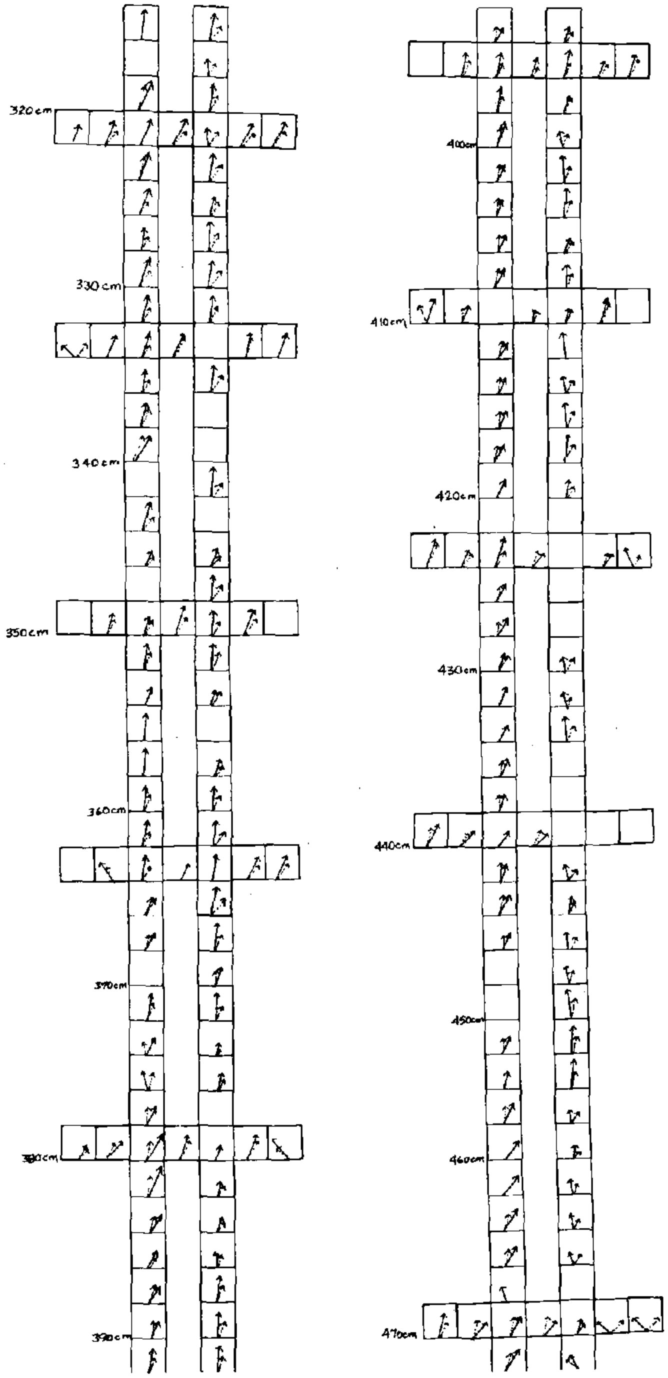


Figure 9. Continued.

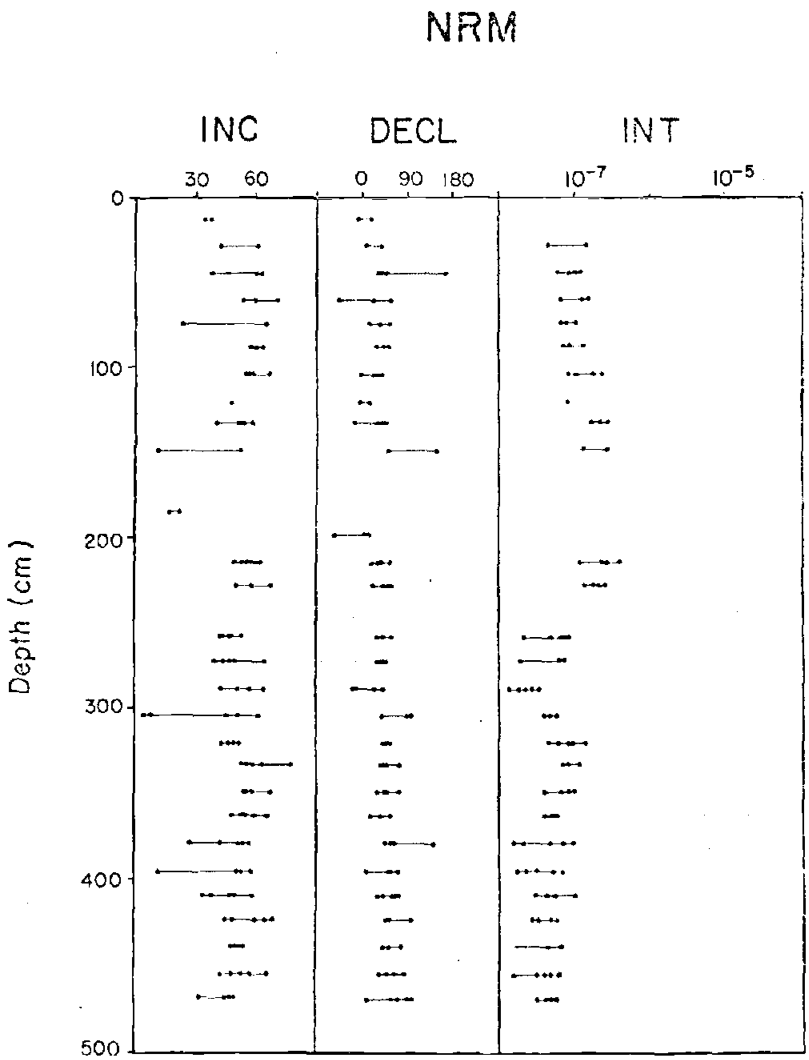


Figure 10a. Results of the across-core measurements for inclination, declination, and intensity as a function of depth are shown before cleaning in the 100 oe field.

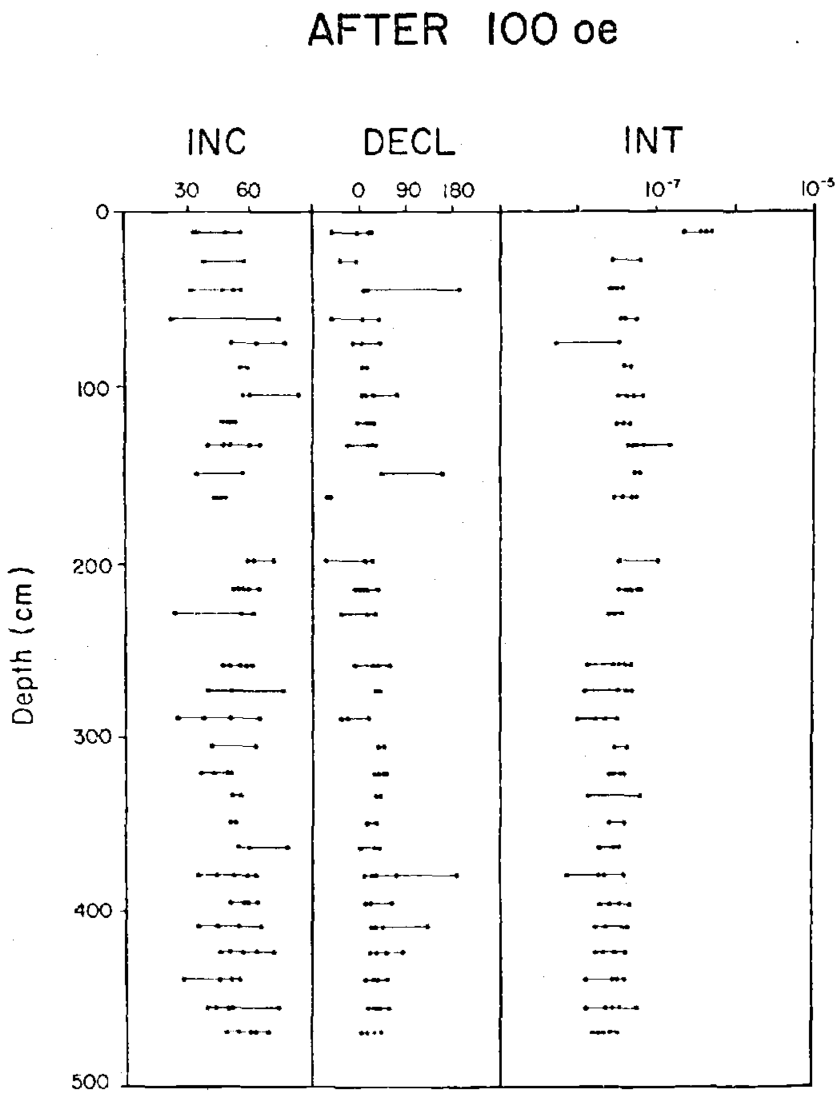


Figure 10b. Results of the across-core measurements for inclination, declination, and intensity as a function of depth are shown after cleaning in the 100 oe field.

INTERPRETATION

In the previous section, data was presented which showed the results of measuring sediment samples from the Santa Barbara Basin for paleomagnetism. From this data several questions about the meaning of the paleomagnetism of core Y74-1-13K are posed. One question is to determine whether or not secular variation is present. Another is to determine the effect of storage upon the magnetization of the samples. A third question involves explaining the steady increase in intensity towards the top of the core and a fourth involves the reason for the abrupt change in the declination values between 155 cm and 178 cm. The final question posed is the lack of agreement between two samples from the same depth in the core (Figure 11).

There is no well-defined pattern of secular variation in any of the geomagnetic components. Even if present, it would be difficult to discern because of the large amount of variation from sample to sample. Furthermore, the short time-span of the core hinders detection of secular variations with longer periods (greater than 2000 years).

Since the core has been stored wet it is possible that realignment of the sediment grains could occur during transportation (Johnson, et al., 1975). Drag is evident along the sides of the core (Figure 12) affecting samples taken within 2 cm of either edge.

The intensity is fairly constant for all samples with the exception of some erratic samples (e.g. 335 cm) and the top of the core. From 25 cm upwards the intensity increases at a steady rate. This increase in intensity of more than a factor of ten may reflect an increase in the

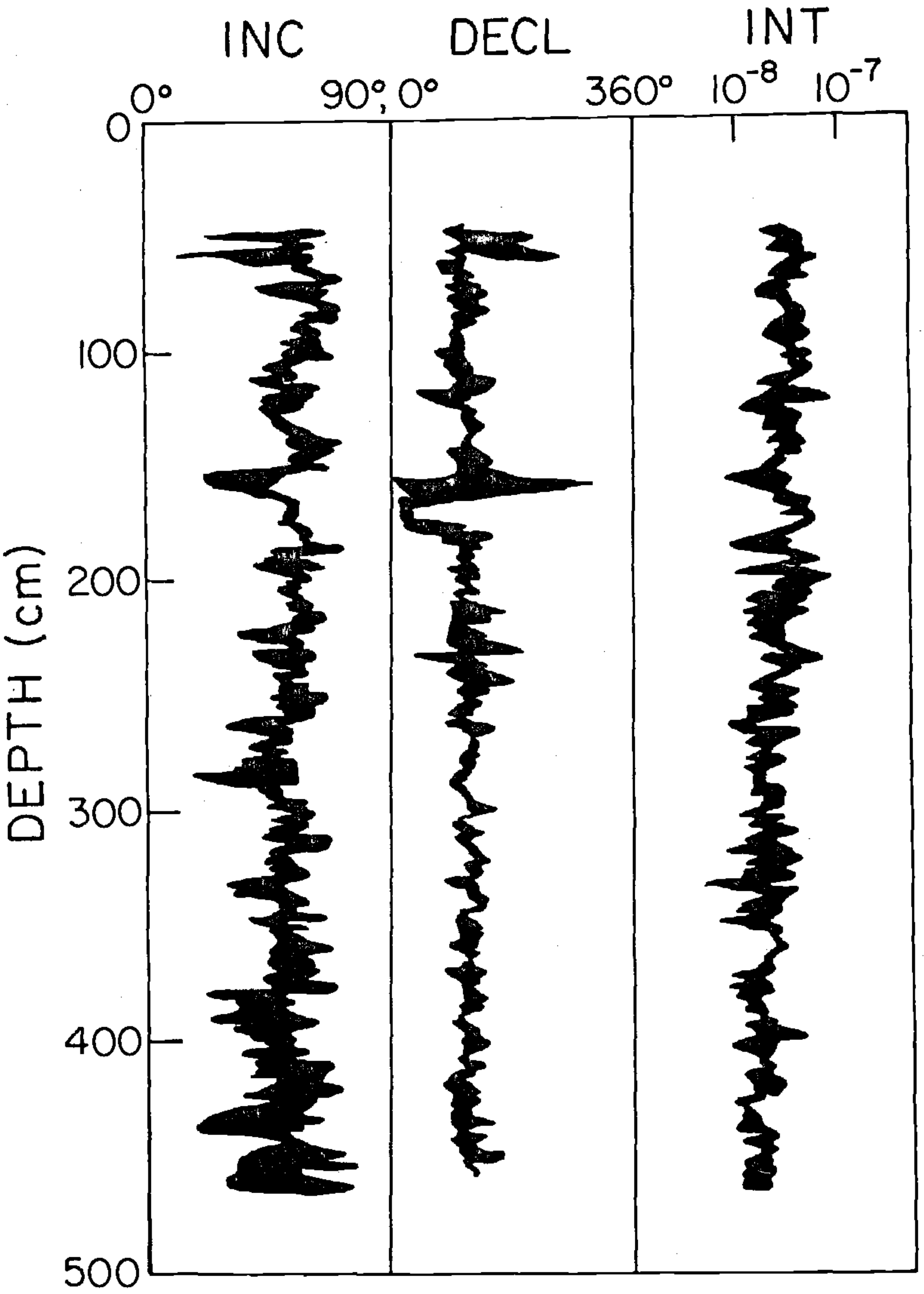


Figure 11. The darkened area indicates the absolute difference in geomagnetic components for the two profiles plotted against depth.

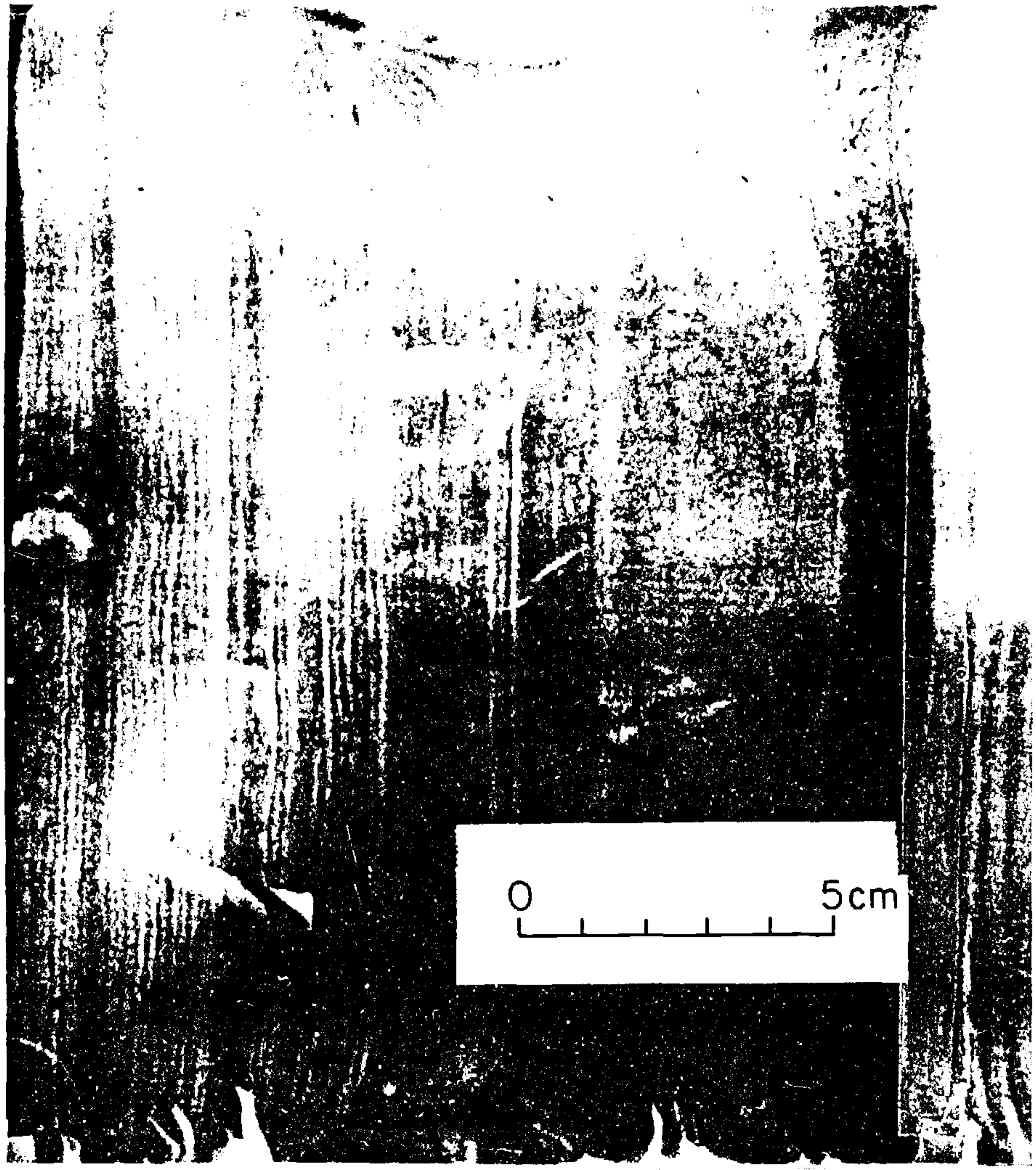


Figure 12. An x-radiograph of the core showing drag along the edges. The turbidite layer to the right side of the figure clearly shows the drag.

magnetite content of the sediment. Perhaps the increase in magnetite volume is due to airborne particles of magnetite from industrial activity onshore (Doyle, et al., 1976). A depth of 25 cm would correspond to about 100 years in this section of the core due to the lack of compaction of the sediment. This agrees with other data on anthropogenic effects in recent sediments from the Santa Barbara Basin and the Baltic Sea (Bruland, et al.; Erlenkeuser, et al., 1973).

Declination values after 155 cm abruptly change 90° away from their previous trend, and return to this trend after 178 cm. The reason for this change is mechanical. The core is divided into three sections and the section between 155 cm and 178 cm was not opened on the same side as the other two sections, creating the change in declination values. The fact that the declination values are otherwise fairly constant throughout the length of the core is evidence that the core barrel did not twist much upon entry into the sediment.

The maximum total sampling errors are approximately 10%, which leaves most of the observed variation between paired samples unexplained. Since shallowing of inclination with depth is not observed in this case, I conclude that much of the sediment in the Santa Barbara Basin is deposited under low-energy conditions, similar to those described by King and Rees (1966). They suggested that when sediments are combined in a dense slurry and allowed to settle, the escape of the water is impeded by the sediment grains. The result is that gravity effects are negligible and depositional DRM does not occur. For this reason, one does not see a systematic shallowing of inclination with depth. The preservation of finely textured rhythmites and the lack of graded bedding in the turbidites is further evidence for a low energy depositional environment.

Moore (1969) suggests that particle by particle deposition occurs in the Santa Barbara Basin. If these sediments are deposited in an environment which does not allow for much movement of the sediment grains after deposition, perhaps the reason that these particular sediments are inconsistent paleomagnetic recorders is because the magnetic grains have enough randomizing variables to dominate any tendency to align parallel to the magnetic field.

Mineralogical variations within the core, especially between samples of the same stratigraphic horizon, are not detectable. It might be thought that the lack of agreement between samples from the same horizon is due to diagenesis of the sediment; however, changes in the chemical environment which would produce diagenetic variations in the same horizon are difficult to imagine.

The major puzzlement of this study is the fact that these marine rhythmites are not good paleomagnetic recorders whereas varves (Granar, 1958) and lake sediments (Creer, _et al_., 1971) are good recorders. Creer, unpubl. data (E. Sholkovitz, pers. comm.), working with sediments in Scotland has found that fresh water sediments and saline water sediments with the same sediment source did not give identical secular variation results. It seems that the sediments deposited in saline water showed no secular variation. Their observations lend credence to the accuracy of the results of this study but as of yet no explanation for this difference due to type of deposition is available.

CONCLUSIONS

From paleomagnetic measurements of the sediment in a five-meter long core from the Santa Barbara Basin spanning the past 4830 years it was determined that the sediment was deposited out of a dense slurry of sediment grains and water. The magnetite grains had a high randomness which meant that the magnetic moment recorded when they became locked in the sediment was highly variable, reflecting these randomizing influences. This initial randomness of the sediment grains is used to explain the large differences in the geomagnetic field components of the two profiles of samples. Part of this randomness seems to be related to the fact that these sediments were deposited in marine water. Why marine water would cause such randomness is not fully understood at this time. In conclusion, the Santa Barbara Basin sediments are not good magnetic recorders and so no information on secular variation for the past 5000 years was obtained.

Other results of the study were that the effect of drag along the side of the core barrel is random and cannot be predicted and, therefore, cannot be corrected for in the results of a study. Also, wide square-diameter cores do not spiral down through the sediment column during the coring process. Finally, the regular increase in magnetic intensity of the sediment from bottom to top in the upper 25 cm of sediment is indicative of increased magnetite volume in the sediment column. It appears that the sediments in the Santa Barbara Basin are contaminated by air-borne magnetite particles from industrial sources.

It would not be fair to conclude from this study that the only accurate studies involving paleomagnetism of deep-sea sediments are those which use paired samples. However, it is fair to conclude that the particular sedimentary environment in the Santa Barbara Basin is such that randomizing effects on the magnetic grains dominate the paleomagnetic record when it is examined in very close detail. Other studies similar to this one need to be conducted on deep-sea sediments from other types of sedimentary environments before it can be concluded that the observations of this study will be repeatable or that they are unique to this study.

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